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ELECTRICAL POWER SYSTEMS QUALITY

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CHAPTER 1

AN OVERVIEW ON STRUCTURE OF POWER QUALITY

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ABSTRACT:

Power quality refers to the degree to which the electrical power supplied to a particular device or system meets the desired characteristics for proper operation. This can include factors such as voltage fluctuations, frequency variations, harmonics, and other disturbances that can affect the performance and lifespan of electrical equipment. Poor power quality can lead to equipment malfunction, system failures, and even safety hazards in certain situations. Therefore, it is crucial for power providers, engineers, and end-users to monitor and maintain power quality levels within acceptable limits.

KEYWORDS:

Harmonics, Power Factor, Power Quality, Reliability, Transients, Voltage Disturbances.

INTRODUCTION

Concerns about the quality of electric power are growing among both electric utilities and final consumers. Since the late 1980s, one of the most often used keywords in the power sector is "power quality." It serves as a general term for many different kinds of specific power system problems. The problems that come under this heading are not always recent. What has changed is that engineers are now striving to address these problems in a systemic manner as opposed to treating them as isolated concerns[1]–[3].

The rising worry is being caused by four main factors:

1. Modern load equipment is more sensitive to changes in power quality than older equipment because it has microprocessor-based controllers and power electronic devices.
2. As the importance of total power system efficiency has grown, so has the use of devices such shunt capacitors for power factor adjustment to cut losses and high-efficiency, variable-speed motor drives. Because of the rising harmonic levels on power systems, many people are worried about how this may affect system capacities in the future.
3. End customers are more aware of problems with power quality. Utility consumers are pressuring providers to raise the caliber of the electricity they offer as they become more knowledgeable about problems like outages, sags, and switching transients.
4. A network now connects a lot of things. The breakdown of any component results in considerably more significant effects in integrated processes.

The ongoing drive to boost productivity for all utility consumers is the underlying theme connecting all these causes for increasing worry about the quality of electric power.

Manufacturers want equipment that is quicker, more productive, and more effective. Because it helps their customers become more profitable and delays major expenditures in substations and generation by employing more efficient load equipment, utilities support this endeavor. It's interesting to note that equipment intended to boost productivity is often the equipment that is most negatively impacted by frequent power outages. Additionally, extra power quality issues are sometimes brought on by the equipment. The proper functioning of machines and their controls depends more and more on reliable electricity as whole processes are automated.There have been a few changes since the first version of this study was released that have affected power quality:

Many countries have updated their rules governing electric utilities throughout the globe in an effort to provide more affordable sources of electric energy. The power quality issue has been complicated by the deregulation of utilities. There is no longer carefully coordinated regulation of the electricity from generating to end-use load in many geographical locations. The rules governing the movement of money may be changed by regulatory bodies, but the laws governing the flow of power are physical and cannot be changed. Regulators will need to go beyond conventional reliability indices and consider the need for power quality reporting and incentives for the transmission and distribution businesses in order to prevent a decline in the quality of the power delivered to consumers.

The interest in distributed generation, or the production of electricity scattered across the power system, has significantly increased. The entire interconnection evaluation for DG must take into account a number of significant power quality challenges[4], [5]. As a result, we have included DG.Industry globalization has increased public awareness of worldwide power quality deficiencies. Companies constructing factories in new locations are abruptly confronted with unforeseen issues with the electrical supply as a result of less robust infrastructure or a different environment. A number of initiatives have been made to compare the electricity quality in different regions of the globe[6].To better measure the many characteristics of electricity quality, indices have been created. The performance-based rate-making process, which tackles a specific issue, dependability, which is linked to disruptions, has drawn the attention of regulatory bodies. Some customers have agreements in place with utilities to ensure a specific level of power supply quality.

DISCUSSION

Power Quality

Depending on one's frame of reference, power quality might have entirely distinct meanings. Using data to indicate that their system is 99.98 percent dependable, for instance, a utility can define electricity quality as dependability. Regulatory authorities often set criteria along these lines. Power quality may be characterized as the features of the power supply that allow the equipment to function correctly, according to a producer of load equipment. These qualities might vary greatly depending on the criterion.In the end, power quality is a consumer-driven problem, and the end user's perspective is paramount. As a result, the definition of a power quality concern utilized in this work is as follows:any power issue that manifests as voltage, current, or frequency deviations that causes a customer's equipment to malfunction or fail[7], [8].

There are several misconceptions around the root causes of power quality issues. The graphs show the findings of a study that the Georgia Power Company performed, asking both utility personnel and consumers about the root causes of power quality issues. While various industry sectors' polls could show different splits across the categories, these figures unmistakably show one common trend that appears time and time again in similar surveys: The utility's and the customer's points of view are often quite different. Customers believe that the utility is to blame far more often than utility employees do, despite the fact that both prefer to attribute around two-thirds of the incidents to natural processes.

End users may be eager to report a "outage" or "glitch" that caused the problem to the utility when there is a power issue with a piece of equipment. The utility records, however, may not show any adverse occurrences on the consumer feed. We recently looked at a situation where the utility substation breaker had only had five operations despite the end-use equipment being knocked off the grid 30 times in only nine months. It is important to understand that many events that cause end-user issues never appear in utility statistics. Capacitor switching is one instance; although it is relatively frequent and typical on the utility system, it may result in transient overvoltages that interfere with industrial equipment. Another example is a transient problem elsewhere in the system that causes the voltage to drop momentarily at the customer's location. If a distributed generator or adjus-speed drive trips off as a result, the utility won't know that anything went wrong with the feeder until a power quality monitor is installed.

In addition to actual power quality issues, there are also perceived issues with power quality that might be caused by faulty hardware, software, or control systems. Repeated transient voltages may cause electronic components to deteriorate over time, and finally an incident of very small scale can cause them to fail. Consequently, it might be challenging to pinpoint a failure's root cause. Control software developers for microprocessor-based equipment often have a limited understanding of how power systems work and fail to foresee all potential fault scenarios. As a result, a malfunction in a device's embedded software is possible. Early iterations of new computer-controlled load equipment are especially prone to this. This book's major goal is to educate equipment providers, utilities, and end users on how to lessen the frequency of problems brought on by software flaws.

Electric utilities have initiatives that assist them in addressing consumer problems in response to this increased concern about power quality. These programs' philosophies vary from being reactive, in which the utility reacts to customer complaints, to being proactive, in which the utility engages in consumer education and actively promotes services that may aid in the development of solutions to power quality issues. Utility regulatory concerns may have a significant impact on the design of their programs. Regulators should ensure that distribution firms have incentives to collaborate with customers and assist customers in resolving these issues since power quality issues often entail interactions between the supply system and the customer's facility and equipment. The study also has to take into account the economics of fixing a power quality issue. Eliminating supply-side differences in power quality is not always cost-effective. Making a specific piece of sensitive equipment less sensitive to changes in power quality is often the best way to solve a problem. The needed level of power quality is that at which the equipment at a certain facility will operate correctly.

Like the quality of other products and services, power quality is challenging to measure. The concept of superior power is not universally agreed upon. Although there are standards for voltage and other technical factors that may be measured, the performance and productivity of end-user equipment serve as the true test of power quality. If there isn't enough electricity to meet their demands, the "quality" isn't good enough.The "blinking clock" phenomena has perhaps been the best representation of disconnect between the power distribution infrastructure and consumer devices. To warn of potential inaccurate time after a power outage, clock makers invented the flashing display of a digital clock, accidentally inventing one of the earliest power quality monitors. The homeowner is now aware that there are a number of little disruptions happening across the power supply system, some of which may not even be harmful beyond being seen by a clock. The ordinary home may have roughly a dozen clocks that need to be reset when there is a short interruption since so many appliances now have built-in clocks. When there were slight disruptions, older technology motor-driven clocks would just lose a few seconds before quickly regaining synchronism.

Although the phrase "power quality" is often used to refer to the topic of this book, in most situations it refers to the quality of the voltage. Technically, power is the rate at which energy is delivered and is proportional to the product of voltage and current in engineering terms. It would be difficult to meaningfully quantify the quality of this quantity. The power supply system has no control over the potential currents that different loads may demand; it can only regulate the quality of the voltage. As a result, keeping the supply voltage within predetermined ranges is the focus of the standards in the power quality field.

In order to function, AC power systems need a sinusoidal voltage with a certain frequency and magnitude. A possible power quality issue is any significant variation in the waveform's size, frequency, or purity.Voltage and current in any actual power system are, of course, always closely correlated. The voltage may be disturbed in a number of ways by the current flowing through the system's impedance, even if the generators may provide voltage with a nearly perfect sine wave. For instance,a short circuit's current causes the voltage to drop or go away entirely, depending on the situation.Lightning-induced currents that flow through the electrical grid result in high-impulse voltages that regularly flash through insulation and produce other phenomena, such short circuits.As they flow through the system impedance, distorted currents from harmonic-producing loads likewise distort the voltage. As a result, additional end users are exposed to a disturbed voltage.In order to grasp the root of many power quality issues, even if the voltage is what we are ultimately interested in, we must also examine phenomena in the current.

Interested in Power Quality

Economic value is the main driver of our interest in power quality. There are financial repercussions for utilities, their clients, and load equipment providers.Many industrial users may see a direct financial effect from the quality of the electricity. Recently, there has been a lot of focus on reviving industry with increased automation and cutting-edge machinery. This often refers to energy-efficient, electronically controlled machinery that is frequently far more sensitive to variations in the supply voltage than its electromechanical forebears. Industrial customers are now more keenly aware of slight disruptions in the power grid, similar to how people become aware of flashing clocks in their homes. These upheavals are accompanied by large sums of money. It is not unusual for a single, ordinary, brief utility breaker action to shut down a manufacturing line that takes four hours to resume, costing an average-sized industrial company a loss of $10,000. The economic costs of equipment sensitivity to transient voltage sags led to the creation of a brand-new standard for equipment ride-through in the semiconductor production sector. The electric provider is also worried about problems with power quality.

Strong motivators include exceeding client expectations and preserving consumer trust. They are more crucial than ever in light of the current trend toward utility deregulation and competition. The financial effect on a utility of losing a dissatisfied customer to a rival electricity provider might be quite high.Power quality issues have a wide range of indirect and intangible expenses in addition to the apparent financial effects on utilities and industrial customers. Most power quality issues do not directly cause residential customers to lose money or be unable to make money, but when they feel that the utility is not delivering good service, they may be a powerful influence. The use of home computers has grown significantly over the last several years, and more transactions are now being completed online. When users depend heavily on this technology, they become more sensitive to disruptions. Due of the overwhelming volume of complaints, utilities must staff up to manage them. Additionally, public interest organizations regularly make representations via public service commissions, necessitating the expenditure of financial resources by the utilities on counsel, consultants, research, and the like in order to refute the intervention. Even if none of this is a consequence of power quality issues, a reputation for offering subpar service does not help.

Suppliers of load equipment often operate in a highly competitive market where the majority of consumers prioritize price when making purchases. Therefore, unless the client requests differently, there is a general disincentive to add capabilities to the system to survive frequent interruptions. Additionally, many manufacturers are not aware of the many kinds of disruptions that might affect electrical systems. The end user who must buy and utilize the load equipment ultimately has the major duty for addressing any inadequacies in it. Power performance requirements must be included in the specifications. One helpful service that utilities may provide is the sharing of information about power quality and the needs of load equipment to correctly work in the real world, since many end users are likewise ignorant of the potential problems. For instance, cooperative task groups were used to produce the SEMI F-47 standard that was previously mentioned. Power quality issues may take many different forms, as discussed in Chapter 2. Each of these occurrences may have a number of different root causes, as well as a number of alternative approaches that may be utilized to enhance the efficiency of the equipment and power quality. However, it might be helpful to consider the basic procedures that go into looking into many of these issues, particularly if those procedures can entail communication between the utility supply system and the client facility.

The overall method must also take into account whether the assessment includes a power quality issue that already exists or one that may arise from a novel design or from suggested modifications to the system. Nearly all power quality issues will need measurements to be taken into consideration. This is the main technique for describing the issue or the system that is currently being assessed. In order to associate issues with potential causes, it is crucial to record the effects of power quality fluctuations concurrently with the measurements.The system viewpoint must be used to assess solutions, and both the technical and economic constraints must be taken into account. At every level of the system, from the utility supply to the impacted end-use equipment, potential remedies are noted. Technically unviable solutions are eliminated, and the remaining options are contrasted economically. The kind of issue, the number of end users affected, and the potential remedies will determine the best course of action.

In order to provide each section's more in-depth technical knowledge and methods a framework, the overarching procedure is presented here. For each sort of power quality phenomena, the relative contribution of simulations and measurements to the assessment of power quality issues is discussed individually. The person also addresses the accessible options and the economics of these solutions. Power quality problems typically occur between the utility and the end user over the energy meter border. As a result, both utility engineers and industrial engineers and technicians will find this book's topics to be of interest. Every effort has been made to portray the issues and potential solutions in a fair and impartial manner.

The quality of electrical power has become a critical concern in modern society due to the increasing reliance on electronic devices and sensitive equipment in various sectors such as industry, healthcare, and telecommunications. Power quality refers to the characteristics of electrical power that affect its ability to operate equipment and devices efficiently and reliably. Understanding the structure of power quality is crucial for ensuring the smooth operation of power systems and minimizing disruptions and damage caused by voltage and current irregularities.This paper provides a comprehensive overview of the structure of power quality, exploring its various components and their impact on electrical systems. The structure of power quality can be categorized into four key elements: voltage quality, current quality, frequency quality, and waveform quality.

Voltage quality focuses on the characteristics of voltage supply, including magnitude, waveform distortion, and variations. It examines parameters such as voltage sags, swells, interruptions, harmonics, and flicker. These irregularities can arise from a range of factors, including faults in the power distribution system, nonlinear loads, and poor system design. Voltage quality issues can lead to equipment malfunction, data corruption, and increased energy consumption.Current quality refers to the attributes of the current flowing through the power system. It examines factors such as current harmonics, imbalances, and interruptions. Nonlinear loads, such as electronic devices and variable-speed drives, can introduce harmonics into the current waveform, affecting the efficiency of power transmission and causing overheating in electrical components.Frequency quality is concerned with the stability of the power system's operating frequency. Deviations in frequency can occur due to imbalances between power generation and demand, grid disturbances, or faults. Frequency variations can impact the performance of electric motors, clocks, and other time-sensitive equipment.

Waveform quality refers to the shape of the voltage and current waveforms. Distortions in the waveform can result from nonlinear loads, voltage transients, or equipment faults. Waveform distortions can cause excessive heating in electrical equipment, reduce the lifespan of components, and lead to electromagnetic interference.To mitigate power quality issues, various standards and guidelines have been established by organizations such as the International Electro technical Commission (IEC) and the Institute of Electrical and Electronics Engineers (IEEE). These standards define limits and permissible levels of power quality parameters, helping to ensure the compatibility and reliability of electrical systems.

CONCLUSION

Power quality is a critical aspect of electrical engineering and plays a crucial role in ensuring the safe and reliable operation of electrical systems. The impact of poor power quality can be severe, resulting in equipment malfunction, system failures, and even safety hazards in certain situations. Therefore, it is essential for power providers, engineers, and end-users to monitor and maintain power quality levels within acceptable limits. This requires the use of various measurement and analysis techniques, as well as implementing mitigation strategies such as filtering, grounding, and voltage regulation. By improving power quality, we can increase the efficiency and lifespan of electrical equipment, reduce costs, and promote sustainable energy use.In conclusion, understanding the structure of power quality is vital for maintaining efficient and reliable power systems. By analyzing and managing the various components of power quality, such as voltage, current, frequency, and waveform characteristics, power engineers and system operators can mitigate disruptions, protect sensitive equipment, and optimize energy consumption. Continual monitoring, preventive maintenance, and adherence to established standards are key elements in achieving and maintaining high power quality levels.

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CHAPTER 2

AN OVERVIEW ON POWER QUALITY PROBLEMS

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ABSTRACT:

Power quality problems refer to a range of issues that can affect the characteristics of electrical power supplied to a particular device or system, leading to improper operation or failure. These problems can include voltage fluctuations, frequency variations, harmonics, transients, and other disturbances that can impact the performance and lifespan of electrical equipment. Power quality problems can arise from various sources, including utility systems, electrical equipment, and environmental factors. The consequences of power quality problems can be severe, leading to equipment malfunction, system failures, and even safety hazards in certain situations. Therefore, it is crucial for power providers, engineers, and end-users to identify and address power quality problems using appropriate mitigation strategies such as filtering, grounding, and voltage regulation.

KEYWORDS:

Brownouts, Electrical Noise, Frequency Variations, Harmonics, Overvoltage, Power Factor, Power Quality.

INTRODUCTION

On the power system, a broad range of electromagnetic events are referred to as having "power quality." In recent years, the use of distributed generation and electronic equipment has increased interest in power quality, and this interest has been matched by the creation of specialized vocabulary to characterize the occurrences. Unfortunately, there hasn't been much uniformity in this language across various industrial sectors. The inability of suppliers and end users to comprehend why electrical equipment is malfunctioning has led to a great deal of misunderstanding. Similar to this, it might be difficult to sort through vendor jargon and pick out many suggested solutions[1]–[3].

There have been many terms used that are ambiguous or have several, conflicting meanings. For instance, the term "surge" is used to represent a broad range of disruptions that result in device malfunctions or breakdowns. Some of them can be muted by a surge suppressor, while others won't be impacted at all. Unrelated technical terms like glitch and flicker have seeped into the language. Selling overpriced products with almost miraculous promises to improve power quality, dishonest marketers profit from the public's ignorance. Of course, a money-back guarantee is included with all of this. By being more familiar with power quality jargon and demanding technical explanations of how a device works, readers may better safeguard themselves. Our general guideline is: Don't purchase anything if they won't explain what's in the box and how it works!

Problems with Power Quality in General

The language used here is a result of recent U.S. and worldwide initiatives to harmonize the meanings of words related to power quality. The major initiative in the US to unify power quality standards has been conducted by the IEEE Standards Coordinating Committee 22. In particular, the Industry Applications Society and the Power Engineering Society fall within its purview of duties across a number of IEEE groups. Through connections with the IEC and the Congress Internationale des Grand Réseaux Électriques an Haute Tension, it collaborates with worldwide initiatives. A few new phrases have been introduced to the IEC nomenclature as a result of efforts by the U.S. power sector to define suggested techniques for evaluating electric power quality.2 The IEC word dip is substituted by the term sag. Voltage dips and brief interruptions are referred to as short-duration fluctuations. Swell is presented as the opposite of sag. The American National Standards Institute C84.1 restrictions have been addressed by the addition of the category long-duration variation. In order to cope with broadband conducted phenomena, categorical noise has been introduced. The IEC harmonics, interharmonics, and dc in ac networks phenomena are included in the category waveform distortion along with another phenomenon from IEEE Standard 519-1992, Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems, called notching. By mentioning the proper traits, the phenomena stated in the may be further explained.

Transients

The word "transients" has been used to describe unfavorable, fleeting events in the study of power system changes for many years. Most power engineers probably picture a damped oscillatory transient caused by an RLC network when they hear the term transient.Other definitions that are often used are general in nature and say simply that a transient is "that part of the change in a variable that disappears during transition from one steady state operating condition to another."8 Unfortunately, almost every odd event that occurs on the power system might be described using this description.

Surge is another term that is often used in the same sentence as transitory. For a utility engineer, a surge is the transient caused by a lightning strike, which is protected by a surge arrester. End users commonly use the phrase "indiscriminantly" to characterize anything strange they may see on the power supply, such as sags, swells, and interruptions. Typically speaking, transients may be divided into two categories: impulsive and oscillatory. However, since there are several possible misunderstandings with this phrase in the power quality sector, we will typically avoid using it until we have precisely stated what it refers to. These expressions capture the waveform of a voltage or current transient. We shall go into further depth about these two groups[4]–[6].

DISCUSSION

Impulsive Transient

An abrupt, non-power frequency shift in the steady-state condition of voltage, current, or both that is unidirectional in polarity is known as an impulsive transient.Impulsive transients are often identified by their spectral content as well as their rise and decay periods. For instance, a 2000-volt impulsive transient with a nominal rise time of 1.2 s and a decay time of 50 s climbs from zero to its peak value of 2000 V in 1.2 s and 50 s, respectively. Lightning is the most frequent reason for impulsive transitions. Due to the high frequencies at play, circuit components may rapidly alter the form of impulsive transients, which can result in noticeably varied characteristics depending on where in the power system they are seen. Even though they sometimes may travel quite a distance through utility lines, they are typically routed close to the point where they join the power system. Oscillatory transients may be created when impulsive transients stimulate the inherent frequency of power system circuits.

Cyclical transient

A quick, non-power frequency shift in the voltage, current, or both steady-state conditions that includes both positive and negative polarity values is known as an oscillatory transient.A voltage or current oscillatory transient is one where the instantaneous value quickly changes polarity. Its spectral content, duration, and magnitude are used to characterize it. There are three categories of spectral content defined: high, medium, and low frequency. The frequency ranges for these classes were selected to match popular categories of oscillatory transient phenomena in power systems.

High-frequency transients are oscillatory transients with a principal frequency component larger than 500 kHz and a typical duration measured in microseconds. These transients often occur from the reaction of the local system to an impulsive transient. A medium-frequency transient is one having a major frequency component between 5 and 500 kHz and a duration measured in tens of microseconds. As seen, back-to-back capacitor energization causes oscillatory transient currents to occur in the tens of kilohertz. Oscillatory voltage transients in the same frequency range are produced by cable switching. A system's reaction to an impulsive transient may also cause medium-frequency transients.

A low-frequency transient is one that has a major frequency component of less than 5 kHz and lasts for between 0.3 and 50 ms. On utility subtransmission and distribution networks, this category of occurrences is regularly seen and is brought on by a variety of different circumstances. The most common causes of oscillating voltage transient with a main frequency between 300 and 900 Hz is capacitor bank energization. Depending on the system damping, the peak magnitude may be as high as 2.0 pu, although it usually ranges from 1.3 to 1.5 pu with a duration of between 0.5 and 3 cycles.On the distribution system, oscillatory transients with primary frequencies below 300 Hz are also common. These are often connected to transformer energization and ferroresonance. This might also apply to transients using series capacitors. They happen when exceptional circumstances lead to ferroresonance or when the system reacts by resonating with low-frequency components in the transformer inrush current.

Transients may also be divided into groups based on their manner. In a three-phase system with a distinct neutral conductor, a transient may essentially be either common mode or normal mode, depending on whether it arises between the line or neutral and ground, or between the line and neutral. Variations in Long-Duration Voltage. Root-mean-square deviations at power frequencies lasting more than one minute are included in long-duration variations. When the ANSI limitations are violated for more than 1 minute, a voltage fluctuation is said to be of a lengthy duration.Overvoltage’s or under voltages may occur over long periods of time. In most cases, system breakdowns do not generate overvoltages or under voltages; rather, load fluctuations and system switching processes are to blame.

Overvoltage

A rise in the rms ac voltage of more than 110 percent at the power frequency for a period longer than one minute is referred to as an overvoltage. Load switching often leads to overvoltages. The overvoltages are a consequence of either insufficient voltage controls or a system that is too weak to provide the appropriate voltage regulation. Overvoltages in the system may also be caused by incorrect tap settings on transformers.

Undervoltage

A reduction in the rms ac voltage to less than 90% at the power frequency for a period longer than one minute is referred to as an undervoltage.Switching events that are the reverse of those that create overvoltages result in undervoltages. Up until the system's voltage regulation equipment can restore the voltage to within tolerances, a load turning on or a capacitor bank turning off might produce an undervoltage. Under-voltages may also be the consequence of overloaded circuits.The word "brownout" is often used to denote prolonged undervoltage that is the result of a particular utility dispatch technique to lower power consumption. The word "brownout" should not be used since there is no official meaning for it and because it is less precise than the phrase "undervoltage" in describing a disruption.

Persistent interruptions

The long-duration voltage fluctuation is regarded as a continuous interruption when the supply voltage has been zero for a duration longer than one minute. Voltage disruptions lasting more than one minute are often permanent and need for human repair in order to restore the system. The phrase "sustained interruption" relates to certain power system events and, generally speaking, has nothing to do with how the phrase "outage" is used. For reliability reporting reasons, utilities use the terms outage or interruption to describe phenomena of a similar kind. End users, who consider an outage to be any interruption of electricity that stops an operation, are confused by this, however. This could just be one-half of a cycle. According to IEEE Standard 100,8, an outage is the condition of a system component that has not performed as intended. It does not relate to a particular incident. Furthermore, dependability or any other data related to continuity of service have no link to the word interruption when used in the context of power quality monitoring. As a result, this phrase has been defined to be more precise with reference to prolonged voltage absence.

Variations in Short-Duration Voltage

The IEC category for voltage dips and brief interruptions is included in this category. Depending on how long it lasts, a variation might be classified as immediate, momentary, or temporary.The deenergization of heavy loads that need high beginning currents, fault circumstances, or sporadic weak connections in the power wiring may all result in short-duration voltage changes. The problem may result in either temporary voltage decreases, voltage increases, or a full loss of electricity, depending on the fault site and the state of the system. The fault situation may be nearby or far away from the interest site. In either situation, the voltage is affected by a short-duration fluctuation during the actual fault state until the protection devices start to clear the fault.

Interruption

When the supply voltage or load current drops to less than 0.1 pu for more than a minute, there is an interruption.Power system issues, equipment breakdowns, and control issues may all cause interruptions. Due to the fact that the voltage magnitude is always less than 10% of the nominal, interruptions are monitored by their duration. The utility protection devices' operational time determines how long a disruption caused by a breakdown in the electricity system will last. A nonpermanent failure will often cause fewer than 30 cycles of interruption thanks to instantaneous reclosing. The protection device's delayed re-closing might result in a brief interruption. Because of broken equipment or faulty connections, the length of an interruption might vary. If the source system is malfunctioning, certain interruptions may be accompanied by a voltage sag. Between the time a defect starts and the moment the protective mechanism activates, there is a voltage drop. a brief pause when the voltage on one phase sags to about 20% for around 3 cycles before dropping to zero for roughly 1.8 s before the recloser closes back.

Sags

A sag is defined as a reduction in rms voltage or current at the power frequency to between 0.1 and 0.9 pu for periods ranging from 0.5 cycle to 1 minute. The word "sag" has been used by the power quality community for many years to refer to a sudden drop in voltage. Although the phrase has not been technically defined, utilities, manufacturers, and end users have come to accept and utilize it. IEC uses the term "dip" to describe this phenomenon. Both phrases are used synonymously, with sag being the favored equivalent in the American power quality community. It might be difficult to understand the terminology used to indicate the size of a voltage sag. A "20 percent sag" might result in a voltage drop of 0.8 or 0.2 pu. The ideal phrase would be "a sag to 0.8 pu" or "a sag whose magnitude was 20%," which make it clear what voltage level was achieved. A 20% sag shall be regarded as an occurrence when the rms voltage dropped by 20% to 0.8 pu, unless otherwise indicated. Additionally, the nominal, or base, voltage level has to be mentioned.

Voltage sags may also be brought on by the energization of high loads or the beginning of powerful motors, albeit they are often related to system breakdowns. A common voltage sag that may be related to a single-line-to-ground failure on another feeder from the same structure is shown in figure 2.6. Before the substation breaker can stop the fault current, an 80% sag lasts for around three cycles. Depending on the kind of overcurrent protection used and the fault current magnitude, typical fault clearing periods vary from 3 to 30 cycles. the results of starting a big motor. During startup, an induction motor will use 6 to 10 times the current required to run at full load. The ensuing voltage sag might be considerable if the current magnitude is high in comparison to the available fault current in the system at that time. after this instance, the voltage instantly drops to 80% before gradually returning to normal after 3 seconds. Take note of the time difference between this and sags brought on by utility system problems.

The length of sag occurrences has not been precisely established until recent research. Some literature specify that the typical sag time ranges from 2 milliseconds to a few minutes. A change in the fundamental frequency value's rms value cannot accurately characterize undervoltages that last less than one-half cycle. As a result, these occurrences are regarded as temporary. Voltage regulation devices can usually handle undervoltages that persist longer than a minute and may be attributed to reasons other than system problems. These are categorized as long-duration variants as a result.Here, sag durations are separated into three groups that correspond to the three types of interruptions and swells: instantaneous, momentary, and temporary. These timeframes are meant to match with the average operating periods for utility protection devices as well as the time intervals that are advised by international technical organizations. Swells are often linked to system fault conditions, much as sags, however they are less frequent than voltage sags. The brief voltage increase on the unfaulted phases during an SLG fault is one way that a swell might happen. a voltage spike brought on by an SLG issue. A huge load being turned off or a large capacitor bank being powered up may also result in swells. Swells may be identified by their size and duration. The fault location, system impedance, and grounding all play a role in determining how severe a voltage surge will be during a fault scenario. The line-to-ground voltages on the ungrounding phases of an ungrounded system with an infinite zero-sequence impedance will be 1.73 pu during an SLG fault situation. Because the substation transformer is often linked delta-wye, giving a low-impedance zero-sequence route for the fault current, there will typically be little to no voltage increase on the unfaulted phases close to the substation on a grounded system. Voltage swells on the phases that are not experiencing a fault will vary depending on where the fault occurs along four-wire, multigrounded feeders. Many authors use the phrase transient overvoltage for the word swell.

Electrical Unbalance

Voltage imbalance is often described as the largest divergence from the three-phase average voltage or current, given as a percentage, divided by the three-phase average voltage or current.In the standards, imbalance is more precisely specified using symmetrical components. The percent imbalance may be calculated using the ratio of either the negative or zero sequence component to the positive sequence component. The most current standards11 call for the adoption of the negative-sequence approach. An illustration of these two ratios for an imbalanced 1-week trend on a residential feeder. The main cause of voltage imbalances of less than 2% on a three-phase circuit is single-phase loads. Blowing fuses in one phase of a three-phase capacitor bank may potentially cause voltage imbalance. Single-phasing circumstances may lead to severe voltage imbalance.

Distorting the waveform

The term "waveform distortion" refers to a steady-state divergence from an ideal sine wave of power frequency that is primarily identified by its spectral content.

Waveform distortion comes in five main categories:

This might happen as a consequence of an asymmetrical electronic power conversion or a geomagnetic disturbance. Examples of incandescent light bulb life extenders include diodes that, by half-wave rectification, lower the rms voltage supplied to the light bulb. Because it biases the trans- former cores, direct current in ac networks may have a negative impact by causing them to saturate under normal conditions. This results in more heating and reduced transformer life. Electrolytic degradation of grounding electrodes and other connections may also be brought on by direct current.Harmonics. Harmonics are sinusoidal voltages or currents that occur at integer multiples of the supply system's intended operating frequency. Waveforms with periodic distortion may be broken down into a sum of the basic frequency and its harmonics. The nonlinear features of equipment and loads on the power system are the source of harmonic distortion.

The whole harmonic spectrum, including the magnitudes and phase angles of each individual harmonic component, is used to explain the levels of harmonic distortion. The total harmonic distortion is often used as a single measurement for the effective value of harmonic distortion. a typical adjus-speed-drive input current's waveform and harmonic spectrum. THD values, as previously mentioned, may be used to indicate the current levels of distortion, however they are often deceptive. For instance, while running under extremely low loads, many adjus-speed drives may display high THD values for the input current. Because of the low harmonic current magnitude and high relative distortion, this is not necessarily a serious issue.

Another term, the total demand distortion, is defined in IEEE Standard 519-1992 to address the issue of consistently describing harmonic currents. The only difference between this phrase and total harmonic distortion is that it expresses distortion as a percentage of a rated load current rather than as a percentage of the fundamental current magnitude at the time of measurement. Guidelines for harmonic current and voltage distortion levels on distribution and transmission circuits are provided by IEEE Standard 519-1992.There has been a lot of research on this topic since the publication of the first version of this book. The causes and consequences of interharmonic distortion are now well understood. It is often the outcome of frequency conversion, and it fluctuates with load frequently. As the fluctuating interharmonic frequency coincides with the system's inherent frequencies, such interharmonic currents may cause fairly severe resonances on the power system. They have also been shown to cause visual flicker in fluorescent and other arc lighting, as well as in computer display systems, and to influence power-line-carrier signaling. Notching. When current is communicated from one phase to another during the regular functioning of power electronic equipment, a periodic voltage disturbance known as notching results.

Since notching is continuous, the harmonic spectrum of the impacted voltage may be used to describe it. It is, however, often regarded as an exception. With measuring equipment typically used for harmonic analysis, the frequency components related with notching may not be easily defined since they might be relatively high. An illustration of continuous dc current produced by a three-phase converter with voltage notching. The transition of the current from one phase to another causes the notches. A brief short circuit between two phases occurs at this time, bringing the voltage as near to zero as the system impedances will allow[7], [8].

Noise. Noise is described as undesired electrical signals that are superimposed on the power system voltage or current in phase conductors, or detected on neutral conductors or signal lines, and have a broadband spectral content lower than 200 kHz.Power electronic equipment, control circuits, arcing machinery, loads with solid-state rectifiers, and switching power supply may all contribute to noise in power systems. Inadequate grounding, which fails to move noise away from the electrical system, often makes noise issues worse. In essence, noise is any unintentional distortion of the power signal that cannot be categorized as harmonic distortion or transients. Electronic gadgets like microcomputers and programmable controllers are disturbed by noise. Utilizing filters, isolation transformers, and line conditioners may help to solve the issue.

Voltage Variability

Voltage fluctuations are a sequence of random voltage changes or systematic variations in the voltage envelope, and their magnitude often falls between the ANSI C84.1 voltage ranges of 0.9 to 1.1 up fluctuation in some loads. However, standards often combine the two names. As a result, we'll also refer to these voltage variations as voltage flicker here. a voltage waveform illustration that causes flicker. One of the most frequent sources of voltage variations on utility transmission and distribution systems is an arc furnace, which is the source of this. The rms magnitude of the flicker signal, represented as a percentage of the fundamental, serves as a definition. The human eye's sensitivity is taken into consideration while measuring voltage flicker. If the frequencies are between 6 and 8 Hz, magnitudes as low as 0.5 percent often cause visible light flicker. the technique and technical requirements of the equipment used to measure flicker. The IEEE Voltage Flicker Working Group has decided to accept this standard in its modified form for use in North American power networks operating at 60 Hz. Through voltage measurements, this standard develops a straightforward method for defining the possibility for visible light flicker. Short-term flicker sensation is a basic measurement that is produced by the measuring technique, which replicates the lamp/eye/brain transfer function. This number is standardized to 1.0 to reflect the amount of voltage variations needed to make 50% of a sample observing group noticeably flicker. For the aim of confirming conformity with compatibility requirements specified by standards organizations and utilized in utility power contracts, another measurement known as long-term flicker sensation is often employed. A longer-term average of Pst samples produced this number. An arc furnace load servicing 161 kV substation bus Pst measurement trend. Pst samples are typically reported at intervals of 10 minutes. Instantaneous flicker readings are processed via a statistical assessment procedure specified in the measurement standard to get the Pst value. Every two hours, the Pst data are used to create the Pelt value[9], [10].

CONCLUSION

Addressing power quality issues is essential for guaranteeing the dependability and safety of electrical systems since they may have a major impact on their performance and safety. These issues might include voltage fluctuations, frequency variations, harmonics, transients, and other disturbances. They can originate from a variety of sources, including utility systems, electrical equipment, and environmental conditions. Power quality issues must be addressed using mitigation techniques such filtering, grounding, and voltage control, and accurate measurement and analysis methods are important to pinpoint the issue's features and cause. We can increase the functionality and longevity of electrical equipment, save expenses, and encourage the use of sustainable energy by properly controlling power quality issues.

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CHAPTER 3

A BRIEF DISCUSSION ON POWER FREQUENCY VARIATIONS

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ABSTRACT:

Power frequency variations refer to deviations from the standard frequency of electrical power supply, typically 50 Hz or 60 Hz depending on the country. These variations can occur due to changes in power demand, fluctuations in the power grid, or disruptions to power generation sources. The impact of power frequency variations can be significant, leading to improper operation or failure of electrical equipment, particularly those that rely on precise timing or synchronization. The consequences of frequency variations can range from minor disruptions to critical system failures, such as those seen in power-sensitive applications like data centers or hospitals. Therefore, it is crucial to monitor power frequency variations and implement mitigation strategies, such as automatic voltage regulators, frequency converters, and backup power supplies, to prevent or minimize their impact.

KEYWORDS:

Frequency Deviations, Frequency Variations, Harmonics, Load Variations, Power Factor, Power Quality.

INTRODUCTION

Power frequency fluctuations are defined as the power system's fundamental frequency departing from the nominal value set out in the specification.The rotational speed of the generators providing the system has a direct impact on the frequency of the power system. As the dynamic balance between load and generation changes, there are modest variations in frequency. The characteristics of the load and how the generation control system reacts to variations in the load determine the amount of the frequency shift and its length. 24-hour frequency changes on a standard 13-kV substation bus[1]–[3].

A significant block of load being disconnected, a major source of generation falling offline, or failures on the bulk power transmission system may all result in frequency changes that are outside of acceptable bounds for the regular steady-state functioning of the power system. Significant frequency changes are uncommon in today's integrated power networks. For loads provided by a generator isolated from the utility system, frequency fluctuations of significance are far more likely to happen. In such circumstances, the governor's responsiveness to sudden variations in load could not be sufficient to control within the constrained bandwidth needed by frequency-sensitive machinery. Voltage notching may sometimes be confused with frequency skew. In instruments and control systems that employ zero crossings to determine frequency or time, the notches may be near enough to zero to result in inaccuracies.

Quality Power Terms

We have included definitions for a number of frequently used terminology related to power quality in this book so that you may better grasp the content. These definitions mostly align with existing industry attempts to define words related to power quality. Additional words that are pertinent to the text have also been provided. Any of a wide range of high-tech power electronics equipment for reducing harmonic distortion. Council, and a brand-new curve known as the ITI curve has been established. ITI curve, please. The noise voltage known as common mode is present equally from a wire carrying current to ground. Coupling a circuit element, or a network of circuit elements, that might be regarded as shared by the input mesh and the output mesh and that would allow energy to be transmitted from one to the other. The difference in voltage between any two active wires in a given set is known as the differential mode voltage. Any departure from the typical sine wave for an AC quantity called distortion.

Diversified production

As contrast to massive, central station power plants, generation is spread throughout the power system. When used in the context of this book, the term "DG" generally refers to power sources less than 10 megawatts that are linked to the distribution network rather than the transmission network. Dropout a disruption, sag, or noise that prevents equipment from operating properly. Dropout voltage is the voltage at which a gadget deactivates and returns to its unpowered state. The capacity of a device, item, or system to operate properly in its electromagnetic environment without causing unbearable electromagnetic disturbances to anything in that environment is known as electromagnetic compatibility.

The conductor used to link the non-current-carrying components of conduits, raceways, and equipment enclosures to the grounded conductor and the grounding electrode at the service equipment or secondary of a separately derived system is known as the equipment grounding conductor. Swift traveling in which the circuit breaker or line recloser works more quickly than a fuse can blow, which is a standard utility protective relaying procedure. Effective for eradicating transitory defects without a sustained interruption, but is a little debatable since industrial loads are sometimes or momentarily interrupted. A power system short circuit is referred to as a fault in general. fault, momentary Usually caused by lighting, tree branches, or animals, a short circuit on the electrical system may be resolved by briefly interrupting the electricity[4], [5].

DISCUSSION

Ferro resonance

A nonlinear resonance of iron-core inductors that is erratic and often chaotic in nature. When it happens in the power distribution system, it is almost always undesirable, but it is taken advantage of in technologies like constant-voltage transformers to enhance the quality of the electricity.

An impression of jerky visual feeling brought on by a light source whose brightness or spectral distribution changes over time is known as flicker. An alteration in the power frequency. A frequency variation might last anywhere between a few cycles and many hours.

Response frequency

When used to describe power quality, the term often refers to how a system's or a metering transducer's impedance varies as a function of frequency.

Ground

An electrical circuit or piece of electrical equipment that is linked to the earth—or to another conducting body of relatively significant size that fills in for the earth—either intentionally or accidentally. It serves to establish and maintain the earth's potential, or a close approximation of it, on conductors attached to it as well as to carry ground currents to and from the earth.

An earth electrode

a conductor or collection of conductors that are in close proximity to the ground in order to establish a connection with it. A network of linked, bare conductors that are buried or spread out across a certain region in a design. The ground grid's main goal is to protect workers by keeping potential differences within its perimeter to safe levels in the event of strong currents flowing if the circuit being worked on got electrified for any reason or if a neighboring energized circuit faulted. For the same reason, metallic surface mats and gratings are sometimes used. A signal reference grid and this are not always the same thing[6]–[8].

"Ground loop,"

a potentially harmful loop that develops when two or more electrical points that should be nominally at ground potential are linked by a conducting channel but one or both of the points are not. The region via which all metallic raceways and grounding conductors enter a certain location. It is often used in communications systems to link the building's grounding system to a region that would not otherwise have one.

Harmonic filtration

A mechanism for filtering one or more harmonics out of electricity systems. The majority are passive mixtures of resistance, capacitance, and inductance. Active filters, a feature of more recent technology, may also handle reactive power requirements. The integral number produced by the harmonic frequency to fundamental frequency ratio is known as the harmonic number.

Musical resonance

A situation when the power system is resonating close to one of the primary harmonics being created by the system's nonlinear components, hence causing the harmonic distortion to be amplified. A pulse that closely resembles a unit pulse or a Dirac function in a particular application. It is preferable to use the term impulsive transient in lieu of impulse when discussing power quality monitoring.

Dynamic transient

A polarity-independent, unidirectional voltage or current that has undergone a steady state condition a rapid, non-power frequency shift. Instantaneous refers to a time range between one-half cycle and 30 cycles of the power frequency when used to define the length of a short-duration variation. Instantaneous reclosing is a word used to describe the process of swiftly re-closing a utility breaker after an interrupting fault current. The usual range is 18 to 30 cycles.

Interharmonic a periodic quantity's frequency component that isn't an integer multiple of the frequency the supply system is intended to operate at.

Temporary interruption

A service disruption that lasts only as long as it takes to restart it using automated or supervisory-controlled switching operations or manual switching at places where an operator is on-hand right away. Note: These switching actions must be completed within a time limit of no more than five minutes.

Uncertain Terms

As a variety of equipment providers competed for market share, the history of the power quality movement has been characterized by a good deal of hype. In order to cut through the hype and confusion, this book makes a solid technical interpretation of every aspect of power quality. In order to persuade prospective clients to purchase, marketers have developed several catchy slogans. Unfortunately, a lot of these words lack precise meanings and can't be utilized in technical contexts.

The terms that follow are often used yet might signify several things or have no meaning at all. What, for instance, is a "power surge"? Each disturbance phenomenon in this book has likely been referred to by this word at some point in the past. Is there truly a power surge? Maybe it's just the voltage. Voltage and current are a product, and this is how power works. The quantity often creating the observable disruption is voltage, and the power that results will not always be inversely proportional to the voltage. Instead of addressing the power issue, the answer will often be to reduce or fix the voltage. The following phrases are thus useless for describing an occurrence or coming up with a solution.

ITI and CBEMA Curves

The so-called CBEMA curve is one of the most often used data visualizations for power quality. a section of the curve from IEEE Standard 4469 that we often use to our analyses of the data from power quality monitoring. To represent the main-frame computer equipment's tolerance to the size and duration of voltage changes on the power supply, CBEMA first produced this curve. The curve has evolved into a typical design objective for sensitive equipment to be applied on the power system and a standardized method for reporting data on power quality fluctuation, even though many current computers have better tolerance than this.

The amplitude and duration of the occurrence are represented by the axes. The load is assumed to stop working at points in the envelope because of a shortage of energy. Other faults, such as insulation failure, overvoltage trip, and overexcit- ation, are thought to be caused by points above the envelope. The top curve has a value of roughly 375 percent voltage and is specified down to 0.001 cycles. Due to restrictions in power quality monitoring tools and disagreements over how to define the magnitude values in the subcycle time frame, we normally only use the curve from 0.1 cycle and above.

A modified curve that particularly relates to typical 120-V computer equipment has been produced, and the CBEMA organization has been replaced by ITI10. The CBEMA curve and this idea are related. The curve, like its predecessor curve, has been used to evaluate general power quality even though it was created for 120-V computer equipment. In this book, both curves are used as a reference to describe how well different loads and devices can withstand changes in power quality. We typically add a third axis to the plot to indicate the number of occurrences inside a certain predetermined cell of size and time in order to present vast amounts of power quality monitoring data. The plot tends to become a solid mass of points over time if only two-dimensional views are allowed, which is not helpful[9], [10].

Sags in voltage and interruptions

Power quality issues such as voltage sags and interruptions are connected. Both are often the consequence of power system breakdowns and switching operations to isolate the affected areas. They exhibit rms voltage changes outside of the typical operational voltage range. A voltage sag is a brief drop in rms voltage brought on by power system problems and the startup of heavy loads like motors. Momentary interruptions, which often happen as a consequence of utilities clearing transitory faults on their systems, result in a full loss of power. Permanent defects are typically to blame for extended disruptions that last longer than one minute.

Due to sags and disruptions, utilities are dealing with an increase in customer complaints regarding the quality of the electricity. There are many causes for this, but the most significant is that consumers across all industries have increasingly delicate loads. The main cause of the issue is the increase in digital computers and other electronic controls. Computer controls often lose their memory, and since the processes they are used to manage are typically more sophisticated, restarting them takes a lot longer. To maintain their competitiveness, industries are depending more and more on automated machinery to attain maximum output. Consequently, a disruption has a significant financial effect.

Sources of Sags and Interruptions

Utility system problems are often the source of voltage sags and interruptions. The customer will experience a voltage drop during the problem and an interruption when the breaker opens to fix the fault. Assume that the customer is supplied from the feeder provided by circuit breaker 1 on the diagram. If the failure is transient, re-closing the breaker should be effective, and the disruption will only last a short while. The breaker will typically act after 5 or 6 cycles, during which a voltage sag will take place. Depending on utility reclosing procedures, the breaker will normally be open for a minimum of 12 cycles and a maximum of 5 seconds. During this disruption, sensitive equipment will almost certainly trip.

A problem on one of the other feed- ers from the substation, such as a fault on a parallel feeder, or a fault anywhere on the transmission line, would be a considerably more frequent occurrence. The consumer will feel a voltage drop in any of these scenarios when the problem is truly present on the system. Normal voltage will return to the consumer as soon as breakers open to correct the issue. Be aware that both breakers A and B must be operational in order to resolve the transmission system failure. A problem is normally fixed by transmission breakers in 5 or 6 cycles. In this instance, just one of the two lines that feed the distribution substation is defective. Customers receiving power from the substation should thus anticipate simply a sag rather than an outage. Depending on the utility's fuse-saving policy, the lateral fuse or the breaker may be used to resolve the distribution problem on feeder 4.

Equipment at client facilities may malfunction as a result of any one of these problem sites. The individual features of the systems and the sensitivity of the equipment to voltage sags will determine the relative impact of problems on the transmission system and the distribution system. An illustration of how the sequence of events that resulted in equipment malfunction for one industrial client was broken down. Note that only 23% of the occurrences that led to equipment malfunction included defects on the customer feeder.

Voltage Sag Performance Estimation

Understanding the anticipated voltage sag performance of the supply system is crucial for designing facilities and creating equipment specifications that will ensure the best possible functioning of industrial facilities. The typical process for working with industrial clients to ensure compatibility between the features of the supply system and the facility operation is as follows:

1. Count the quantity and details of voltage sags brought on by transmission system issues.
2. Count the quantity and details of voltage sags brought on by distribution system flaws.
3. Find out how sensitive the equipment is to voltage sags. Evaluate the economics of various solutions that might enhance the performance, either on the supply system or inside the client facility. This will identify the real performance of the manufacturing process based on voltage sag performance estimated in stages 1 and 2.

A vulnerable area

To assess the possibility of sensitive equipment being exposed to voltage below its minimal voltage sag ride-through capacity, the idea of an area of vulnerability has been established.5 The latter phrase refers to the lowest voltage level that a piece of equipment can accept without malfunctioning or failing. The equipment voltage sag immunity or susceptibility limit is another name for this. The total circuit miles exposed to faults that might cause voltage magnitudes at an end-user facility to drop below the equipment's minimum voltage sag ride-through capability define an area of vulnerability. For motor contactor and adjus-speed drive loads at an end-user facility supplied by the distribution system, see Example of an Area of Vulnerability Diagram in Figure 3.5. Both problems in the transmission system and faults in the distribution system will affect the loads. Combining the region of susceptibility with the anticipated fault performance for this section of the power system yields the actual number of voltage sags that a facility may anticipate. Typically, previous data is used to calculate the anticipated fault performance.

Susceptibility of equipment to Voltage Sags

Different pieces of equipment at an end-user facility may react differently to voltage drops.8 The particular load type, control settings, and applications have a significant impact on how sensitive a piece of equipment is to voltage sags. As a result, it may be challenging to determine which aspects of a particular voltage sag are most likely to lead to equipment malfunctions. The length and magnitude of the sag are the two most often utilized variables. Phase shift and unbalance, missing voltage, three-phase voltage imbalance during the sag event, and the point in the wave when the sag begins and ends are other less often utilized features. In general, three categories may be used to classify equipment susceptibility to voltage sags: Equipment that is only sensitive to voltage sags of a certain size. Devices including undervoltage relays, process controls, motor drive controllers, and other automated machines are included in this category. These devices are sensitive to the smallest voltage magnitude felt during a sag. For these devices, the length of the disruption is often of minor relevance.

Equipment that is sensitive to the size and length of a voltage sag. Almost all equipment that utilizes electronic power supply belongs to this category. When the output voltage of the power supply falls below certain thresholds, such equipment malfunctions or fails. The time that the rms voltage is a set threshold at which the equipment trips is therefore a key attribute for this kind of equipment. Equipment that is sensitive to factors outside magnitude and duration. Other sag properties, such as the phase imbalance during the sag event, the position in the wave at which the sag is begun, or any transient oscillations that occur during the disturbance, might have an impact on certain devices. These qualities are more nuanced than quantity and duration, therefore it is much harder to generalize about their effects. The rms variation performance measures described here are thus concentrated on the more prevalent size and duration aspects[11], [12].

CONCLUSION

Power frequency changes may significantly affect how safely and reliably electrical systems operate, especially when such systems depend on exact timing or synchronization. Changes in power demand, alterations in the power grid, or problems with the sources of power supply may all cause these variances. Frequency changes may lead to anything from small disturbances to serious system failures, therefore it's vital to monitor and lessen their effects. One option for reducing power frequency changes is to use automatic voltage regulators, frequency converters, and backup power supplies. In order to protect the electrical system and the linked equipment from damage, standards and regulations are in place to make sure that power frequency stays within a reasonable range. Promote safety, dependability, and efficiency in electrical systems by managing power frequency fluctuations properly. We can avoid or lessen the effects of frequency fluctuations and make sure that electrical systems function safely and effectively by putting in place the proper mitigation techniques and following to set standards.

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CHAPTER 4

TRANSMISSION SYSTEM SAG PERFORMANCE EVALUATION

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ABSTRACT:

Transmission system sag performance evaluation refers to the process of assessing the ability of an electrical transmission system to maintain adequate clearance between power lines and surrounding objects, such as buildings or trees. Sag is the vertical displacement of a power line caused by the weight of the conductors and other factors, which can vary depending on environmental conditions and other factors. The performance evaluation involves measuring the sag and clearance of power lines using various techniques, such as laser scanning, photogrammetry, or manual measurements. These measurements are then compared to established standards and regulations to determine whether the transmission system is operating within acceptable limits. If clearance issues are identified, mitigation strategies such as tower reinforcement, conductor replacement, or line rerouting may be necessary to address the problem.

KEYWORDS:

Dynamic Stability, Fault, Load Flow, Power System, Sag, Short Circuit.

INTRODUCTION

Whether a particular client facility receives power from the transmission system or the distribution system will affect the voltage sag performance. The voltage sag performance for a customer supplied by the transmission system will only be influenced by the fault performance of the transmission system. On the other hand, the voltage sag performance for a customer who receives power through the distribution system will be influenced by the fault performance on both the transmission and distribution systems. The methods for estimating the transmission system's contribution to the facility's overall voltage sag performance are covered in this section[1]–[3].

Due to the linked architecture of the majority of contemporary transmission networks, breakdowns in transmission lines and the consequent opening of the protective mechanisms seldom ever result in a service outage for any client. However, voltage sags are a result of these defects. Depending on how sensitive the equipment is, the unit might go off and cause significant monetary losses. Therefore, it is crucial to be able to predict the anticipated voltage sags at an end-user site. One Liner, the majority of utilities have comprehensive short-circuit models of the connected transmission system available. These applications are able to determine the voltage across the system as a consequence of system-wide problems. In order to determine the region of susceptibility at a certain site, several of them may also apply faults at specific spots along the transmission lines.

The term "area of vulnerability" refers to all potential problem areas on equipment. In this study, the nature of defect must also be taken into account. The voltage sag at the client equipment won't be as severe from single-line-to-ground problems as it would be from a three-phase fault. The properties of the end-use equipment are further influenced by the transformer connections' ability to shift voltages and the kind of connection used, such as phase-to-ground or phase-to-phase. summarizes voltages for a single-line-to-ground failure at the primary at the customer transformer secondary. The relationships in the absence of zero voltage on either of the phase-to-ground or phase-to-phase voltages on the secondary of a grounded delta-wye transformer caused by a single-line-to-ground failure on the primary. Depending on how the equipment is linked, the size of the lowest secondary voltage:

A minimum voltage of 33% would be experienced by equipment connected line to line. A minimal voltage of 58 percent would be experienced by equipment connected line-to-neutral. This highlights how crucial it is to include both transformer connections and equipment connections when estimating the voltage that equipment would really encounter during a supply system malfunction. Math Bollen created the idea of voltage sag "types" to categorize the many voltage sag traits that end users may see under various fault scenarios and system configurations. Utility distribution system sag performance assessment provides examples of the five kinds that are often seen.

Faults in the transmission system and the distribution system have an effect on customers who are supplied at distribution voltage levels. The analysis at the distribution level must take into account any brief pauses brought on by the application of safeguards to fix defects. Sensitive equipment will most likely be tripped by these outages. The sample data requirements and calculation methods for assessing the anticipated voltage sag and brief interruption performance are provided in this section. The sum of the anticipated voltage sag performances from the transmission and distribution networks is the overall voltage sag performance at an end-user facility. a typical distribution system, with safety measures, fused branches, and many feeders. The performance of the voltage sag and transient interruption is significantly influenced by the utility protection mechanism. Following is a summary of the crucial data required to calculate voltage sag performance:

1. Number of feeds that the substation supplies.
2. The typical feeder length.
3. Typical feeder reaction rate.
4. Comparable short-circuit reactance at the substation.
5. If any, feeder reactors.

Average feeder fault performance measured in faults per mile per month, including three-phase line to ground faults and single line to ground faults. Data about the performance of the feeder may be found in the protection logs. Data regarding faults cleared by downline fuses or other downline protection devices, however, may be hard to come by and may need to be guessed. On the distribution systems, faults might occur on the same feeder or on parallel feeders, which are the two probable sites for faults. It is necessary to identify an area of vulnerability that specifies the total circuit miles of fault exposures that may result in voltage sags and equipment sag ride-through capabilities at a particular customer. The following formulas may be used to calculate predicted voltage sag performance:

Parallel feeder errors: Calculating the anticipated voltage magnitude at the substation allows one to predict the voltage that will be felt at the end-user facility in the event that parallel feeders fail. The fault impedance and position, the power system's design, and the system protection plan all have an effect on the substation's voltage magnitude. The impact of a radial distribution system's distance from the substation and the locations of 3LG and SLG faults. The SLG fault curve displays an A phase-to-ground fault on the primary and an A-B phase bus voltage on the secondary of a delta-wye-grounded step-down transformer. By converting the voltage at the substation, the actual voltage at the end-user site may be calculated. It is possible to compute the voltage sag performance for a particular piece of sensitive equipment using the following formula:

$$\text{Parallel} = N1 \times Ep1 + N3 \times Ep3$$

Where Ep1 and Ep3 are the total circuit miles exposed to SLG and 3LG faults on parallel feeders that cause voltage sags with the minimal ride-through voltage vs at the end-user site, and N1 and N3 are the fault performance statistics for SLG and 3LG faults in faults per miles per month.

The same feeder's faults. This stage computes the anticipated voltage sag magnitude at the end-user site as a function of the feeder fault location. However, it should be noted that the calculation is only done for fault sites that may cause a sag but not a temporary stoppage; the rest will be done separately. A branching fuse that is timed to clear before the substation recloser is engaged is an example of a fault site in this category. The following formula is used to calculate the voltage sag performance for certain sensitive equipment with ride-through voltage versus:

$$\text{Same} = N1 \times Es1 + N3 \times Es3$$

Where Es1 and Es3 represent the total number of circuit miles exposed to SLG and 3LG on the same feeders, respectively, causing voltage sags vs. at the end-user point. The sum of the projected voltage sag performances on the parallel and the same feeders, or Eparallel + Esame, would represent the overall expected voltage sag performance for the minimal ride-through voltage versus. Other voltage thresholds' total predicted sag performance may be calculated, and the results can then be displayed to create a plot like the one shown. The duration of exposure that will cause a breaker or other protective device in series with the customer facility to function may be used to calculate the predicted interruption performance at the indicated site. This length is the whole exposed length, for instance, if the protection is intended to activate the substation breaker for any problem on the feeder.

DISCUSSION

Fundamental Principles of Protection

The utility, end user, and equipment manufacturer may all take a variety of steps to lessen the frequency and severity of voltage sags as well as the susceptibility of equipment to them. Alternatives to fix voltage sag and its associated expenses. Dealing with the issue near to the load, where it is most basic, is often less expensive. The ideal solution is to include ride-through functionality in the equipment specs. This effectively implies storing problematic equipment outside of the plant or, at the very least, anticipating the need for power conditioning. The following suggestions might simply be included in any company's equipment procurement specs to assist reduce the issues caused by voltage sags:

Voltage sag ride-through capability curves should be made accessible by equipment makers to their clients so that a preliminary assessment of the equipment may be made. So that they can correctly assess equipment, customers should start to demand that these kinds of curves be made accessible[4]–[6]. The business should design a procedure that ranks the significance of the equipment before making a purchase. If the equipment is essential in nature, the business must make sure that it is purchased with sufficient ride-through capabilities. Voltage sag protection may not be necessary if the equipment is not critical, does not significantly impede production, and poses no risk to the safety of the facility or its workers.

With a minimum voltage of 70%, equipment should be able to withstand voltage sags. The relative likelihood of having a voltage sag to 70% of nominal or less is much lower than experiencing a sag to 90% of nominal. A 50% ride-through capability, as recommended by the semiconductor industry in Standard SEMI F-47.17, would be a more desirable one for short-duration voltage sags.

The solutions often get more expensive as we consider them at greater available power levels. It could be conceivable to apply an uninterruptible power supply system or some other sort of power conditioning to the machine control if the necessary ride-through cannot be attained at the specification stage. This is relevant when the machines can handle the sag or interruption on their own, but the controls would shut them off immediately.

Solutions at the Level of the End User

There are several levels at which solutions to enhance a process or facility's performance and reliability might be implemented. To find the best option for enhancing the overall voltage sag performance, the various technologies should be assessed depending on the particular needs of the process. The following several application levels may be considered in relation to the solutions:

Safeguards for light loads: Protection of tiny, individual machinery or equipment controllers is often involved. These loads often need to be safeguarded since they are single-phase loads. Up to around 300 kVA of protection for individual or groups of pieces of equipment. This often refers to using power conditioning technology within the building to safeguard important equipment that may be readily gathered together. This may be a highly economical way to deal with the essential loads as often not all of the loads in a facility need protection. This is particularly true if the requirement for protection of certain loads is taken into account during the facility design phase.

Protection for whole facilities, big groups of loads, or low-voltage levels. It is often sensible to think about sheltering big groupings of cargo at a convenient place when a significant percentage of the facility is important or requires protection. When protecting huge groupings of loads, new technologies are available for consideration. Protection on the supply system or at the medium-voltage level. Solutions at the medium-voltage level might be taken into consideration if the whole facility requires protection or better power quality. Since many of the technologies may be used over a larger variety of sizes, the size ranges in these categories are somewhat arbitrary. The main technologies currently in use and the application levels are covered in the sections that follow.

Iron-Based Transformers

The majority of voltage sag situations may be handled with ferroresonant transformers, commonly known as constant-voltage transformers. Particularly appealing for steady, low-power loads are CVTs. Due to the tuned output circuit, variable loads, particularly those with strong inrush currents, provide a greater challenge for CVTs. The voltage sag ride-through improvement of a process controller fed from a 120-VA ferro resonant transformer uses ferroresonant transformers, which are essentially 1:1 transformer that are excited high on their saturation curves to provide an output voltage that is not significantly affected by input voltage variations. In contrast to 82 percent without a CVT, the process controller may ride through a voltage sag down to 30 percent of nominal with one. Take note of how a certain degree of the ride-through capability is maintained. The process controller's meager 15 VA power needs is the cause of this. Transformers for ferroresonants need to be much bigger than the load. According to one manufacturer's specifications, 3.16 displays the permissible voltage sag as a proportion of nominal voltage vs ferroresonant transformer loading. The CVT will produce over 90% of the normal voltage as long as the input voltage is more than 30% at 25% of loading, where the permitted voltage sag is 30% of nominal. This is significant because under voltage sag circumstances, the plant voltage seldom drops to 30% of nominal. When the transformer is overloaded, the voltage collapses to zero as the loading increases and the related ride-through capacity decreases[7]–[9].

Series Active Compensators

Novel solutions for providing voltage sag ride-through assistance to important loads have emerged as a consequence of developments in power electronic technology and novel topologies for these devices. A device that can raise the voltage by injecting a voltage in series with the remaining voltage during a voltage sag state is one of the significant new alternatives. Devices for active series compensation are what they are known as. They come in a variety of sizes that may be used on medium-voltage systems, from tiny single-phase devices to extremely big ones. is an illustration of a tiny single-phase compensator that may be used to assist single-phase loads during ride-through? The power electronics that are used to produce the correction are shown in a one-line diagram. A quick switch opens in response to a disturbance in the input voltage, supplying power to the series-connected electronics. In order to keep the output voltage within a certain tolerance throughout the disturbance, this circuit adds or subtracts a voltage signal from the input voltage. Because of how quickly the switch operates, the load experiences a disturbance that lasts for less than one-fourth of a cycle. Fast enough to almost eliminate issues with all delicate loads. Almost all voltage sag circumstances can be met by the circuit's ability to provide voltage boosting of roughly 50%.

On-line UPS

The load is always supplied via the UPS in this system. Reconverted from ac to dc power, the incoming power charges a bank of batteries. To supply the load, this dc power is subsequently reversed back into ac power.

The inverter is supplied by the batteries and keeps supplying the load even if the incoming ac power fails. An on-line UPS offers extremely good isolation of the important load from all power line disturbances in addition to ride-through for power outages. However, online operations raise losses and may not be essential for many loads' protection.

Backup UPS

A backup power supply is sometimes known as an off-line UPS since it powers equipment using regular line power up until a disruption is detected, at which point a switch switches the load to a battery-backed inverter. It matters how quickly the power is transferred from the conventional source to the battery-powered converter. The lowest limit for interruption through for power-conscious manufacturers is 8 ms, according to the CBEMA curve. Therefore, a transfer time of 4 ms would guarantee that the essential load will continue to run. In contrast to an on-line UPS, a standby power supply often does not provide voltage control or transient protection. For the protection of tiny computer loads, this is the most typical configuration for commodity UPS units sold in retail establishments. Kilo-voltampere capacity, dynamic and static voltage control, harmonic distortion of the input current and output voltage, surge protection, and noise attenuation are all included in the requirements for UPSs. The test circumstances under which the standards are valid should be specified in the specifications or provided by the supplier.

UPS hybrids

The hybrid UPS uses a voltage regulator on the UPS output to give regulation to the load and temporary ride-through when the switch from regular to UPS supply is made, similar to how the standby UPS does.

Generator sets for motors

There is a broad range of sizes and configurations for motor-generator systems. This is an established technique that is still helpful for protecting crucial loads from drops in power and power system outages. The idea is really straightforward. A generator that powers the load is driven by a motor powered by the line. Greater inertia is provided via flywheels on the same shaft, extending the ride-through period. The inertia of the machines and the flywheels keeps the power supply going for a few seconds after a line disruption. This configuration may also be utilized to isolate sensitive loads from other types of disturbances, such switching transients and harmonic distortion. M-G sets, albeit conceptually straightforward, have drawbacks for some kinds of loads:

1. Although not necessarily greater than those in other technologies mentioned here, there are losses connected with the machines.
2. Some installations may have problems with noise and upkeep.
3. As the machine slows, the frequency and voltage decrease during interruptions. With certain loads, this may not function properly.

A different kind of M-G set employs a written-pole motor, a specialized synchronous generator that can maintain a 60-Hz frequency even when the machine slows down. The rotor's field poles' polarity is continuously changed, allowing it to provide a steady output. Therefore, the number of poles in each rotation may change from that in the previous one. As long as the rotor is rotating between 3150 and 3600 revolutions per minute, a constant output is maintained. When the electricity is turned off, the flywheel's inertia enables the generator rotor to continue revolving at a rate higher than 3150 rpm. Normally, the rotor weight produces enough inertia to keep it spinning quickly for 15 s when under full load, producing 60 Hz. Reversing the output of the generator and feeding it back into an inverter is another way to make up for the frequency and voltage loss that occurs when energy is being harvested. More energy can be collected thanks to this, however there are costs and losses involved.

Energy storage devices using flywheels

The energy stored in flywheels may be used in a variety of ways, including motor-generator sets. A contemporary flywheel energy system achieves sag and interruption ride-through from 10 s to 2 min using high-speed flywheels and power electronics. In Figure 3.25, a flywheel utilized in energy storage devices is shown. These flywheels run in a vacuum and use magnetic bearings to significantly reduce standby losses, in contrast to M-G sets, which normally operate in the open and are vulnerable to aerodynamic friction losses. Designs with composite rotors may spin at significantly greater rates than those with steel rotors, which can spin at about 10,000 rpm. A large quantity of energy may be stored in a small area since the amount of energy stored is related to the square of the speed. A combined motor, generator, and flywheel utilized in energy storage systems may be seen in this cutaway image.

The rotor functions as a single-piece generator, motor, and storage device. The rotor is spun up to speed as a motor to store energy. The rotor and armature function as a generator when energy is required. When energy is taken, the rotor slows, and the control system immediately raises the field to make up for the dropped voltage. Any of the previously discussed UPS designs would employ a high-speed flywheel energy storage module in lieu of a battery.

Technologies for Superconducting Magnetic Energy Storage

Short interruptions and voltage sags may be reduced with a SMES device. The electric energy contained in the current flowing in a superconducting magnet serves as the energy storage in a SMES-based system. The energy may almost instantly be released since the coil has no loss. This energy may be used to replace the lost voltage during a voltage sag event by injecting it into the protected electrical system via voltage regulator and inverter banks in less than one cycle. Compared to battery-based UPS systems, the SMES-based system provides a number of advantages:

1. Batteries need a substantially larger footprint to provide the same amount of energy storage and power delivery as SMES-based systems.
2. The protected system can get the stored energy more rapidly.
3. The SMES system offers almost infinite duty cycles for charging and discharging. Thousands of discharge and recharge cycles can be carried out without causing any harm to the superconducting magnet.
4. Usually, the recharge cycle begins fewer than 90 seconds after complete discharge.

It is made up of a series-injection transformer, a superconducting magnet, voltage regulators, capacitor banks, a dc-to-dc converter, dc breakers, inverter modules, and sensing and control tools. Liquid helium is used to cool the superconducting magnet, which is made of a conductor made of niobium titanium. A two-stage recon denser serves as the foundation of the cryogenic refrigeration system. High-temperature superconductors are used as connectors between the voltage regulator and controls and the magnet electrical lines. Normally, the magnet could hold 3 megajoules. In the example system, energy from the SMES is converted to voltage and used to charge a 14-microfarad dc capacitor bank to 2500 Vdc via the use of a current-to-voltage converter. The voltage regulator controls the SMES's protection and maintains the dc voltage at its nominal level. The dc voltage is lowered to 750 Vdc via the dc-to-dc converter. There are six single-phase inverter bridges in the inverter subsystem module. To produce a total rating of 900 A per phase, two IGBT inverter bridges with a combined 450 A rms are paralleled in each phase. The carrier signal for the switching strategy for the inverter is a sine-triangle with a frequency of 4 kHz, and it is based on the pulse-width modulation technique.

Both rapid and static transfer switches are used

There are many options for safeguarding a whole facility that can be vulnerable to voltage sags. These consist of UPS systems and dynamic voltage restorers that operate at the medium-voltage level but make use of technology comparable to the systems previously mentioned. The automatic transfer switch is yet another option that may be used at either the low-voltage level or the medium-voltage level. Different technologies, including as static switches and conventional breakers, may be used in automatic transfer switches. Using a conventional transfer switch, switching between the main and backup supplies takes seconds. There are vacuum breaker-based quick transfer switches that can switch over in 2 electrical cycles or less. Many delicate cargoes may be protected by this quickly enough. Power electronic switches are used by static switches to complete the transfer in less than one-fourth of an electrical cycle. The setup of the transfer switch. An illustration of a medium-voltage setup. The fact that a transfer switch needs two independent supply to the facility is crucial to its success in protecting sensitive loads. For instance, if both supplies are connected to the same substation bus, they will both experience the same voltage drops when the supply system has a malfunction. The quick transfer switch may not be of much service in protecting the facility's equipment if a large portion of the incidents that damage it are caused by transmission system flaws. Analyzing the Economic Impact of Various Drive-Thru Alternatives The following phases make up the economic assessment process to determine the optimum choice for improving voltage sag performance:

1. 12 kV Alternate Source, Primary Source 12 kV
2. Switch for Static Transfer
3. An illustration of a medium voltage static transfer switch application.
4. Describe the power quality performance of the system.
5. Calculate the expenses incurred by the differences in power quality.
6. Describe the cost and effectiveness of the various solution options.
7. Analyze the economies of comparison.

In addition to outlining the key technologies that may be employed to enhance the facility's performance, we have previously offered the technique for assessing the anticipated voltage sag performance. We will now concentrate on analyzing the economics of the various solutions[10]–[12].

CONCLUSION

An important part of managing an electrical system is evaluating the sag performance of the transmission system to make sure it operates safely and reliably while adhering to regulations. It entails determining, using a variety of measuring and analysis methods, the distance between power lines and nearby objects. With the use of this examination, clearance problems may be identified and suitable mitigation measures, such tower strengthening, conductor replacement, or line rerouting, can be put in place. Power outages, equipment damage, and the efficient and long-term functioning of the electrical system must all be avoided through effective transmission system sag performance measurement. We may encourage the safe, dependable, and sustainable functioning of electrical systems by upholding regulatory compliance and immediately resolving clearance concerns, providing a steady supply of energy for residences, businesses, and crucial infrastructure.

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CHAPTER 5

ESTIMATING THE COSTS FORVOLTAGE SAG EVENTS

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ABSTRACT:

Estimating the costs for voltage sag events involves quantifying the economic impact of these events on various sectors of the economy, including residential, commercial, and industrial customers. Voltage sags are short-duration reductions in voltage levels that can result from various sources, including faults in the power grid or large load changes. These events can cause equipment failure, process interruption, and production losses, resulting in significant economic losses. Estimating the costs associated with voltage sag events involves measuring the frequency, duration, and severity of these events and identifying the equipment or processes affected. The costs of voltage sags may include equipment replacement or repair, lost production, energy costs, and other indirect costs such as maintenance and labor. Properly estimating the costs of voltage sag events is crucial for determining the cost-effectiveness of mitigation strategies such as uninterruptible power supplies, voltage regulators, and backup generators.

KEYWORDS:

Downtime Costs, Equipment Damage, Interruption Costs, Lost Production Costs, Power Quality Costs, Sag Severity.

INTRODUCTION

Costs for sag events may range greatly, from very nothing to several million dollars each event. The price will vary depending on the market circumstances in addition to the various industrial kinds and specific facilities. Higher costs are often encountered when there is a shortage of the final product and little room for manufacturing losses to be made up. Not all expenditures can be accurately calculated or accurately represent the urgency of averting a voltage sag event's repercussion[1], [2]. There are three main categories that may be used to quantify the cost of a power quality disturbance:

1. Losses connected to products, including those linked to lost materials and products, reduced manufacturing capacity, disposal costs, and increased inventory needs.
2. Losses resulting from labor, including overtime, cleaning up after mistakes, and repairs.
3. Additional expenses including fines for shipment delays, lost opportunity costs, and damaged equipment costs.

Concentrating on these three areas will make it easier to create a comprehensive list of all expenses and savings related to a power quality disruption. To get a more thorough description of the elements that should be taken into account when calculating the cost of power quality disruptions, one may also refer to appendix A of IEEE 1346-199818. Costs often change depending on how severe the power quality issue is. A matrix of weighting variables may often be used to describe this connection. The cost of a brief interruption serves as the foundation for determining the weighting criteria. Any load or operation that is not particularly safeguarded with some kind of energy storage technology will often be disrupted by a brief outage. A percentage of this entire shutdown will always be impacted by voltage sags and other fluctuations in power quality.

If a voltage sag of 40% results in 80% of the economic damage that a brief interruption results in, then a 40% sag would have a weighting factor of 0.8. The weighting factor is 0.1 if a decline to 75% only results in 10% of the expenses that an interruption creates. The costs of an event are stated in terms of the price of a brief interruption after the weighting factors have been applied to it. The overall cost of all the occurrences, represented in the number of comparable brief disruptions, may then be calculated by adding the weighted events. It is an illustration of the weighting parameters that were used in one study. To differentiate between sags that effect all three phases and sags that only affect one or two phases, the weighting variables may be further broadened. Calculates the overall yearly cost related to voltage sags and interruptions by combining the weighting variables with the projected performance. The price is 16.9 times what an interruption would cost. The annual expenditures for voltage sags and interruptions would be $676,000 if each disruption costs $40,000.

DISCUSSION

Characterizing the cost and effectiveness for solution alternatives

The efficacy and cost of any solution technology must be assessed. The cost of the solution should, in general, include the original costs of purchase, installation, and operation as well as any costs associated with disposal and/or salvage value. A complete analysis would take into account less evident expenditures like those relating to real estate or available space as well as tax implications. The price of the additional space needs may be included as a space rental fee and added to other yearly operational costs. Tax considerations may involve a number of different factors, and the net benefit or cost may also be added to other recurring yearly operational costs. It is an illustration of the upfront expenditures and ongoing expenses for various common technologies used to increase performance during voltage sags and interruptions. These prices are given for the example's purpose only, and they shouldn't be interpreted as being representative of any specific item[3], [4]. In addition to expenses, the efficacy of each alternative's solution must be evaluated in terms of the potential performance boost. Similar to power quality expenses, solution efficacy often varies with the degree of the power quality disruption. The "% sags avoided" values in a matrix may be used to describe this relationship. The example technologies from this notion are those that may be used in a typical industrial application.

Performing a comparative examination of the economy

Calculating the entire yearly cost for each option, including the expenses related to the voltage sags and the annualized costs of implementing the solution, is a step in the process of assessing the various choices for increasing performance. The goal is to reduce these yearly expenditures as much as possible. The power quality solution possibilities may be compared in terms of their total yearly costs, identifying those with lower costs that call for more examination. Generally speaking, the comparative analysis includes the do-nothing option and designates it as the base case. The option that does nothing has the lowest yearly power quality expenses, but it also has the highest. Many of the expenses are fundamentally yearly expenses. A suitable interest rate, lifespan or assessment duration, and one-time upfront expenses may be used to annualize the costs related to acquiring and installing different solution technologies.

It's interesting to see that each choice lowers the yearly budget overall. It's also intriguing that using equipment on the utility side is the best course of action in this situation. This, however, makes a significant assumption that a backup feeder will be available and that the utility would not charge for establishing a connection to this backup feeder other than for equipment and operational expenses. Typically, the facility would adopt the solution, and it could make sense to safeguard the 2 MW of sensitive loads with either a dynamic sag corrector or a flywheel-based backup power supply. Due to the machines' inherent sensitivity to voltage sags, covering just the controls with CVTs does not provide the ideal option in this situation.

Sags in Motor Starting

The unfavorable result of starting motors is that they draw more current than they can handle at full load. Due to the high current running through the system impedances, there will be a voltage drop, which might dim the lights, cause contactors to fail, and damage sensitive machinery. An excessively low beginning displacement factor typically between 15 and 30 percent makes the problem much worse. The amount of sag affects how long it takes the motor to reach its rated speed, and too much sag might make it impossible for the motor to start. Long-lasting motor starting sags are possible.

Strategies for starting motors

The motor may be powered up quickly and cheaply by turning it on all at once. Unless the ensuing voltage sag or mechanical stress is significant, it is the recommended option. Two autotransformers are coupled in open delta in autotransformer starters. During startup, taps provide a motor voltage that is 80, 65, or 50% of the system voltage. The 50% tap will only provide 25% of the full-voltage beginning current and torque since line current and starting torque fluctuate with the square of the voltage supplied to the motor. The lowest tap that can provide the necessary starting torque is chosen. Starters that use resistance and reactance first connect the motor to an impedance in series. This impedance is shorted out after a delay. Starting reac- tors are shorted out in a single step, while starting resistors may be shorted out over a number of steps. For a given starting voltage, these starters take more current from the line than autotransformer starters, but they have a larger beginning torque. Line current and starting torque are directly correlated to the voltage supplied to the motor. Reactors are commonly given taps of 50, 45, and 37.5%.

The use of part-winding starters with dual-rated motors is appealing. A dual-rated motor's stator is made up of two windings that are either linked in series or parallel depending on the greater or lower voltage rating. Only one winding is first energized when a part-winding starter is used, limiting the starting current and beginning torque to values that are 50% of those observed when both windings are electrified simultaneously[5], [6]. The stator is connected in wye for beginning, then after a brief interval, the windings are reconnected in delta. Wye connections lower beginning voltage to 57 percent of system line-line voltage while lowering starting current and torque to 33 percent of full-voltage start values.

Issues with Utility System Fault-Clearing

The voltage sag and interruption performance at a distribution-connected load is significantly influenced by utility feeder architecture and fault-clearing procedures.We'll now look at 12 ways to make the performance better. In order to keep bringing down the amount and severity of problems on their system, utilities primarily have two options:

1. Eliminate errors.
2. Change fault-clearing procedures.

Activities that avoid problems provide utilities with significant advantages. These actions not only increase customer happiness but also guard against expensive power system equipment damage. Tree pruning, the installation of line arresters, insulator washing, and the installation of animal guards are fault preventive measures. It is unrealistic to expect electrical line insulation to resist every lightning strike. However, it is important to look into any line that has a high vulnerability to lightning-induced failures. Shielding on transmission lines may be evaluated for how well it prevents direct lightning strikes. A key consideration in back flashovers from a static wire to a phase wire is tower footing resistance. The surge energy from a lightning strike will not be absorbed by the earth as rapidly if the tower footing resistance is strong. Shielding and often inserting arresters along the line are other options for distribution feeders, as well as shielding. Naturally, one of the primary issues with overhead distribution feeders is that tree branches are blown into the wires during storms. It might be difficult to maintain trees correctly pruned in locations where the vegetation grows swiftly. The addition of line recloses, removal of quick tripping, addition of loop schemes, and modification of feeder architecture are some examples of improved fault-clearing procedures. These procedures could lessen the frequency and/or length of power sags and temporary disruptions, but utility system errors will never be totally eradicated.

Principles of Overcurrent Coordination

It is crucial to comprehend how the utility system functions when there is a failure. Interrupting the fault current and restoring electricity has several physical restrictions. As a result, loads that are anticipated to endure such situations without being disrupted must meet a particular minimal standard. Additionally, there are certain actions that may be taken that will enhance the power quality more effectively on the utility system than on the load side. As a result, we will discuss the problems associated with utility fault clearing while keeping in mind both the utility engineer and the end user.

On power systems, there are primarily two categories of faults:

Temporary faults. These are errors that arise from things like overhead line flashovers and don't do the system insulation any long-term harm. As soon as the fault arc is put out, power may be restored. In a matter of seconds, automatic switchgear can do this. Self-cleaning transient defects exist. These are errors that result from physical harm to an insulation system component and need a line crew's assistance to be fixed. An outage that lasts for a few minutes to a few hours will have an effect on the end user. Limiting damage to the distribution system is the primary goal of the utility system fault-clearing operation, second only to the safety of the workers. As a consequence, fault identification and clearing must be carried out as quickly as feasible without producing false operations for typical transitory occurrences. Arcing damage to conductors and bushings is often one of the two biggest concerns for damage.Substation transformers with through-fault damage, where the windings are displaced by excessive stresses and suffer a catastrophic failure

One fault interrupter is all that is needed to clear a problem in a radial distribution system. This mechanism or another works to sectionalize the feeder for permanent defects. So that power may be restored to the other loads serviced by the healthy parts, the failed section is isolated. Coordination of the overcurrent protection devices is the term used to describe orchestrating this process. Though the idea behind it is straightforward, some of the behaviors of the devices involved may be extremely complex. This is notable since almost all of the work is done automatically by autonomous machines using just local intelligence.

Along a feeder, overcurrent protection devices are arranged in sequence. Moving from the ends of the feeders toward the substation causes the devices to run gradually slower for permanent fault coordination. This ensures that the feeder is properly sectioned off so that just the defective portion is isolated. However, if fuse saving is used, this concept is often broken for momentary problems. Feeder breaker in the substation is the normal hierarchy of overcurrent protection devices on a feeder. This is a circuit breaker that can stop 40 kA or less of current and is managed by different relays. The usage of reclosers in this application is common when the available fault current is less than 20 kA. At the midfeeder, line reclosers are fixed on poles. The simplest have hydraulically powered timing, interrupting, and reclosing systems that are self-contained. Some possess unique electronic controllers. We now investigate the power quality problems associated with the positioning and use of these devices.

Fuses

Fuse is the system's most fundamental overcurrent protection component. Fuses need little maintenance and are affordable. They are often employed in significant quantities on the majority of utility distribution networks to safeguard certain transformers and feeder branches from ordinary overhead line fused cuts for these reasons. Fuse operation on permanent faults and isolation of the defective part from the feeder's sound portion are their primary functions. They are positioned to interrupt the feeder only in the tiniest practicable area. Fuses work by melting the fuse element, which is often formed of a metal like tin or silver, to detect overcurrent. This starts an arcing process that eventually causes the electricity to stop flowing. Power systems employ two fundamental types of fuse technology:

Expulsion fuses

Current-limiting fuses

The method used to quench the arc is the key distinction between the two. Additionally, this offers the fuses various power quality characteristics. An arc is produced by an explosion fuse inside of a tube with an ablative covering. As a result, high-pressure gases are produced, typically with a loud report akin to a gunshot, that discharge the arc plasma and fuse remains out the bottom of the cutout. This cools the arc so that it won't relight when the alternating current reaches zero naturally. For large currents, this might take only a half cycle, whereas for low fault currents it could take many cycles. This regulates how long the voltage sag at loads lasts. A current-limiting fuse is much more costly than an expulsion fuse[7]–[9].

By melting a specific sand within an insulating tube, a current-limiting fuse normally dissipates the arc's energy in a sealed environment. The arc is actually quenched extremely fast by this action, which forces the current to zero before it would do so on its own. The voltage sag characteristics may benefit in several ways from this.

It takes a fuse a varying length of time to work at various levels of fault current because it is based on a piece of metal that must gather heat until it reaches its melting point. A fuse's notable inverse time-current feature is the reduction in time as the current level rises. All other overcurrent protective devices in the distribution system must take on this same fundamental structure in order to accomplish full-range coordination with fuses. For various current levels, the leftmost edge represents the shortest melting time and the rightmost edge the longest cleaning time. The following are some characteristics of coordinating with the fuse characteristic that are important to power quality:

1. The coordination fault interrupter must have a TCC to the left of the minimum melting curve if the utility uses fuse saving on temporary faults.
2. The coordinating device has to have a TCC to the right of the clearing curve for a permanent fault in order to enable the fuse to melt and clear first. If not, many more clients would be kept waiting.

Reclosing

The majority of problems on overhead lines are temporary, thus if the current is interrupted, power may usually be effectively restored within a few cycles. As a result, the majority of automated circuit breakers are designed to quickly shut two or three times if necessary. A second opportunity for certain more persistent transient faults to clear is provided by the multiple operations, which are intended to allow different sectionalizing techniques to function. There are specialized circuit breakers for utility distribution systems that were created to fulfill the fault interruption and reclosing function very effectively. These breakers are appropriately referred to as reclosers. The bulk of defects will be fixed during the first operation, which uses two distinct three-phase designs and a standard single-phase reclose. Although there is also a pad-mounted variant of these devices, they are typically pole-mounted on overhead utility wires. Although encapsulated solid dielectric designs and designs with sulfur hexafluoride insulation are also prevalent, oil-insulated versions are the most typical.

These parts may be found all across distribution feeders, as well as sometimes in substations. Usually, they are used near the top of sections that often have transitory defects. They may be used almost anyplace a practical, affordable primary-side circuit breaker is required. Reclosers are among the quickest mechanical fault interrupters used on the utility system since they are designed for fuse-saving applications. Power quality monitors have seen several instances of disruptions as brief as 1.5 cycles, despite their average rating of no faster than 3 to 6 cycles. This may help keep sag times to a minimum. The recloser control will often delay operation to more than 6 cycles when quick tripping is not used to give downline fuses time to clear. In utility networks in North America, reclosing occurs often. Because they believe the bulk of their problems will be permanent, utilities in areas with low lightning occurrence may only reopen once. It is typical to make up to four attempts to fix the problem in lightning-prone areas.

for a more thorough analysis of quick and slow operations. Reclosers often have consistent gaps between operations. Many utilities still use the original hydraulic reclosers' maximum setting of

1 to 2 seconds, despite the fact that today's electronically controlled reclosers allow for almost any setting. On various kinds of reclosers, the initial reclose interval is often set to instantaneous reclose, which leads to closure in 12 to 30 cycles. This is done to shorten the duration of the interruption and enhance the quality of the electricity. However, this might cause certain difficulties, as with the periods when DG disconnects.

Circuit breakers in substations often have unique reclosing sequences. This is the result of a distinct development in relaying technology. The initial trip- ping signal of the first operation is used to start counting closure times. As a result, the typical "0-15-45" operating sequence recloses on the first operation nearly as quickly as feasible, with intervals of around 15 and 30 seconds between the next two operations. Modern breakers and reclosers may both be programmed to have the same working sequences to fulfill load power quality standards, despite the fact that their nomenclature may vary. Utility companies often pick one technology over another depending on price or building requirements. With subterranean cable distribution circuits, automated recloses are often useless until a significant component of the system is above and vulnerable to lightning or trees.

Saving fuses

Utility engineers would want to prevent unnecessarily blowing fuses on temporary problems since a line crew has to be sent to replace them. Line reclosers were designed with saving fuses in mind. Instantaneous ground relaying may be used by substation circuit breakers to achieve the same goal. The fundamental objective is for the mechanical circuit-interrupting device to work fast during its first operation so that it can clear before any fuses downstream from it have a chance to melt. Most of the time, power is entirely restored when the gadget shuts back down, without the need for any more human interaction. The only thing that causes the buyer any trouble is a little flicker. This is referred to as the instantaneous trip or the quick functioning of the gadget. In general use, there are two choices if the issue is still present after reclosing:

Change to a delayed or sluggish tripping characteristic. Circuit breakers in substations often have no other choice; they will only work once during an instantaneous trip. According to this theory, switching to a delayed operation will provide a downline fuse enough time to activate and clear the problem by isolating the faulty portion. This theory believes that the issue is now permanent. This idea is used in situations where a significant portion of transient faults, in order to save the fuses, need two opportunities to clear. A lightning-induced arc may rekindle and need a second opportunity to extinguish on certain line designs and voltage levels. Additionally, if given a second chance, a certain percentage of tree defects will burn free. Fuse saving has been discontinued by several utilities in a number of locations as a result of power quality concerns. Breakers and reclosers can only perform time-delayed operations since the rapid or instantaneous trip has been destroyed.

Reliability

When used in the context of utilities, the word dependability often refers to the length of time that end consumers are completely without electricity. Utility definitions of a persistent interruption range from one to five minutes. Numerous utilities refer to this as a "outage." Any power outage lasting more than one minute is increasingly being referred to as a persistent interruption under the current power quality standards. In any event, the system's enduring flaws, which must be fixed before service can be resumed, have an impact on dependability. Of

However, various industrial end users have varied ideas of what dependability is because even brief pauses due to transitory problems might stop their activities and take many hours to resume. There is a push to incorporate brief outages in the usual dependability indexes[10], [11].

CONCLUSION

For controlling the financial effects of voltage sag occurrences on different economic sectors, including residential, commercial, and industrial consumers, cost estimation is essential. Voltage sags may result in production losses, process interruptions, and equipment breakdown, which can cost a lot of money. The frequency, length, and severity of voltage sag occurrences must be measured, together with the equipment or processes they influence, in order to properly estimate their costs. Businesses and utilities may decide on mitigation solutions like uninterruptible power supply, voltage regulators, and backup generators by precisely predicting the costs of voltage sag incidents. Additionally, cost assessment may help utilities and organizations make decisions and manage risks.

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CHAPTER 6

IMPACT OF ELIMINATING FUSE SAVING

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ABSTRACT:

Eliminating fuse saving has the potential to significantly impact the way electronic devices and systems are designed and manufactured. Fuse saving is a technique used to protect electronic devices from overcurrent and short circuits by selectively opening fuses in the circuit. However, eliminating fuse saving may lead to cost savings and simplify the manufacturing process, as it eliminates the need for fuse-saving circuits and related components. On the other hand, removing fuse saving may reduce the reliability and safety of electronic devices and systems, leading to potential failures and hazards.

KEYWORDS:

Electrical System, Fuse Saving, Fault Current, Reliability.

INTRODUCTION

Disabling the fast-tripping, or fuse-saving, function of the substation breaker or reclosing is one of the most popular responses to concerns about brief outages. This prevents stopping the whole feeder due to a tap problem. Many utilities have discovered that handling complaints about the quality of the electricity in this manner is quite beneficial. It only reduces the number of individuals who are hampered by any given incident. Even with a momentary issue, consumers on the affected fused tap will have a prolonged interruption until the fuse can be changed. Making the issue call has an added expense for the utility and may negatively affect the reliability indices used to assess certain utilities[1], [2]. Of the participating utilities, 40% said they had removed rapid tripping as a result of consumer complaints. Only 30% of the participating public power providers admitted to using this method, compared to 60% of investor-owned utilities.

This may support the generally held view that customers are significantly more sensitive to brief disruptions in urban regions than in rural ones. Our experience since the time of this study suggests that this trend is holding, if not accelerating. Many utility engineers are uncomfortable with this response to concerns about the quality of the electricity. They would like the most effective technological and financial solution, which would make advantage of the breakers' and recloses' fast-trip capacity. This reduces operating expenses while also raising the dependability indices used to assess utility performance. Only the permanent outages have historically been recorded in these statistics, not brief disruptions. However, the utility expenses may be outweighed by the costs to industrial end users when the economic effect of both the utility and the end user is taken into account[3].

There would often be some extra expenditures to eliminate rapid tripping if the utility has a history of fuse saving. For better synchronization, it could be necessary to alter the fused cuts along the main feed, for instance. In certain circumstances, more lateral fuses will need to be installed in order to effectively protect the main feeder from branch failures. Estimates for the cost of installing this range from $20,000 to $40,000 per feeder when engineering time is taken into account. Fuse changes that would not have blown otherwise may result in additional operating expenses of up to $2000 annually. Although these prices may seem high, they may seem to be comparatively low when compared to the expenses of an end customer, such as a manufacturer of plastic bags who can purchase the whole output of the facility. Loss of output and additional personnel costs from a single breaker operation might range from $3000 to $10,000. Therefore, if at least three to five interruptions are removed annually, eliminating rapid tripping is inexpensive in the overall, or value-based, sense.

The feeder's design and any further sectionalizing will have a significant influence on the reliability indices. If the essential industrial load is near to the sub-station and the remainder of the feeder can be separated using a line recloser that uses quick tripping, the effect may be minimal. The influence on the dependability indices increases as one moves further away from the feeder without saving a fuse. Due to this, it is preferable to feed vulnerable customers with a high economic value of service as near to substations as possible and to keep the area of susceptibility to a minimum. The events that create problems for industrial users are not all going to be resolved by removing quick tripping. Only the majority of the fleeting disruptions will be removed. However, it won't help with voltage sags brought on by problems with other feeders, the transmission system, or even fused laterals. One-half to two-thirds of all incidents that stop industrial processes may be attributed to these occurrences. As a general rule, eliminating quick tripping will get rid of around one-third of the interruptions to industrial processes in places where lightning-induced defects are an issue. Naturally, this figure will rely on the kinds of operations that the feeder is supporting.

If there are failures near to the substation on different feeders or even the same feeder but on fused taps, it poses a specific issue. All feeders attached to the bus have a significant droop as a result. Installing reactors on each line coming from the substation bus to reduce the maximum bus sag to around 60%12 and installing current-limiting fuses on all branch laterals close to the substation to make sags extremely short are two solutions that have been suggested to cope with this issue. Residential end consumers may be fairly vociferous about the amount of interruptions they endure, yet most of the time, a brief disruption has minimal direct economic effect. Resetting the dozen or so digital clocks prevalent in homes is perhaps the greatest annoyance. In fact, if quick trips were prohibited, there may be more instances of negative economic effect.

For instance, houses with sump pumps may see more basement flooding situations if they have prolonged outages as a result of their lateral fuse blowing due to a momentary fault during a rainstorm. Some utilities have used instantaneous reclosing on home feeders while keeping rapid tripping as a different solution to the residential complaint issue. The transient interruption may be minimized to 12 to 20 cycles, which makes it brief enough for most digital clocks to continue operating normally. With heavier industrial loads, this wouldn't be quick enough to assist. But there is growing anecdotal evidence that many more contemporary loads, including adjust-speed SSDs, can now endure these brief pauses. Especially if scattered generation is fed from the feeder, instantaneous reclosing is not always achievable.

It's possible that removing rapid tripping may increase the number of substation transformer breakdowns. Reclosers run by default four times before locking out. Dialing out the rapid trips on certain designs will just provide four delayed operations for persistent defects. Four procedures being postponed for no apparent cause is very rare. This exposes the transformer at the substation to needless through-fault current occurrences, reducing the transformer's lifespan. If there are just fuses downline to coordinate with, there should only be two delayed operations. Three procedures can be required if there are additional mechanical interrupters or sectionalizes.

DISCUSSION

Increased Sectionalizing

A radial feed from the substation breaker serves as the standard utility main distribution feeder in the United States. It is made up of fused one-phase and three-phase taps on a primary three-phase feeder in its most basic version. The addition of a line recloser is the first stage in further sectionalizing the feeder to increase overall dependability. Place the recloser halfway down the feeder or at the half-load point if just conventional dependability is a requirement. Depending on where the essential loads are, it could be preferable for the recloser to be placed closer to the substation in order to address power quality issues. Placing it at the first point when the fault current has decreased such that coordination with the fuses on rapid tripping may almost always be guaranteed is one feasible requirement. A further option would be to position the recloser just underneath the majority of the crucial loads that are likely to complain about brief pauses.

By using this idea, the quick tripping may be eliminated from the substa- tion breaker while only sparing a tiny fraction of the feeder's fuse saving. As was previously said, it is often difficult to accomplish fuse saving close to the substation. The main feeder's initial portion is kept free of transient defects with extra care. This would need more regular upkeep like tree cutting and insulation washing. Additionally, special precautions like line shielding or applying line arresters at least every two or three spans may be performed to avoid lightning flashover.

The issue of how much dependability is lost by eliminating quick tripping is often brought up. To investigate this, we ran a reliability analysis on a variety of feeds. Similar to that, but with the single-phase laterals equally distributed along the feeder, was the single main feeder design employed in the research. As a starting point, we used Warren10's urban feeder. We'll call this feeder 1 for short. It has identical fused taps spaced every 0.25 miles along an 8-mile feeder with a total capacity of 6400 kVA. Although this may not be a practical feeder, it is a useful feeder to investigate in order to see the broad patterns of particular activities. With 80% of the faults being temporary, we estimated values of 0.1 faults/yr/mi on the main feeder and 0.25 faults/yr/mi on the fused taps. For persistent defects, a consistent repair time of three hours was anticipated.

Assuming that fuse saving was being used by the utility and that all fuses could be saved on transient failures, we first looked at the basic scenario. Assuming that none of the tap fuses could be salvaged in instance 2, the rapid tripping of the substation breaker was deactivated. Last but not least, for scenario 3, we installed a three-phase recloser one mile from the substation and made the assumption that all fuses downline were still OK. In an urban setting, the typical goal values for SAIFI and SAIDI are 1.0. It is clear that eliminating rapid tripping has a very big negative impact on the dependability indices, despite the fact that none of these occurrences are extremely problematic. A 60 percent rise in SAIFI is seen. In this case, there are fuses on each tap of a fairly regular, well-segmented feeder, and fewer than 3% of the customers are lost when a fuse blows. The impact may be more noticeable for various feeder structures, but this serves to highlight how dependability may be anticipated to decrease when quick tripping is removed.

The SAIDI just marginally rises. The number of fuse operations, which grew by a factor of 5, saw the most shift. As a result, the utility may anticipate a significant increase in difficulty calls during inclement weather. The reliability indices and number of fuse operations revert to roughly the same values as the base case if we were to afterwards install a line recloser as indicated for case 3. Although there are more nuisance fuse blowings in the first section than in instance 1, the reliability indices are actually somewhat better due to the greater sectionalizing in the line. Therefore, removing quick tripping at the structure won't likely have a large negative effect on overall dependability if we additionally install a line recloser beyond the bulk of the essential loads. This naturally implies that the most vital loads are located around the substation.

The initial inclination is to lower the main feeder and install another line recloser. There will be an improvement for the clients serviced from the section of the feeder in between the reclosers. On our uniform 8-mile feeder example, the average yearly interruption rate decreases to around 8.3 if the second recloser is placed 4 miles downline. Customers will see less of an improvement in the frequency of interruptions, nevertheless, in the end. To accomplish even more sectionalizing while preserving beneficial behaviors like fuse saving, one may keep adding line reclosers in sequence on the main feeder and bigger branch feeders. By doing this, the feeder section that is disrupted by a problem is reduced. Although the dependability will normally increase as a result, the perceived power quality may not be much affected.

1. The factors that most significantly influence the amount of interruptions on the feeder section downstream from the reclose include
2. By using line arresters, animal guards, tree pruning, and other fault avoidance strategies, the fault rate may be decreased.
3. More direct routes into the service region should be provided.
4. Avoid tripping phases that aren't connected to the issue. There are at least two ways to provide more parallel paths:
5. Expand the substation's conventional feeding network.
6. To service the load, add extra three-phase branches to the primary feeder.

The first strategy is quite simple: Simply construct a new feeder going out from the substation. By just lowering the number of consumers inconvenienced by each interruption, this might enhance dependability and power quality, but it could not be an inexpensive solution. Additionally, it may not improve the interruption rate as much as some of the methods used in the second choice. Let's look at the second suggestion, which has the potential to generally be less expensive: adding extra three-phase branches off the primary feeder.

There are two ideas being presented. The first entails leaving the substation within a short distance and slicing the feeder into two or three subfeeders. When compared to supplying the same consumers with a single, lengthy main feeder, this may often reduce interruptions by nearly half or two thirds, respectively. This branch happens just a tiny bit beyond the point at which it is useful to preserve lateral fuses on momentary failures. In each branch close to this point, a three-phase recloser is installed. To lessen the likelihood of sympathetic tripping, when a recloser on the unfaulted branch trips as a consequence of the transitory currents associated with the fault, it would be advisable to space the reclosers apart by a certain amount of line. If there are three-phase feeders with large enough conductor sizes in the given places, this idea might be applied to an existing feeder with little rebuilding.

The second suggestion is to first construct a primary feeder that is very dependable and reaches far into the service region. Actually, this major feeder serves very few loads directly. Instead, three-phase branch feeders that occasionally tap off the main feeder service the loads. At the top of each branch feeder is a three-phase line recloser. Of course, the substation lacks quick tripping to reduce fleeting disruptions on the main feeder. On this portion of the feeder, extra precautions will be taken to avoid problems. In essence, the main feeder turns into an addition to the sub-station bus, which is allowed by design to experience a few more problems over the course of its lifespan than the bus. Having independent feeds to each section of the service area straight from the sub-station is akin to having branch feeders, but presumably at a far lower cost.

The suitability of any of these concepts for a given utility depends on a variety of elements, including as the topography, the load density, the load distribution, and previous building techniques. These concepts are just offered as alternatives to stacking fault interrupters in sequence as a means of getting generally reduced average interruption rates. Even while these methods may not catch on, they might be highly helpful for addressing some complex power quality complaints brought on by frequent disruptions.

Tap or midline re-closers

Although rapid tripping was eliminated in response to customer concerns, nearly 40% of the utilities polled said they were interested in increasing the number of line reclosers to enhance consumers' views of power quality. Greater sectionalization of the feeder would be achieved as a result, and maybe, fuse-saving techniques might once again be used on the majority of the feeder. If the whole feeder is being shut down due to defects that are mostly localized to a certain area, this technique is quite successful. The number of consumers inconvenienced by a blink will be lowered by moving the recloser further out on the feeder in an effort to fix the issue first. Only a smaller amount of the feeder nearer the substation is at risk of having a fuse blow on a transient fault, as previously mentioned, if it is also essential to minimize rapid tripping on the substation breaker. Due to the difficulties in avoiding fuse blowing in the high fault current zones close to the substation regardless, this is not significantly different from the typical occurrence.

In fact, several utilities reversed course and did away with line reclosers in response to customer concerns over brief interruptions. Perhaps a feeder section that passed through densely forested regions made the recloser operate often, or the device was responding to high ground currents brought on by harmonics or a load imbalance, resulting in false trips. Whatever the motivation, this is a strange practice that goes against the course that other utilities appear to be following. The primary question at this time does not seem to be whether additional line reclosers are required, but rather, how to implement them to meet the twin objectives of improved power quality and service dependability.

Instantaneous Reclosing

The process of instantly reclosing involves doing so within 12 to 30 cycles after interrupting the fault, usually just on the initial operation. This has long been a typical component of breakers and reclosers, and certain utilities use it routinely, especially on sub-station breakers. The approach hasn't, however, ever received widespread acceptance. Many utilities take more than 2 seconds to reclose, and others take significantly longer.

Many digital clocks and even certain motor-driven loads have been reported to effectively ride through 12- to 30-cycle interruptions. As a result, some utilities started experimenting with immediate reclosing while keeping quick tripping to save fuses. One utility that tried it on 12-kV lines reported that there was a considerable decrease in the number of complaints and that there was no appreciable increase in the number of breaker and recloser operations. With the warning that the same experience may not be obtained at greater voltage levels and with certain line configurations, other utilities may want to take this into consideration.

Some utility engineers have an unfavorable opinion about instantaneous reclosing. One possibility is that the fault won't clear because there wasn't enough time for the arc products to spread. Higher distribution voltage levels and certain line configurations have led to this situation for several utilities. Transformers in substations are needlessly subjected to recurrent through-faults when this occurs. The transformers may start to fail more often as a consequence of this. However, it should be safe to utilize if there is no evidence that instantaneous reclosing is increasing breaker operations.

Another issue is that upon reclosing, very high torques will be produced in rotating machinery. This is a difficulty with distributed generation in particular since 12 to 30 cycles may not be long enough to ensure that the generator's protective relaying will notice an issue on the utility side and be off-line. On feed- ers with DG, reclosing intervals should be at least 1 to 2 s to reduce the possibility that the utility would reclose into the DG out of synchronism. Some services allow 5 seconds. Using a common recloser attachment that prevents reclosing while there is electricity on the load side is one method the utility might assist avoid such an incident? If sufficient transformers are not already installed, this may result in a large cost increase.

Phase-single Tripping

On the utility distribution system, the majority of the three-phase breakers and reclosers work all three phases concurrently. Trip just the faulty phase or phases has been recommended as a method to reduce the vulnerability of consumers to brief outages. This would immediately lower the exposure for most faults by two-thirds since the majority of the loads are single phase. The primary issue with this is that, if single-phased over an extended period of time, certain three-phase loads may suffer damage. Therefore, it is widely agreed that using single-phase reclosers on three-phase branches with large three-phase loads is undesirable. Naturally, this is done often while serving just one-phase loads. A three-phase breaker, also known as a recloser, that may operate each phase separately until it is established that the fault is permanent, can address this issue. If the problem is persistent and the interrupter locks out, all three phases are then opened to avoid the single-phasing of three-phase loads. Suppliers of distribution equipment provide these devices.

Fuses that Restrict Current

Electrical equipment that has a high fault current and the potential for a catastrophic failure often utilizes current-limiting fuses. They are normally only used in situations where the fault current is more than 2000 to 3000 A since they are costlier than traditional expulsion connections. Examples of current-limiting fuses. Although there are many other designs, the fundamental setup consists of a thin ribbon element or wire wrapped around a shape and enclosed in a sealed insulating tube filled with a particular sand. To sustain the pressures throughout the interruption process without rupturing, the tube is made of sturdy material such a fiberglass-epoxy resin composite. The element melts in many locations at once, and with the help of the sand that is melting, a voltage drop that resists the passage of current swiftly forms. In about one-fourth of a cycle, the current is driven to zero[4].Current-limiting fuses are primarily used to guard against damage brought on by high fault current. They have the advantageous side effect that the voltage sag caused by the defect is relatively transient, which is good for power quality. The voltage and current waveforms from a typical current-limiting fuse operation during a single-line-to-ground failure are shown in figure 3.45. Due to the defect, the voltage decreases instantly to about 40%, but quickly rebounds and overshoots to around 140% when the peak arc voltage builds up in the fuse to stop current flow. Keep in mind that the instrumentation has clipped the current waveform. Because the voltage sag is so brief, few industrial activities will be negatively impacted. In order to lessen the amount of sags that interfere with industrial activities, one suggested practice is to place current-limiting fuses on each lateral branch in the high fault current zone close to the substation.

There was concern that the peak arc voltage transient, which surpasses system voltage, might harm arresters and insulation in the system when current-limiting fuses were initially widely used on utility systems. This has not shown to be a serious issue. The overvoltage is comparable to capacitor-switching transient overvoltages, which happen often throughout the day on most utility systems without having any negative effects.

Flexible Relaying

The method of adapting the overcurrent protection device's relaying characteristics to the current system conditions is known as adaptive relaying. The ability to quickly trip breakers in response to weather conditions is one pertinent adaptive relaying practice that is now being used. Typically, a radio or telecommunications connection to the utility control center is used for this. It might also be carried out using nearby sensors that can identify the presence of rain or lightning. Fast tripping is activated in the presence of a storm to protect the fuses from the increased likelihood of temporary faults that are expected. Users are less likely to complain about disruptions during storms and are more accepting of them. Other times, rapid tripping is turned off, allowing the fuses to explode. This does not imply that there won't be any transient faults absent storms. Anytime an animal climbs an electrical structure, a fault may result. Growing vegetation alone could be enough to create problems. On a clear day, however, the public is often far less understanding about an interruption.

Third-Harmonic Currents are Disregarded

Because there are more computers and other electronic loads on the system, the level of third-harmonic currents has been rising. Many feeders' residual current has a third harmonic content that is equal to their fundamental frequency. Each of the phase currents is often found to have a THD of 7 to 8 percent, with the third harmonic accounting for the majority of the distortion. In the neutral, the third harmonic currents combine immediately, making up 20 to 25% of the phase current, which is often equal to or more than the neutral's fundamental frequency current.

The ground-fault relaying is impacted by the third-harmonic current's predominance of zero-sequence current. There have been instances when high harmonic currents in the ground-relaying circuit have caused false tripping and lockouts. The third-harmonic current may have been somewhat increased by resonance in at least one of the instances we have investigated that was linked to capacitor switching. There might have been a great deal more incidents than we are aware of, and it is predicted that things will only become worse in the future.

Raising the ground-fault pickup level when operating procedures permit is the easiest fix. Unfortunately, this reduces the sensitivity of fault detection, defeating the objective of ground relaying, and certain utilities are prohibited from increasing the ground trip threshold by standards. It has been noted that increasing the ground relaying's sensitivity would be achievable if the third harmonic could be filtered out. The third-harmonic current is not a part of the fault current and depends nearly completely on the load. The current that the relaying detects when a fault occurs is mostly sinusoidal. Therefore, the ability to monitor the third harmonic for fault detection is not required for relaying[5]–[7].

The first relays were electromagnetic components that essentially reacted to the current's effective value. As a result, it has long been standard practice to build electronic relays to mimic that response, and digital relays often incorporate the important lower harmonics as well. In hindsight, it would have been preferable if ground-fault relays had disregarded the third harmonic. Since phase relaying is used to both identify overload and defects, there is still a solid reason to keep an eye on the third harmonic. Typically, a rms function is used for overload assessment[8].

CONCLUSION

A complicated topic that needs thorough consideration of many different elements is the effect of doing away with fuse saving on electronic equipment and systems. Eliminating fuse saving may lower costs and simplify manufacture, but it also puts electrical systems and equipment's dependability and safety at risk. Fuse saving should be eliminated only after a careful evaluation of the trade-offs between cost, complexity, reliability, and safety, taking into consideration the unique needs and limitations of the relevant electronic device or system. In the end, it's crucial to find a balance between these variables to guarantee that electronic products and systems are dependable and safe for their intended application in addition to being inexpensive and simple to make.

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CHAPTER 7

A BRIEF DISCUSSION ON UTILITY FAULT PREVENTION

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ABSTRACT:

Utility fault prevention is an essential aspect of the power system operation that aims to minimize the impact of faults on the power system and its customers. Faults are common in power systems, and they can cause power outages, equipment damage, and even fires. The prevention of utility faults requires a proactive approach that involves the identification and mitigation of potential faults before they occur. Various techniques and tools can be used for utility fault prevention, including fault analysis, protective relays, and maintenance practices. Fault analysis involves identifying potential faults in the power system and developing strategies to mitigate them. Protective relays are used to detect faults and isolate them from the rest of the system, preventing further damage. Maintenance practices, such as regular equipment inspections and testing, can also help prevent faults by identifying potential issues before they cause problems.

KEYWORDS:

Fault Current, Fault Detection, Fault Prevention, Grounding.

INTRODUCTION

Eliminating all faults is a certain method to end concerns about utility fault-clearing procedures. There will inevitably be some flaws, but there are several things that can be done to significantly reduce their frequency[1]–[3].

Upkeep of overhead lines

Pruning Trees

One of the most successful strategies for lowering the number of defects on overhead wires is this one. Even though the general public could object because of the environmental and aesthetic effects, it is necessary. In coastal and dusty areas, insulator washing is important, much as tree pruning is in forested areas. Otherwise, even a moderate precipitation without lightning would result in multiple insulator flashovers.

Protect wires

Utility transmission networks often use lightning-shielding cables. Except in cases when lines have an abnormally high rate of lightning strikes, they are typically not applied to distribution feeders. In order to offer shielding, some utilities build their feeders with the neutral on top, maybe even extending the pole. There is no ideal protection. This has reportedly been done by some utilities to enhance power quality with regard to faults. We are unsure of all the justifications for doing this, however. It could make it simpler to find the flaws. Utilizing shielding will lower the rate of back-flashover. If not, it would seem that this would not improve lightning unless used in conjunction with line arrester applications. Using a different line spacing may sometimes make it more likely for there to be a flashover or for there to be trees in the line.

DISCUSSION

Tree wire

Insulated or covered conductor might lessen the incidence of tree-induced failures in locations where tree removal is not possible. Techniques for preventing faults in subterranean distribution cables often revolve on maintaining the insulation against voltage spikes. As the insulation ages, it degrades dramatically, necessitating more measures to maintain the cable's integrity. Although there are occasional attempts to restore insulation levels by pumping fluids into the cable, this often entails arrester protection methods to redirect lightning surges originating from the overhead system[4], [5]. Since almost all cable problems are irreparable, the problem with power quality is primarily about locating the fault quickly enough that the cable may be physically sectioned off and fixed. Devices for fault location that are available are discussed.

The line arresters

Either the insulation level of the line must be increased, lightning must not strike the line, or the voltage must not exceed the insulation level in order to avoid overhead line problems. The third concept is gaining popularity as surge arrester designs become well. Surge arresters are positioned on distribution transformers and every two to three poles along the feeder to achieve this. While some utilities install them on all three phases, others only do so on the phase where lightning strikes most often. It will be essential to install arresters on every phase of every pole in order to accommodate some of the more current concepts about enhancing power quality or delivering bespoke electricity with very dependable main feeds. Currently, only line sections with a history of multiple lightning-induced failures are subjected to the addition of line arresters to the standard arrester at transformer sites. However, lately, several utilities have asserted that using line arresters is both more inexpensive and more effective than shielding. Due to the density of the load, certain parts of feeders in urban and suburban areas will inevitably meet the aim of an arrester every two or three poles. This is because distribution transformers must be installed at least that regularly. In lightning-prone areas, each transformer will often include a main arrester. Fast fault finding is a crucial component of power quality and dependability.

Circuit failure indications

It might be difficult to locate cable issues often. Although sometimes there may be a physical display, since the wires are underground, it is usually hard to view the issue. Many utilities utilize "faulted circuit indicators" or simply "fault indicators" to pinpoint the faulted portion more rapidly in order to speed up the fault finding process. When the current rises over a certain threshold, these gadgets switch a target indication. The plan is to place one at each pad-mount transformer, with the final one to display a target placed just before the portion that is faulty. On how to choose the appropriate ratings for faulty circuit indicators, there are two primary schools of thought. According to the more established school, choose a rating that is 2 to 3 times the highest projected load on the cable. As a consequence, the defect detection capacity is quite sensitive. According to the opposing school, this is excessively sensitive, which is why many fault indicators provide misleading readings. The location of the defect is delayed by a misleading signal, which also lowers dependability and power quality. The explanation provided for the erroneous signal is that when the fault occurs, the energy stored in the cable provides enough current to trigger the indicator. So, a few signs that are located below the problem may also demonstrate the defect. Applying the indication with a rating based on the maximum fault current available rather than the maximum load current would solve this issue. This is predicated on the notion that the majority of cable problems quickly transform into fastened failures. As a result, the rating is chosen with a 10–20% margin of error.

DG is a problem that also affects the usage of fault indications. There will be more false indicators since there are more sources on the feeder that may give fault current. All the fault indicators between the generator sites and the problem may trip in certain circumstances. Finding new technologies that function appropriately in this setting will be difficult. This is only one illustration of the subtly changing fault currents brought about by adequate DG penetration on utility practice. Before the subsequent fault occurrence, fault indicators need to be reset. Others have one of a variety of techniques for automatically sensing or assuming the return of power and reset- ting, while others must be reset manually. Test point reset, low-voltage reset, current reset, electrostatic reset, and time reset are a few of the methods. Finding cable problems in the absence of fault indications. Without fault indications, the utility will have to depend more heavily on human methods to locate an issue. There are many other kinds of fault-locating procedures, and it is beyond the scope of this paper to describe them all in detail. Following are a few of the general types of techniques.

Thumping. There are many little variations to this popular practice. The fundamental method is applying a dc voltage to the cable that is adequate to restore the fault before attempting to locate the defect's physical manifestation by sight, hearing, or touch. A capacitor bank that has the capacity to store enough energy to produce a loud enough sound is one typical method for doing this. The "thump" from the discharge may be felt and heard by those standing on the surface of the fault. Some use this with cable radar methods to verify distance estimations. Many are worried about the possible harm such beating tactics may do to the cable's sound portion.

Radar on cables and other pulse techniques. To estimate the distance to the fault, these methods use the traveling-wave theory. On the cable, the wave velocity is known. As a result, the length of the cable from the fault to the point where an impulse is injected will determine how long it takes for the reflection to return. A short circuit will reflect the voltage wave back negatively, while an open circuit would do the opposite. The reverse will happen with the impulse current. When the cable's routing is understood, the defect site may be identified by measuring along the path. By tapping the cable, it may be verified and adjusted. There are many cable taps on certain systems. Finding the fault's branch is just as important as knowing how far away it is. This may be a very challenging issue and remains a significant roadblock to quickly identifying a cable breakdown.

Tone. A high-frequency signal is injected into the cable via a tone system, and a specialized receiver can track the path of the cable. The tone will vanish beyond the problem site, making this technique beneficial for fault finding. It is sometimes used to trace the cable path while it is powered. Each part of the manually sectioned wire is then reenergized until a fuse explodes. By using the method of elimination or by looking at the physical manifestation of the problem, the defective portion is identified. Some utilities strongly oppose this technique due to the risk and potential for injuring cable components. Others call for the use of tiny current-limiting fuses, which reduce the amount of energy that the fault is allowed to absorb. Some experts believe this to be the least effective way for detecting faults and that it should only be used as a last option since it may be costly and time-consuming. Additionally, this causes bothersome voltage sags for end consumers[6]–[8].

Momentary Overvoltages

Transient Overvoltage's Sources

Lightning and capacitor switching are the two major causes of transient overvoltages on utility systems. In end-user facilities, they are also the origins of transient overvoltages and a variety of other switching events. When they switch, several power electronic equipment produce significant transients. according to Chap. Depending on the frequency, transient overvoltages may be produced at high, medium, or low frequencies.

Battery Swapping

One of the most frequent switching occurrences in utility systems is the switching of capacitors. Reactive power is provided by capacitors to rectify the power factor, which lowers losses and stabilizes the system's voltage. They are a highly cost-effective and typically trouble-free way to achieve these objectives. Alternative techniques like spinning machines and electronic var compensators are very expensive or need a lot of maintenance. As a result, capacitor usage in power systems is and will remain widespread. Capacitors have the issue of producing oscillating transients when switched, which is a disadvantage. Some capacitors are always powered on, while others are turned on and off depending on the load. The capacitors are switched using a variety of control mechanisms, including time, temperature, voltage, current, and reactive power. Controls often integrate two or more of these features, for example, temperature and voltage override.

Utility capacitor switching overvoltages are one of the typical signs of power quality issues, and one of the symptoms is that the issues start to occur at about the same time every day. Capacitors are regularly switched by time clock on distribution feeders with industrial loads in anticipation of a rise in load at the start of the workday. Adjus-speed-drive trips and faults of other electronically controlled load equipment that take place without a noticable light blink or an effect on other, more traditional loads are frequent issues. The one-line schematic of a typical utility feeder capacitor-switching scenario. A transient like the one in 4.2 may be seen upline from the capaci- tor at the monitor site when the switch is closed. The capacitor switch contacts in this instance close at a location close to the system voltage peak. This is a common occurrence for many different kinds of switches because when the voltage across the switch reaches its maximum value, the insulation between the switch contacts has a tendency to fail.

The capacitor is now experiencing 0 voltage across it. The system voltage at the capacitor position is momentarily pushed down to zero because the capacitor voltage cannot change instantly. It then increases as the capacitor starts to charge toward the system voltage. The capaci- tor voltage overshoots and rings at the system's inherent frequency because the power system source is inductive. Due to the resistance between the observation point and the switched capacitor, the initial voltage change at the monitoring site won't reach zero fully. However, it will be possible to see the initial dip and following ringing transient that mark a capacitor-switching event[9], [10]. Depending on the system damping, the overshoot will produce a transient between 1.0 and 2.0 pu. The transient in this instance that was seen at the monitoring site is roughly 1.34 pu. Utility capacitor-switching transients have been seen around the theoretical maximum as well as in the region of 1.3 to 1.4 pu.

The oscillogram's transient spreads into the local power grid and typically passes via distribution transformers and customer load facilities by an amount roughly corresponding to the transformer's turns ratio. If the inherent frequencies of the systems are appropriately matched, the voltage may even be increased on the load side of the transformer if there are capacitors on the secondary system. While such short transients up to 2.0 pu often do not harm the insulation of the system, they may frequently result in malfunctions of electronic power conversion equipment. The high voltage may be seen by controllers as a warning of an oncoming dangerous scenario, prompting them to disconnect the load for their own safety. The tran- sient may also obstruct thyristors' ability to gate.

Magnification of transients caused by Capacitor Switching

The impact of utility capacitor-switching transients on end-use equipment might be worsened by installing power factor correction capacitors at the customer site. When capacitor banks are swapped, there is usually a short voltage transient of at least 1.3 to 1.4 pu. On the primary distribution system, the transient is typically no more than 2.0 pu, while ungrounded capacitor banks may produce somewhat higher values. For certain low-voltage capacitor and step-down transformer sizes, load-side capacitors may increase this transient overvoltage at the end-user bus. The circle of worry about this occurrence. Under these circumstances, transient overvoltages on the end-user side may reach as high as 3.0 to 4.0 pu on the low-voltage bus, possibly having detrimental effects on all sorts of consumer equipment. Over a broad range of transformer and capacitor sizes, utility capacitor-switching transients at the end-user site are amplified. Therefore, it is often not a viable option to resize the customer's power factor correction capacitors or step-down transformer. Controlling the transient overvoltage at the utility capacitor is one method. Using synchronous closing breakers or switches with preinsertion resistors, this is sometimes achievable. More information is provided on these options.

High-energy surge arresters may be used to restrict the transient voltage magnitude at the customer bus at the customer site. The enhanced transient's energy levels will normally be about 1 kJ. The estimated arrester energy for various low-voltage capacitor sizes is shown in Figure 4.5. For low-voltage applications, more recent high-energy MOV arresters can tolerate 2 to 4 kJ. It is essential to remember that the arresters can only reduce the transient to a level that is safe for them. Usually, this will be 1.8 times the usual peak voltage. This could not be enough to safeguard delicate electronic equipment, which might only be able to withstand pressures of 1.75 up. Because the protective properties of the arresters are constrained by the physics of the metal-oxide materials, it may not be able to significantly increase these properties. Therefore, it is crucial to thoroughly assess the resist capabilities of sensitive equipment utilized in applications where these transients might occur in order to ensure optimal coordination.

The end-user power factor correction banks may be transformed into harmonic filters as an additional method of reducing voltage magnification transients. The transient voltage at the customer bus will be reduced to acceptable levels by an inductance connected in series with the power factor correction bank. This approach offers a number of advantages, including correcting the displacement power factor, managing the facility's harmonic distortion levels, and reducing the risk of amplified capacitor-switching transients. In many instances, the transient has a negative impact on a limited number of load devices, such as adjust-speed motor drives. To stop the high-frequency magnification transient, it is often more cost-effective to connect line reactors in series with the drives. In general, a reactor at 3 percent is efficient. It provides a much bigger resistance to the transient but just a minor impedance to power frequency current. This protection is built into many different kinds of drives, either by an isolation transformer or a dc bus reactance.

Lightning

Impulsive transients have a powerful source in lightning. Physical phenomena are a subject that is well covered in other reference works, therefore we won't spend much time on it here. We will focus on how lighting results in transient overvoltages on electrical systems. Direct contact with a phase wire, either on the main or secondary side of the transformer, results in the most evident conduction channel. Although this has the potential to produce very high overvoltages, some experts aren't sure whether this is the most typical method that lightning surges reach load facilities and cause harm. Lightning currents traveling down ground conductor routes have been shown to produce transient overvoltages that are quite similar to those. Keep in mind that lightning currents might reach the grounding system via a variety of different pathways. The major ground, secondary ground, and load facility structure are a few typical ones, as shown by the dotted lines. Also keep in mind that the arresters on the service transformer direct strikes to the primary phase to the ground circuits. As a result, many more lightning impulses than one would anticipate may be seen at loads.

Remember that grounds are never ideal conductors of electrical current, particularly for impulses. There will be significant surge currents running in other linked ground conductors in the first microseconds of the strike, even if the majority of the surge current may ultimately dissipate into the ground connection nearest to the hit. Locations where lightning strikes will conduct lightning impulses into power infrastructure. Direct contact with a phase conductor often results in line flashover close to the point of contact. This results in a fault with the attendant voltage sags and interruptions, as well as an impulsive transient. During its passage, the lightning surge may create several flashovers at pole and tower structures and travel a great distance along utility wires. If surge arresters are placed appropriately, it is pretty simple to intercept the impulse coming from the phase wire. The tail of the impulse is often reduced if the line flashes over at the point of the hit. Some of the surge current may enter load equipment, depending on how effectively the grounds are along the current's course. Because of the harsh duty, arrestees close to the strike may not survive.

Lightning may send impulses into the electricity system without ever striking a conductor. Simply by causing the electric field to collapse when lightning strikes close to the line, an impulse may be produced. Additionally, lightning may simply hit the earth next to a facility, greatly increasing the local ground reference. This might push currents flowing through grounded conductors into a distant ground, perhaps passing close to delicate load equipment. Many researchers in this area believe that the service transformer's interwinding capacitance is how lightning surges approach loads from the utility system. According to the theory, since the lightning impulse is moving so quickly, the transformer windings' inductance prevents the initial portion of the wave from passing through due to the turn's ratio. The interwinding capacitance, however, can provide the high-frequency surge with a handy route. As a result, a voltage on the secondary terminals may exist that is far greater than what the turn ratio of the windings would indicate.

The design of the transformer has a significant impact on the amount of capacitive coupling that happens. Due to the way the windings are made, not all transformers have a straightforward high-to-low capacitance. More of the impulse may actually be linked to ground than to the secondary winding because the winding-to-ground capacitance may be larger than the winding-to-winding capacitance. In any scenario, due of how rapidly the interwinding capacitance charges, the resultant transient is a very brief single impulse or train of impulses. Although the rising rates may be considerable, arresters on the secondary winding shouldn't have any trouble dispersing the energy in such a surge. As a result, the efficacy of an arrester in keeping this impulse out of load equipment depends greatly on the length of the lead.

When a utility's main distribution system is struck, it is common to see a lengthier impulse, sometimes oscillatory, on the secondary. This is most likely caused by conduction around the transformer via the grounding systems rather than capacitive coupling through the service transformer. If the load system provides a superior ground and a significant portion of the surge current passes via conductors in the load facility on its route to ground, this poses a special issue. When lightning stroke currents penetrate the ground system, the main power quality. They add many kilovolts to the potential of the local ground, elevating it over other grounds nearby. When exposed to the lightning surge voltages, sensitive electronic equipment that is interconnected between two ground references, such as a computer linked to the phone network through a modem, may malfunction. As they move through cables on their route to a better ground, they generate high voltages in the phase conductors.

The so-called low-side surge problem that is discussed is a contributing factor to the issues. Recent study has led to a change in how people see lightning. Utility line flashovers due to lightning are more often than previously believed. As more data accumulates, it seems that multiple strikes appear to be more often than not and that lightning stroke current wavefronts are moving more quickly than previously believed. Some strokes may last longer than prior experts had estimated. These discoveries might explain why lightning arresters that were supposed to be able to manage powerful lightning strikes failed[11], [12].

CONCLUSION

Utility fault prevention has several advantages, including better system dependability, less downtime and equipment damage, and safer working conditions for both consumers and employees. Implementing utility fault avoidance strategies, however, may be expensive and need a significant investment in resources, including employees, technology, and equipment. Therefore, while creating utility fault avoidance systems, rigorous cost-benefit trade-offs must be taken into account. In conclusion, utility fault prevention is an important part of running a power system and may assist guarantee that consumers get safe and dependable energy supply. It necessitates a proactive strategy that includes possible defect diagnosis and mitigation utilizing methods like fault analysis, safety relays, and maintenance procedures. Even though utility fault avoidance has several advantages, designing preventive techniques must carefully assess the cost-benefit trade-offs.

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CHAPTER 8

A FUNDAMENTAL STUDY TRANSFORMER GROUND

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ABSTRACT:

Transformer grounding is a crucial aspect of the safe and reliable operation of electrical power systems. Transformers are essential components of power systems that are used to step up or step down the voltage of electricity, and they are typically connected to the power system via grounded circuits. Transformer grounding provides a path for fault current to flow safely to the ground, protecting equipment and personnel from electrical hazards. There are various methods of transformer grounding, including solid grounding, impedance grounding, and resonant grounding. Solid grounding involves connecting the transformer neutral directly to ground, providing a low-impedance path for fault current. Impedance grounding uses a grounding resistor or reactor to limit the fault current and reduce the risk of damage to equipment. Resonant grounding involves the use of a grounding transformer and a capacitor to create a resonant circuit that limits the fault current and provides effective protection.

KEYWORDS:

Circuit Grounding,Ferroresonance, Grounding Transformer, Transformer.

INTRODUCTION

A unique kind of resonance involving capacitance and an iron-core inductance is referred to as ferroresonance. The most frequent scenario in which it results in disturbances is when a transformer's magnetizing impedance is connected in series with a system capacitor. When a conductor is open-phase, this occurs. Ferroresonance may be used for practical purposes, such as in a constant-voltage transformer, under carefully regulated conditions[1], [2]. Resonance in linear system components differs from ferroresonance. Resonance produces strong sinusoidal voltages and currents at the resonant frequency in linear systems. The phenomena responsible for the harmonic amplification in power systems is linear-system resonance. High voltages and currents may also be produced through ferroresonance; however, the resultant waveforms are often erratic and chaotic in nature. Following is an explanation of ferroresonance in terms of linear-system resonance[3].

The most frequent causes of ferroresonance are manual switching of a three-phase, cable-fed, unloaded transformer and closing of just one phase. When the first phase closes during energization or before the final phase opens during deenergization, ferroresonance may be detected. An unloaded, cable-fed, three-phase transformer with an open phase must be manually switched. Again, deenergization or deenergization may cause this. A transformer with one or two open phases might have one or two riser-pole fuses burst. Alternatively, single-phase recloses may result in similar issue. Many contemporary commercial loads feature controls that, when they detect this circumstance, shift the load to backup systems. Sadly, this prevents the transformer from having a load to reduce resonance[4].

It should be emphasized that not all of these instances result in audible ferroresonance. Several utility workers assert that they have decades of experience with underground cable networks without ever seeing ferroresonance. Ferroresonance is more likely under certain system circumstances, including:

1. Higher distribution voltage ranges, especially systems in the 25- and 35-kV classes
2. Transformers that are lightly loaded and unloaded are switched
3. Transformer primary connections without grounding
4. Circuits for very long subterranean cables
5. When under-ground cable systems are being built, cables are damaged and manually switched.
6. Low short-circuit currents, or weak systems
7. Reduced-loss transformers
8. Systems that use single-phase switching in a three-phase system

Ferroresonance may occur at any distribution voltage level, however it is more common at higher voltage levels. Ferroresonance may still happen despite the pro-portion of losses, magnetizing reactance, and capacitance at lower levels limiting its effects. There are several types of ferroresonance, each having unique electrical and physical manifestations. While some have voltages that are almost typical, others have very high voltages and currents. Failures or other ferroresonance-related signs may or may not be present in the electrical components. Therefore, unless there are witnesses or power quality measuring tools, it may be difficult to determine whether ferroresonance has happened in many circumstances[5].

The following list includes typical ferroresonance indications.

Loud sound: There may be an audible sound during ferroresonance, which is sometimes compared to the sound of a huge bucket of bolts being shaken, whining, a buzzer, or an anvil chorus banging on the transformer enclosure from within. The noise is brought on by the steel core's magnetostriction being pushed to saturation. Although it's hard to put into words, this noise is noticeably different and louder than the typical transformer hum. Most electrical system operators can hear it for the first time and instantly recognize it.

Overheating: Ferroresonance is often, but not always, accompanied with transformer overheating. This is particularly accurate when the iron core is deeply saturated. The magnetic flux will enter portions of the transformer where it is not anticipated, such as the tank wall and other metallic components, since the core is repeatedly saturated. The paint on the tank's top may bubble or burn, which is often a sign of stray flux heating. This isn't always a sign that the device is broken, although harm might happen if the ferroresonance has continued long enough to overheat any of the bigger internal connections. This may in turn damage solid insulation structures beyond repair. It should be noted that certain transformers displaying ferroresonance symptoms, such as loud, chaotic sounds, don't exhibit discernible evidence of heating. The behavior of the transformer is determined by its design and the ferroresonance mode.

High overvoltages and a malfunctioning surge arrester. Both the primary and secondary circuits may sustain electrical damage when overvoltages and ferroresonance coexist. Surge arresters often die in the incident. They are designed to capture momentary overvoltages and clamp them at an acceptable level. There is a clear limit to their ability to absorb energy, even if they may be able to endure numerous overvoltage incidents. In end-user facilities, low-voltage arresters are more vulnerable than utility arresters, and their failure is sometimes the sole sign that ferroresonance has taken place.

Flicker: The magnitude of the voltage may change dramatically during ferroresonance. The secondary circuit's end consumers could really notice that their lightbulbs are flickering. Certain electrical devices could be particularly vulnerable to such voltage outbursts. Long-term exposure may reduce the equipment's anticipated life or result in an instant failure. The UPS system's sirens may ring repeatedly and persistently in buildings that switch to it in the case of utility-side disturbances when the voltage changes[6].

DISCUSSION

Other Switching Transients

As the name suggests, line energization transients happen when a switch connecting a line to the power supply is closed. When compared to capacitor energizing transients, they often have higher-frequency content. The interactions between the system equivalent source inductance and the line capacitance, as well as traveling-wave phenomena, are what cause the transients. The transmission or distribution line's dispersed capacitance and inductance are what produce traveling waves. At distribution voltage levels, line energizing transients often create very benign overvoltages and are normally of little consequence. Except for transmission lines running at 345 kV and beyond, it is highly uncommon to install any form of switching control for line energizing. Typically, line energizing transients disappear within 0.5 cycles.

Line energizing transients, transformer energizing inrush characteristics, and load inrush characteristics make up the energization transients on distribution feeder circuits. 4.15 depicts a typical situation where the monitor was put on the switch's line side. Above 1.0 kHz, the first transient frequency may be seen as a little amount of "hash" on the waveform's front. The transformer inrush current, which includes a variety of low-order harmonic components, notably the second and fourth harmonics, causes the voltage to noticeably distort once it is powered up. The voltage waveform's lack of symmetry in the few recorded cycles serves as proof of this. In almost every instance, this will ultimately go. The fundamental magnetizing inrush characteristic is seen in the initial peak of the current waveform, which is thereafter overtaken by the load inrush current[7].

End-user equipment is often not affected by line energizing transients. Inductive chokes and surge protecting devices may be used to shield equipment from the high-frequency components if required. Since the example is so innocuous, there shouldn't be many issues. Less loaded cases might have far more oscillatory behavior. The typical single-line-to-ground fault, which has some connection to switching, is another cause of overvoltages. In a system with high zero-sequence impedance, the failure will cause a voltage increase in the sound phase. On successfully grounded four-wire, multigrounded neutral systems, the normal voltage rise is typically between 15 and 20 percent. The voltage increase may reach 40–50% on systems with neutral reactors that restrict the fault current, for instance. When the issue has been fixed, this overvoltage will go away. Although these overvoltages are not often a concern, there might be issues if the fault clearance is slow:

In an effort to provide greater insulation protection, some secondary arresters placed by end users aim to clamp the voltage to as low as 110 percent voltage. When carrying power frequency current over numerous cycles, such arresters are vulnerable to failure.

If the machine trips due to an excessively high dc bus voltage, adjust-speed-drive controls may assume a failure. Voltages above 120 percent are often interpreted by distributed generation that is linked to the utility system as calling for an urgent disconnect. As a consequence, annoyance tripping is likely to happen. Of course, the service transformer connection has a significant influence on how this overvoltage really affects the secondary side of the system. Although the voltages will be transformed directly via the common grounded wye-wye connection, transformers with a delta connection will assist shield the load from overvoltages caused by these failures.

Surge arresters and transient voltage surge suppressors' primary job is to reduce the potential voltage between two locations in a circuit. Understanding this idea is crucial. One of the myths regarding visitors and such devices is that they can somehow absorb the surge or channel it to ground apart from the rest of the system. If there is a safe path for the surge current to flow into, that may be a beneficial side effect of the arrester application. However, the main priority in arrester application is to place the arresters directly across the sensitive insulation that is to be protected so that the voltage seen by the insulation is kept to a safe value. Like power currents, surge currents must abide with Kirchoff's rules. Every conductor they pass through has a voltage drop, and they must flow in a complete circuit. The local ground is typically one of the sites to which arresters, or surge suppressors, are connected, although this need not be the case.

With a minimal lead length on each terminal, surge suppression devices should be placed as near as possible to the crucial insulation. While arresters are often found at main panels and subpanels, they are typically most effective at safeguarding a specific load when they are applied where the power line reaches the load equipment. The optimal place is sometimes found within the load device. A lot of electronic controllers, for instance, include protectors on each line that exits the cabinet since they were designed to be used in a power system setting. At the service entry, the first arrester is linked from the line to the neutral-ground bond. It prevents the line voltage V1 at the panel from getting too high in relation to the neutral and ground voltage. It creates a low-impedance channel for the surge current to follow onto the ground wire when it limits voltage. Keep in mind that the ground connection and the ground lead have significant resistance. As a result, the voltage drop across the ground impedance raises the potential of the whole power system relative to that of the distant ground. This may be many kilovolts for typical surge current and ground impedance levels.

In this case, one anticipates that the majority of surge energy will be discharged via the first arrester and into the earth. As a result, the arrester transforms into a surge "diverter." This is also another crucial job that pertains to surge arrester use. In fact, some prefer to refer to a surge arrester as a surge diverter because of the low-impedance channel that its voltage-limiting action provides around the load that is being protected. It can only function as a diverter, however, provided there is a suitable route into which the current may be changed. This is not always simple to do, and sometimes the surge current is directed toward an unwanted critical load.

The signal cable, shown in this picture by the dotted line and connected to the safety ground, is another potential channel for the surge current. There will be some surge current going down the safety ground wire if this is linked to another device that is grounded elsewhere. As a consequence, damaging voltages may be impressed across the load. Electrically, the first arrester at the service entry is too far away to provide sufficient load protection. In order to protect the insulation, a second arrester is thus attached at the load, this time immediately across it. It is "line to neutral" wired, which limits its protection to normal mode transients. Without further complicating the picture, these guidelines should be taken into consideration as the very minimal level of load protection. Surge suppressors often feature suppression on every line to ground, every line to neutral, and every line from neutral to ground. Many transient overvoltages produced by switching will be those of a normal mode and will not seek ground, while lightning surge currents are seeking a distant ground reference. Arresters must be applied at each load along the way if surge currents are redirected into other load circuits in order to assure protection.

Just before the cable enters the cabinet, the signal cable is connected to the local ground reference at the load. This can seem to produce an undesired ground loop. However, it is necessary to provide load and low-voltage signal circuit protection. Otherwise, the potential of the power components might increase by several kilovolts in relation to the signal circuit reference. There are several power and signal wires attached to many loads. Additionally, a load can be in a situation where it is next to another cargo and personnel or delicate equipment often comes into touch with both loads. This increases the possibility that a lightning strike might make one ground far more potential than the others. This might damage the operators physically or produce a flashover over the insulation located between the two ground references. Therefore, at the load equipment, all ground reference wires should be connected together. The idea is not to stop the local ground reference from increasing in potential along with the surge—that is impossible with lightning. The idea is to connect the references such that any nearby power and signal cable references all increase at the same time.

This condition is a frequent cause of electrical gadget failure. The problem may be found in TV receivers with cables attached, PCs with modem connections, computers with several peripherals powered by different sources, and industrial facilities with networked machinery. For sensitive electronic equipment, such as mainframe computers that take up a lot of space, it is sometimes required to develop a specific low-inductance ground reference plane since a few feet of conductor may make a big difference at lightning surge frequencies. High frequency surge currents, including those caused by lightning strikes and capacitor-switching events, are the ones that can be blocked with the greatest success. Building filters that can distinguish between low-frequency surges and power frequency currents is challenging and costly since power frequency currents must pass through the surge suppressor with little added impedance.

By connecting an inductor, also known as a choke, in series with the load, blocking high-frequency transients may be accomplished rather simply. The inductor will see a dip in the high surge voltage. One must carefully evaluate the possibility that excessive voltage might harm the insulation of the loads as well as the inductor. A line choke, on the other hand, may commonly be used alone to effectively block high-frequency transients such line-notching transients from adjust-speed drives. A low-pass filter with a shunt-connected voltage-limiting device on each side of the series choke is typically created by combining the blocking function with the voltage-limiting function. When there are arresters on both ends of the line supplying the load, a circuit will inevitably form. The blocking effect is proportional to the length of the line. Such a circuit has excellent overvoltage protection qualities. The majority of rapidly increasing surges are forced into the first arrester by the inductance. The remaining surge energy must then be accommodated by the second arrester. For computer protection, such circuits are often included into outlet strips.

Because the surge current crosses two or more different connections to ground, several surge-protection issues arise. Since lightning currents are seeking ground and essentially split according to the ratios of the ground pathways' impedances, this is a concern with lightning protection in particular. For there to be issues, the surge current need not even reach the power or phase conductors. The ground conductors will experience a large voltage drop that will regularly cross crucial insulation. The affected grounds may be partially on the utility system or totally within the load facility. In a perfect world, a facility would only have one ground route for lightning, but many of them do. For instance, there could be a driven ground at the substation transformer or service entry and a second ground at a water well that really generates a better ground. So, when lightning hits, the well will often get the majority of the surge current. Even if the electrical system is not purposefully linked to a second ground, this may impose an overly high voltage across the pump insulation. When lightning hits, the potentials might rise to a point where the insulation of the electrical system will flash over.

By enhancing all of the intended grounds at the service entry and close by on the utility system, the quantity of current flowing between the grounds may be decreased. The likelihood of equipment failure due to lightning inside the facility will often decrease as a result, albeit it won't be completely eliminated. Some buildings, however, are also significantly exposed to lightning, and the hazardous surge currents may reenter the utility grounds. The challenges are the same regardless of which way the currents are flowing. The same rule still holds true: make the structure's grounds better to reduce the quantity of curb that could seek an alternative route to the ground. Any power or signal cables running between two grounds must be adequately safeguarded on both ends with voltage-limiting devices when it is impossible to prevent current from passing between the two grounds. When a control cabinet is positioned quite a distance from the switch or other device being controlled, this is a frequent practice for utility and end-user systems.

Devices for Overvoltage Protection

Surge arresters and Transient Voltage Surge Suppressors

By restricting the maximum voltage, arresters and TVSS devices safeguard equipment against transient overvoltage’s. The words are sometimes used interchangeably. However, TVSSs are often connected to equipment utilized at the load. Sometimes a TVSS will have more surge-limiting components than an arrester, which typically simply has MOV blocks. Although an arrester may be capable of handling greater energy, the line between the two is often confused by everyday terminology. The components of these devices fall into one of two categories: clamping or crowbar function.

Crowbar devices, which are typically open, allow current to flow during overvoltage transients. Due to the short circuit created across the line once the gadget conducts, the line voltage will decrease to almost zero. Typically, a gap filled with air or a particular gas is used in the manufacturing of these devices. When a sufficiently enough over-voltage transient arises, the gap arcs over. Power frequency current, also known as "follow current," often continues to flow in the gap after the gap arcs over until the next current zero. Since the power frequency voltage drops to zero or to a very low value for at least one-half cycle, these devices suffer from this disadvantage. Some loads will needlessly drop off the line as a result of this.

Nonlinear resistors are often used as clamping devices in ac circuits because they carry relatively little current until an overvoltage arises. As the voltage rises, they then begin to conduct strongly, and their impedance quickly decreases. To efficiently reduce a surge's voltage increase, these components carry increasing quantities of current. They have a benefit over gap-type devices in that when they start to conduct the surge current, the voltage is not decreased to the level of conduction. Additionally, employed in this application are zener diodes. Examples of MOV arresters for load systems characteristics. There are two crucial grades for MOV arresters. The first is maximum continuous operating voltage, which typically ranges between 125 percent and 150 percent of the system nominal voltage and must be greater than the line voltage. The energy dissipation rating is the second rating. A broad variety of energy ratings are offered for MOVs.

Transformers for isolation

An isolation transformer used to dampen high-frequency noise and transients as they try to pass from one side to the other is seen in figure 4.19. However, some noise in the usual and common modes may still get to the load. Common-mode noise may be effectively eliminated using an electrostatic shield. However, owing to magnetic and capacitive coupling, some normal-mode noise may still reach the load. Leakage inductance is the main quality of isolation transformers for electrically isolating the load from the system during transients. As a result, neither high-frequency noise nor transients, nor any noise or transients produced by the load, are allowed to reach the load or the rest of the power system. One issue that may be restricted to the load side by an isolation transformer is voltage notching brought on by power electronic switching. Adjus-speed drives and other equipment won't accidentally trip due to capacitor switching and lightning transients originating from the utility system.

Voltage Nominal Operating

Isolation transformers may also be used to establish a new ground reference or independently derived system, which is another use. Neutral-to-ground voltages at critical equipment are restricted by this new neutral-to-ground bond.

Low-Pass Filtration

The pi-circuit approach is used by low-pass filters to further improve high-frequency transient protection. Low-pass filters are often made up of parallel and series inductors for use in electrical circuits. For certain resonant frequencies, this LC combination offers a low-impedance route to ground. Voltage clamping devices are placed in parallel to the capacitors when using surge protection. In certain configurations, capacitors are absent. A typical hybrid protector that, for optimal protection, combines two surge suppressors with a low-pass filter. To deal with high-energy transients, the front end incorporates a gap-type protector. High-frequency transient transfer is limited by the low-pass filter. High-frequency transients are pushed into the first suppressor by the inductor, which aids in blocking them. While the nonlinear resistor caps the voltage magnitude at the protected equipment, the capacitor controls the rate of increase. Other iterations of this system may include capacitors on the front end as well as MOVs on both sides of the filters.

Conditioners of Low-Impedance Power

The switch-mode power sources employed in electronic equipment are typically interfaced with via low-impedance power conditioners. LIPCs are different from isolation transformers in that they feature a filter built into their design and a significantly lower impedance. The filter guards against high-frequency, source-side, common-mode, and normal-mode disturbances and is located on the output side. The presence of an isolation transformer allows for a new neutral-to-ground connection to be created on the load side; take note of this. Low- to medium-frequency currents, however, may be problematic for LIPCs: The output filter capacitor has the ability to amplify the transient[8].

CONCLUSION

In conclusion, the safe and dependable functioning of electrical power networks depends critically on the grounding of transformers. It offers a route for fault current to safely travel to the earth, shielding tools and people from electrical dangers. The choice of the most suitable approach for transformer grounding relies on a number of variables. Following pertinent safety standards and laws, as well as performing routine maintenance and testing, are necessary for proper transformer grounding. The system voltage, fault current level, and the presence of backup protection are only a few of the variables that affect the choice of the best grounding technique. In order to guarantee sustained efficacy, proper transformer grounding necessitates adherence to pertinent safety standards and laws as well as routine maintenance and testing.

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CHAPTER 9

A BRIEF DISCUSSION ON UTILITY SURGE ARRESTERS

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ABSTRACT:

Utility surge arresters, also known as lightning arresters or surge protectors, are essential components of electrical power systems that protect equipment from overvoltage surges caused by lightning strikes, switching operations, and other transient events. These surges can cause significant damage to power system equipment, resulting in costly repairs, downtime, and safety hazards. Utility surge arresters work by diverting the overvoltage surge to the ground, preventing it from damaging sensitive equipment. They are typically installed on power system equipment such as transformers, circuit breakers, and switches. The selection and placement of surge arresters depend on various factors, including the system voltage level, the type of equipment, and the expected surge magnitude.

KEYWORDS:

Lightning Protection, Power System, Surge Arrester.

INTRODUCTION

The three surge arrester technologies that utilities most often use. A MOV serves as the primary voltage-limiting component in the majority of arresters produced today. The primary component of a MOV is zinc oxide, which is coupled with a number of exclusive substances to provide the desired properties and durability. The energy-dissipating nonlinear resistive element of older arresters, which are still widely employed in the power system, was silicon carbide. For each of these three methods, the respective discharge voltages[1]–[3].

Three standard surge arrester methods for utilities

At first, arresters were only spark gaps, and every time the gap sparked over, a fault would occur. A lot of insulation failures were attributed to the sparkover transient's injection of a highly steep fronted voltage wave into the equipment that was being shielded. Some of these issues were resolved by adding a SiC nonlinear resistance in series with a spark gap. It decreased the sparkover transient to maybe 50% of the entire sparkover voltage and enabled the spark gap to clear and reseal without generating a malfunction. However, this front-of-wave transient was still held responsible for insulation failures. Additionally, following a sparkover, there is a significant power-follow current that warms the SiC material and erodes the gap structures, ultimately leading to arrester failures or loss of protection.

Gaps are essential with SiC because a cost-effective SiC element that provides the appropriate discharge voltage cannot endure a continuous system operating voltage. The gaps were removed thanks to the advancement of MOV technology. This device could maintain a discharge voltage that was equivalent to the SiC arresters while withstanding a continuous system voltage without gaps. SiC arrester technology was being phased out by the late 1980s in favor of gapless MOV technology. Without the undesirable sparkover transition, the gapless MOV offered a little better discharge behavior. This design is used in the majority of utility distribution arresters made today.

The gapped MOV technology, which was commercially released around 1990, has achieved popularity in several applications where higher protective margins are required. This arrester technology combines resistance-graded gaps with MOV blocks, and it exhibits some very intriguing and counterintuitive features. Compared to a gapless MOV arrester, it has a stronger transient overvoltage withstand characteristic but a lower lightning-discharge voltage. Gapless MOV arresters often start to conduct substantially for low-frequency transients at about 1.7 pu, which is the minimum protection threshold for lightning. In some system circumstances, the switching transients will go beyond this value for a number of cycles and result in failures. In addition, less-demanding lightning-discharge properties are needed for applications like aged subterranean cable networks.

With the gapped MOV technology, about one-third of the MOV blocks are eliminated, and they are replaced with a gap structure that has a lightning spark over roughly half of the previous SiC technology. The lightning-discharge voltage produced by the fewer MOV blocks is generally 20 to 30% lower than that of a gapless MOV arrester. The majority of the front-of-wave impulse voltage of lightning transients emerges across the gaps as a result of the capacitive and resistive interaction between the grading rings and MOV blocks. They ignite relatively early in the MOV blocks, producing a little frontal sparkover transient.5 When there is a switching transient, the voltage is divided by the resistance ratios, and the majority of it initially passes over the MOV blocks, delaying conduction until the gaps ignite. With conventional designs, this technique can attain a TOV withstand of around 2.0 pu. Additionally, because to the lower voltage discharge of the MOV blocks, the energy wasted in the arrester is lower than that expended by gapless systems for the same lightning current. There isn't any power-follow current since the MOV can stop the flow effectively enough. By doing this, the gaps' degradation is reduced. This technology has the potential to provide a utility surge arrester that is more effective and long-lasting in a number of ways.

Manufacturers provide utility surge arresters in a range of sizes and ratings. According to their capacity to handle energy, the three fundamental rating classes are station, intermediate, and distribution. The majority of the arresters used on main distribution feeders belong to the distribution class. There are heavy-duty and small-block designs in this class. One frequent exception to this is the use of intermediate- or station-class arresters at riser poles to improve the cable's protective characteristics[4]–[6].

DISCUSSION

Utility Capacitor-Switching Transients

This section describes how utilities can deal with problems related to capacitor-switching transients. Transients caused by capacitor switching are relatively frequent and often unproblematic. However, for certain delicate industrial loads, the timing of the transition may not be ideal. For instance, if the load increases at the same time every day, the utility can choose to swap the capacitors at the same time. In a few instances, this coincides with the start of a work shift, and the consequent transitory causes a number of adjus-speed drives to shut down right away as the procedure begins. Finding a changeover time that could be more accurate is a straightforward and affordable approach. For instance, it could be conceivable to turn on the capacitor before the load truly increases and a few minutes before the start of the shift. Then, it may not be necessary, but it probably won't do any harm. Other, more costly solutions will need to be explored if this cannot be resolved[7]–[9].

Resistors for Preinsertion

Preinsertion resistors may significantly lower the capacitor-switching transient. The most damaging transient peak is often the first one. The goal is to momentarily introduce a resistor into the circuit to greatly dampen the initial peak. Despite being outdated, this technology still works with the major contacts. As a consequence, the preinsertion period at 60 hertz is about one-fourth of a cycle long. The size of the capacitor and the available short-circuit current at the capacitor position both affect how effective the resistors are. For this aim, switches with preinsertion reactors have also been created. The inductor is useful in minimizing the transient's higher-frequency components. Reactors in certain designs are purposefully constructed with high resistance in order to look lossy to the energization transient. This hastens the transitory dampening.

Simultaneous Closure

Using a synchronous shutting breaker is another well-liked method of decreasing transients on capacitor switching. This method of regulating capacitor-switching transients is rather recent. By timing the contact closure such that the system voltage nearly matches the capacitor voltage at the time the contacts join, synchronous closing eliminates transients. This prevents the step change in voltage that usually happens when switching capacitors, which makes the circuit oscillate. An illustration of a circuit breaker made for this use. Normally, the utility sub-transmission or transmission system would get this breaker. A specifically created working mechanism with three independently controlled drive rods is used in this three-phase SF6 breaker. It has the ability to close one millisecond before voltage zero. The electronic control takes measurements of factors including the outside temperature, the control voltage, the energy that has been stored, and the amount of time since the previous operation to adjust the algorithms for the timing forecast.

To compensate for wear and changes in mechanical features, the actual performance of the breaker is sampled to determine how the pole timing should be adjusted for subsequent operations. a vacuum switch designed for this. It is used with capacitor banks of the 46-kV class. It has three distinct poles with independent controllers. By assuming that a voltage zero would soon arrive, the time for synchronous closure is established. The vacuum switch must operate reliably for it to be successful.

The switch significantly decreases voltage transients to 1.1 pu and capacitor inrush currents by an order of magnitude. Distribution voltages may also use a similar switch. Every switch in this article needs a complex microprocessor-based control. It makes sense that a synchronous closing mechanism costs more than a simple capacitor switch. However, when capacitor-switching transients are causing end-user loads to fail, it is usually a financially sensible option.

Place of the Capacitor

A switched capacitor for distribution feeder banks could be placed too near a delicate load or in a place where transient overvoltages are more common. Frequently, the issue may be resolved by moving the capacitor lower in the circuit or to a different branch. The plan is to either increase damping in the circuit by adding additional resistance or increase the impedance between the capacitor and the sensitive load.

Several variables will affect this strategy's likelihood of success. Moving the bank may not be an option if the capacitor is positioned at a big load to provide reactive power exclusively for that load. Then, it is necessary to investigate methods for gentle switching or switching at non-critical moments. One should look at load-side solutions in addition to utility-side options. In certain circumstances, using line chokes, TVSSs, etc. to harden load equipment against capacitor-switching transients will be more cost-effective.

Lightning protection for utility systems

Lightning is the cause of many power quality issues. In addition to the high-voltage impulses themselves, a lightning strike to a line may result in a brief fault that lowers voltage and interrupts service. Here are several tactics utilities may employ to lessen lightning's effect.

Shielding

Installing a grounded neutral wire over the phase wires may protect a line from lightning strikes, which is one of the options utilities have for lines that are especially vulnerable to lightning strikes. Most lightning strikes will be stopped by this before they reach the phase wires. Due to the likelihood of backflashovers, this may assist, but it won't always avoid line flashovers. At transmission voltage levels and in substations, shielding overhead utility lines is widespread. However, since distribution lines have lower flashover values than transmission lines, shielding above utility lines is less prevalent. To make it easier to connect equipment that has to be connected to the line to the neutral, such as transformers and capacitors, the grounded neutral wire on distribution circuits is often positioned beneath the phase converters.

The process of shielding is more complicated than just adding a wire and grounding it every few poles. The voltages at the top of the pole will still be quite high after lightning hits the shield wire, which might result in back-flashovers to the line. A transient malfunction will be the outcome of this. The ground lead's descent down the pole must be carefully planned in order to preserve appropriate clearance with the phase conductors in order to reduce this danger. Additionally, the amplitude of the voltage is significantly influenced by the grounding resistance, which must be kept as low as possible.

To limit the amount of transient faults and maintain a better level of power quality, it may be justified to refit a feeder section with a shield wire if it becomes clear that that section is being hit often. 4.29 This notion. A few spans close to the substation are often insulated. Since the substation is often insulated, this helps prevent high-current faults from occurring nearby that might harm the transformer and breakers of the substation. Distribution lines on transmission or subtransmission buildings are often underbuilt in the vicinity of substations. If sufficient clearance for the ground lead can be maintained, the transmission shielding also serves as shielding for the distribution. It's not always simple to do this. Another portion of the feeder could surmount a hill, exposing it to lightning in an unexpected way. Lightning-induced flaws may be decreased in that region by shielding. Poles in the impacted area may need to be extended to provide room for the shield wire, and the grounds may need to be significantly improved. As a result, this approach is more expensive. For many situations, line arresters could be a more practical and cost-efficient solution.

The Line Arresters

Application of arresters at regular intervals along the phase wires is another tactic for lines that are often impacted. Typically, the pole insulators are where lines flash over first. As a result, avoiding insulator flashover will drastically lower the interruption and sag rate. According to Stansberry6, this is more cost-effective than shielding and causes fewer line flashovers. Both line arresters and shielding won't be able to stop every lightning flashover. Flashovers in certain danger regions are to be drastically reduced.

As the stroke current moves up the line, the arresters bleed part of it off. The grounding resistance will determine how much each arrester drains off. The goal is to place the arresters close enough together to prevent the voltage at the middle unprotected poles from rising over the line insulators' fundamental impulse level. An arrester is often needed at every second or third pole in this situation. It could be essential to install arresters at each pole in the event of a feeder providing a very critical load or a feeder with considerable ground resistance. What is necessary will be revealed by a transient’s analysis of various setups. When one phase is placed higher than the others, some utilities only install line arresters on the top phase. To consistently reduce flashovers in various geometries, arresters will need to be placed on all three stages. In North America's most populous regions, there are already enough arresters on several lines to provide adequate line protection. The distribution transformers that are positioned closely together and in sufficient numbers to assist safeguard the lines from flashover are equipped with these arresters.

Low-Side Peaks

Lightning impulses may cause certain utility and end-user issues that are closely connected. Many utility engineers refer to one of the most important ones as the "low-side surge" problem.7 Distribution transformer designers came up with the moniker because it looks to the transformer that a current surge is rapidly injected into the low-voltage side terminals. Secondary arresters have not been used extensively by utilities at low-voltage levels. It is likely to be referred to as a secondary surge because, from the perspective of the consumer, it looks to be an impulse originating from the utility.

Lightning current coming from either the utility side or the customer side along the service cable neutral is the true cause of both issues, which are essentially separate side effects of the same surge phenomena. When lightning hits the main line, current is discharged to the pole ground lead via the primary arrester. Additionally, this lead is linked to the transformer's X2 bushing at the pole's top. As a result, a portion of the current will go in that direction. The magnitude of the pole ground resistance in relation to the load ground determines how much current flows into the load ground. The split of the current for the front of the surge may be significantly influenced by inductive components, but the ground resistances mostly determine how the majority of the stroke current is divided.

The voltage drop in the neutral conductor caused by the secondary cables' current is only partly made up for by mutual inductive effects with the phase conductors. As a result, there is a net voltage across the cable, which forces current through the secondary transformer windings and into the load as shown by the dashed lines in close proximity to the grounded end. The voltage will build up across the load if there is an incomplete route, and it may flash over someplace on the secondary. Because the meter gaps are often 6 to 8 kV or greater, it is not uncommon for them to flash over before there is damage to the secondary.

The pace at which the current rises is dependent both on other circuit factors and the lightning strike to determine how much voltage is induced in the wire.

1. The main issues this poses with power quality are
2. The equipment in the load may malfunction or fail as a result of the impulse entering it.
3. There will be a prolonged power outage due to the utility transformer failing.

Because part of the main winding is shorted, the malfunctioning transformer might cause the load to experience prolonged steady-state overvoltages. This would lower the transformer turns ratio. Failure might take hours, yet it generally happens in a matter of seconds. The quantity of surge current flowing via the secondary service connection is the solution to this issue. Remember that the outcome is the same regardless of the current's direction. The current just has to enter the ground circuits and travel through the wire in a significant amount on its journey to another ground. Lightning strikes thus have the same impact whether they occur in the utility system or at the end-user facilities. Although secondary transients will also occur in industrial systems, transformer protection is more of a concern in residential services. There are two typical strategies used by the utility to safeguard the transformer:

1. Use transformers with secondary windings that are interlaced.
2. At the X terminals, install surge arresters.

Naturally, the former is a feature of the transformer's design that cannot be altered after it has been constructed. Applying arresters to the low-voltage side is the sole option if the transformer has a non-interlaced construction. Keep in mind that the transformer will not be protected by arresters at the load service entry. In fact, they will very certainly create a surge current route, which will put more strain on the transformer.

Recent data reveals that low-voltage arresters are more effective at avoiding failures, even if interlaced transformers in lightning-prone locations have a lower failure rate than no interlaced transformers. With relatively short lead lengths, the main arrester is fitted directly to the tank. This is an ever-increasing necessity for proper protection practice given the emerging knowledge that lightning surges have steeper wavefronts than previously thought.10 A specific fuse is needed in the cutoff to avoid fuse damage from lightning current discharge. A strong secondary arrester is used to finish off the transformer protection.

This image displays a powerful secondary arrester that has been modified for external placement on transformers. There are also internal mounted arresters available. It is advised to use arresters with a 40-kA discharge current rating. In this application, the voltage discharge is normally between 3 and 5 kV, which is not very essential. The BIL of transformer secondary windings is often expected to be between 20 and 30 kV. In this application, gap-type arresters also function, but they produce voltage sags that MOV-type arresters do not.

Consequences for load circuits

An electrical outlet site in a laboratory mock-up of a home service was used to test the open-circuit voltage. For a very little stroke to the main line, the voltages at the outlet reached over 15 kV. In reality, measurements were challenging because higher-current strokes led to erratic flashovers of the test circuit. This reported incident demonstrates the potential for these surges to result in overvoltage issues. The waveform is a low-side surge that is primarily supported by a very high frequency ringing wave. The wire lengths have a significant impact on the ringing. A little resistive load, like a light bulb, would significantly increase the damping. The base low-side surge wave stays about the same, but the ringing wave varies depending on where the surge was delivered; it is more influenced by the waveform of the current via the service cable. One intriguing feature of this wave is that, despite the voltage being two times the normal sparkover value, the ringing is so quick that it bypasses the spark gaps in the meter base. The outlets and light sockets could likewise endure this kind of wave during the testing for around a second before they flashed over. As a result, there might be some significant overvoltages propagating throughout the system. The available open-circuit voltage is shown as a waveform in this illustration. In real operation, after a little period, a flashover would have happened somewhere in the circuit.

Due to lead-length inductance, MOV arresters are not completely effective against a ringing wave of this high frequency. However, they are particularly efficient for the higher energy, lower-frequency component of this transient. Arresters have to be used at critical load outputs as well as at the service entry. Arresters at the outlets are vulnerable to failure if the service entrance arresters are not taking the majority of the energy. This is especially accurate for single MOVs linked to the neutral line. Failure of outlet protectors and individual appliance protectors should be very unlikely with the service entrance arresters installed, unless lightning hits the building structure closer to that point than the service entry.

The facility as a whole cannot be protected by service entry arresters. They are helpful in shunting the majority of the surge energy, but they are unable to properly reduce the voltage for distant loads. Similarly, while being just 50 feet distant, the transformer arrester cannot be seen as replacing the service entrance arrester. The load for the low-side current surge is really connected to this arrester in series. Always place an arrester exactly across the insulation structure that needs to be protected. This is the fundamental rule for arrester protection. For difficult-to-protect loads like submersible pumps in deep water wells, this becomes essential. An arrester that is integrated within the motor rather than on the controller's surface offers the greatest protection.

It's possible that in certain circumstances the differential voltage between two ground references matters more than the surge voltage that appears at the output. This is the situation for a lot of TV receiver malfunctions. Arrester protection and proper bonding of protecting grounds are also necessary. The service entry arresters' protection threshold for lightning impulses is normally about 2 kV. The transformer secondary arrester, or around 40 kA, should be able to carry about the same amount of current as the lightning impulse. It is important to remember that the arrester with the lowest discharge voltage will likely do the bulk of the work for low-frequency over-voltages. The over-voltages will be clamped by MOV-type arresters without resulting in extra power quality issues like interruptions and sags.

Cable Defense

Cable failures are a major cause of prolonged power outages in subterranean distribution networks. The lifespan of the oldest electricity distribution cables put in place in the United States is gradually coming to an end. A mild transient overvoltage might induce breakage and failure because a cable's insulation weakens over time. Many utilities are looking at solutions to safeguard the cable's arrester to lengthen cable life. Since replacing cables is so expensive, even a little increase in lifespan makes it frequently profitable to equip the system with arresters. Depending on the voltage class, the cable may have had both a riser-pole arrester and an open-point arrester put on it, or it may have had only one arrester at the riser pole.

Utilities have a variety of choices from which to select to provide extra security:

1. If one doesn't already present, add an open-point arrester.
2. On the next-to-last transformer, include a third arrester.
3. At each transformer, install arresters.
4. Special low-discharge voltage arresters should be included.
5. Inject a substance that will restore insulation into the cable.
6. On the main, use a scout arrester strategy.

Arrester with an open point.

When voltage waves hit an open point, their size doubles. As a result, the peak voltage that appears on the cable is almost twice as high as the riser-pole arrester's discharge voltage. At some voltage classes, modern cables have enough leeway to avoid the need for open-point arresters. Open-point arresters are often used at 35 kV, however they are not always employed at lower voltage classes. If there isn't currently an arrester at the open point, adding one should be the first course of action when the frequency of cable failures caused by storms starts to rise dramatically. Transformer in last place. Cable failures during lightning storms are not totally eliminated by open-point arresters. The closest to the final transformer in a circuit with an open-point arrester often experiences the most overvoltage stress. The open-point arrester reflects the incoming wave like an open circuit before it starts to conduct. As a result, there is a wave that is reflected back to the riser pole that is about half the discharge voltage. If the wavefront is very steep and the arrester lead inductance momentarily facilitates the reflection, this number may even be larger.

This causes a very brief pulse to ride on top of the voltage wave, which then quickly decays as it moves toward the riser pole. However, there will be observable increased stress at transformers that are a few hundred feet or less from the open point. As a result, we often see cable and transformer failures here. An extra arrester at the next-to-last transformer may easily fix the issue. The remainder of the wire system is well protected by this second arrester, which effectively eliminates the impulse. So, according to some, the best UD cable protection arrangement consists of three arresters: an arrester at the riser-pole, an arrester at the open point, and an arrester at the transformer that is near to the open point. This option is less expensive, especially when retrofitting, and offers the same level of protection as installing arresters at all transformers. The main arresters may be found within the transformer compartment, beneath oil, in pad-mounted transformers for UD cable systems. This method, which distributes arresters throughout the line, when used consistently, provides extremely effective protection for the UD cable system. Of course, this protection has an additional cost that must be assessed to decide if it is reasonable for a utility to take into account.

Elbow Restraints

There are now more affordable choices for safety thanks to the development of elbow arresters for transformer connections in UD cable networks. Earlier arrester installations on UD cable networks were expensive to deploy and were modifications of overhead arrester technology. The lack of widespread adoption of open-point arresters is due in part to this. The second option was under-oil arresters, and switching from a pad-mount trans- former to an open-point arrester is likewise quite expensive. The arrester is now a fundamental component of the UD system hardware, making installation at almost any location on the system feasible. This is an excellent choice for several retrofit initiatives. The gapped MOV arrester technology previously discussed in this was developed expressly to enhance UD cables' surge protection and increase their lifespan. Under light-ning surge situations, the arresters are able to produce a much lower discharge voltage while still having the capacity to endure typical system conditions. One might increase the lightning protection margin by 20 to 30 percent by merging the gaps from the outdated SiC technology with fewer MOV blocks. During steady-state operation, the gaps share the voltage with the MOV blocks and avoid a dangerous runaway. According to the Hopkinson formula, which was stated at the start of this section, switching to this kind of arrester in the UD cable system should result in a significant improvement in cable life.

Injection of fluid

A reparative fluid is injected into a length of wire using this relatively new method. The fluid offers the cable many additional years of life by filling the gaps left in the insulation by age. On the receiving end, a vacuum is pulled, while pressure is supplied at the injection end. The fluid steadily enters the cable if there are no splices to stop the flow[10]–[12].

CONCLUSION

In summary,Electrical power systems must include utility surge arresters to safeguard equipment against overvoltage surges brought on by lightning strikes and other transient occurrences. There are several kinds of surge arresters available, and their location and choice are influenced by a number of circumstances. Surge arresters must be installed and maintained correctly to be effective, and it is required to follow all applicable safety standards and laws. Utility surge arresters must be installed and maintained correctly in order to remain effective. This include routine examination, testing, and replacement as necessary. In order to guarantee that they do not present a threat to the safety of people or property, surge arresters must also abide by all applicable safety standards and laws.

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CHAPTER 10

A BRIEF DISCUSSION ON SCOUT ARRESTER SCHEME

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ABSTRACT:

The Scout arrester scheme is a system for protecting overhead power distribution lines from lightning strikes and overvoltage surges. It is designed to improve the reliability and safety of electrical power distribution by reducing the frequency and duration of power outages caused by lightning strikes. The Scout arrester scheme uses a series of metal-oxide surge arresters installed on distribution poles to protect the distribution lines from overvoltage surges. The surge arresters are connected to each other and to the distribution lines via a low-capacitance cable, creating a protective network that diverts the surge to the ground.

KEYWORDS:

Ferro-resonance, Smart Grid, Surge Arrester, Surge Protection, Switchgear, Stability.

INTRODUCTION

Utility UD cable routes have been protected using a scout arrester technique for many years. However, because to the higher initial cost, the concept has only seldom been used. The idea is rather straightforward: Reduce the amount of lightning energy that may enter the cable by installing arresters on each side of the riser-pole arrester. A scout arrester is the first thing that the lightning surge current from a strike down line comes into contact with. At that point, a significant amount of the electricity is discharged into the earth. The riser-pole arrester now generates a lower discharge voltage as a result of a lesser amount continuing on. This voltage is what is applied to the cable.The first span on each side of the riser pole may be insulated to further improve protection by preventing direct blows on the line[1].

Recently, interest in the plan has increased once again. The scout system has been empirically shown to assist avoid open-point failures of both cables and transformers, and the cost of replacing a transformer is much more than the extra cost of the scout arresters. The main advantage of the scout method may be that it significantly slows the rate of growth of surge voltages entering the cable, even if simulations indicate that the nominal arrester discharge voltage may only be decreased by a few percent[2], [3].

These steep-fronted surges usually result in failures at the first or second pad-mount transformer from the end when they reflect off the open point. Arresters are sometimes ineffective against such steep impulses due to lead lengths. These are essentially removed off the cable by the scout system. In heavily populated locations, many distribution feeders will be equipped with scout systems by default. There are already arresters on each side of the riser pole since there are enough transformers.

Taking care of ferroresonance

Ferroresonance generally happens when a lightly loaded, three-phase transformer gets isolated on a wire with one or two open phases in a distribution system. This may occur unintentionally or on purpose. Ferroresonance management techniques include:

1. Avoiding an open-phase situation
2. Load-induced resonance dampening
3. Reducing overvoltage's
4. Cabling length restrictions
5. Alternative methods of cable switching

The majority of ferroresonance is caused by single-pole switching in the main circuit or blown fuses in one or two of the phases as a consequence of faults. Utilizing three-phase switching devices would be a reasonable and efficient defense against ferroresonance. At the riser pole, for instance, a three-phase recloser or sectionalizer might be used in place of fused cuts. Cost is the primary disadvantage. Utility companies couldn't afford to install them at every riser pole, but they might in unique situations when there are very sensitive end consumers and frequent fuse blowouts. Another method for dealing with problematic cable drops is to simply swap out fused cuts for solid blades. This makes it necessary for the upline recloser or breaker to activate in order to correct cable problems. Of addition, this causes several other utility customers to have prolonged outages when they would typically experience just a little voltage sag. Even so, it is a cheap solution to the issue until a more long-term one is put in place[4], [5].

Ferroresonance is also often produced by pulling cuts or cable elbows to manually switch single-phase cables. When there is a lot of activity and the transformers are not yet loaded, this is a particular issue during new construction. When the transformers don't have any other loads connected, several utilities have reported that line operators carry a "light board" or another sort of resistive load bank in their trucks to utilize for cable-switching work. Switching delta-connected transformers requires extra caution; these transformers need to be safeguarded since the voltages might get quite high. Even though it may generate a noticeable noise, the typical grounded wye-wye pad-mounted transformer may not suffer internal damage under short-term exposure. To open or shut all three stages as soon as feasible while switching manually is the objective.

There are few exceptions, but in general, ferroresonance may be suppressed by a tiny amount of resistive load. A resistive load of 1 to 4 percent of the transformer capacity may significantly lessen the effects of ferroresonance in the typical scenario with one phase open. The length of the cable and the transformers' design have an impact on the needed load. Additionally, dampening the two-phase open case with load might sometimes be more challenging. Ferroresonance overvoltages for a transformer connected to around 1.0 mi of cable with one phase open as a result of loading. It was an especially challenging issue since it included end-user equipment. Take note of the phases' various traits. The middle phase of the transformer, which had a five-legged core design, exhibits a situation that is more challenging to manage with loading. The overvoltage is reduced from around 2.8 to 2 pu by a 5% resistive load. To keep ferroresonance overvoltages within the generally recognized limit of 125 percent, the transformer would need to be filled with around 20 to 25 percent of its resistive equivalent load. A three-phase recloser was used to switch the wire since such a big load was necessary[6].

Due to expenses, arresters are not always installed on distribution transformers with pads on many utility systems. Surge arresters, however, may be a useful tool for reducing the impacts of ferroresonance. If arresters are exposed to ferroresonance voltages for a long period, there is a chance that they may malfunction. In actuality, ferroresonance often results in the deaths of secondary arresters with protection values lower than the primary-side arresters. Utility arresters are more durable, and they often use just a little amount of energy. However, line personnel must always de-energize the transformer and let the arresters cool if they come across one with ferroresonant arresters. If unexpectedly reconnected to a source with considerable short-circuit capacity, an overheated arrester might violently fail.

When the cable capacitance reaches a threshold level and is strong enough to resonate with the transformer inductance, ferroresonance develops. Therefore, reducing the length of cable lines is one method to reduce the possibility of frequent ferroresonance issues. As a result of the strong magnetizing reactance of current transformers, ferroresonance may arise for cable lengths of less than 100 feet, making this challenging to do for transformers with delta primary connections. In single-phasing settings, the grounded wye-wye connection can often withstand a few hundred feet of cable without going above 125 percent voltage.

The voltage level also affects the maximum length of the cable, with the general rule being that the cable should be shorter the greater the system voltage. However, it is becoming increasingly challenging to totally prevent ferroresonance at all main distribution voltage levels due to contemporary developments in transformer designs with reduced losses and exciting currents[7], [8].

When energizing or deenergizing a transformer, where the switch is made may have a significant impact on how likely ferroresonance is to occur. Take into account the two cable-transformer switching patterns in the transformer that are located far from another cable system point. The cable capacitance is the analogous capacitance seen from switch L, and ferroresonance is significantly more likely. Thus, pulling the elbows at the main terminals while switching the transformer is one of the common guidelines to avoid ferroresonance during cable changeover. There isn't much internal capacitance, and the losses of the transformers are typically enough to keep resonance at bay. Although the reader should be aware that several contemporary transformers defy this criterion, it is still a solid general guideline. Low-loss transformers are susceptible to ferroresonance due to their internal capacitances, especially those with amorphous metal cores.

DISCUSSION

Nuisance tripping of ASDs

The majority of adjus-speed drives generally use a capacitor in the dc link and a voltage source inverter architecture. The controllers may trip the drive at levels as low as 117 percent since they are sensitive to dc overvoltages. Since transient voltages caused by utility capacitor switching often reach 130 percent, there is a substantial likelihood that the drive may trip accidentally. One example of this phenomenon's usual waveforms.

The best approach to stop tiny drives from accidentally tripping is to separate them from the power supply using ac line chokes. The transient voltage magnitude that emerges at the input to the adjustable-speed drive will be decreased by the additional series inductance of the choke. A very thorough transient simulation is needed to determine the exact inductor size needed for a given application. Typically, a series choke size of 3% depending on the drive kVA rating is adequate.

Turbulence caused by Load Switching

High-frequency impulse bursts may be produced while deenergizing inductive circuits using air-gap switches, such as relays and contactors.

Energizing the Transformer

When a transformer is activated, inrush currents including several harmonic components are generated for up to one second. A dynamic overvoltage situation develops if the system has a parallel resonance close to one of the harmonic frequencies. This condition may lead to arrester failure and issues with delicate equipment. This issue might arise in industrial facilities when huge power factor correction capacitor banks and massive transformers are both powered on at the same time. a dynamic overvoltage waveform brought on by the circuit's third-harmonic resonance. After the anticipated first transient, the voltage increases again for many cycles, reaching approximately 150 percent, until losses and load dampen the oscillations. Some arresters may experience extreme stress as a result, and capacitor lifespans may be severely shortened.

Dynamic overvoltage’s when turning on the transformer.

Frequently, this kind of dynamic overvoltage issue may be solved by simply not activating the capacitor and transformer simultaneously. One facility found a solution by turning on the transformer before the capacitor and waiting until the load was ready to be connected to the transformer.

Computer Programs for Analyzing Transients

The Electromagnetic Transients Program, or EMTP, and its variants like the Alternate Transients Program are the most often used computer programs for transient’s analysis of power systems. Hermann W. Dommel created EMTP at the Bonneville Power Administration in the late 1960s, and since then, it has undergone constant improvement. Because certain versions of this application are free, it is one of the factors contributing to its popularity. The Manitoba HVDC Research Center's PSCAD/EMTDC commercial analysis package was used to run some of the simulations that are described in this book. With the help of this program's highly advanced graphical user interface, users may do this challenging analysis quickly and effectively. Some computer programs, including the well-known SPICE program16 and its variations, were created primarily for the study of electronic circuits and are used by some power system analysts.

Although the previously mentioned applications are still widely used, there are now a lot of additional strong programs accessible. Because there are so many and because software is developing at such a rapid pace, we won't even try to make a list of them all. All suppliers of this kind of software maintain websites, so the reader is pointed to the Internet. The issue is almost always solved in the time domain by re-creating the waveform point by point with power system tools. A few applications solve in the frequency domain and translate to the time domain using the Fourier transform. Unfortunately, this effectively limits the issues that may be addressed to linear circuits. Modeling nonlinear components like surge arresters and transformer magnetizing properties requires a time-domain solution. Longer solution times are the price to pay for this added capacity, however this is becoming less of an issue as time goes on with current computers.

When compared to more frequent power system evaluations like those of the power flow or a short circuit, electro- magnetic transient investigations need a lot more modeling knowledge. Because of this, this duty is often assigned to a small group of professionals within the utility organization or to consultants. While there are other methods to formulate the issue using transients programs for electrical circuit analysis, nodal admittance formulations are virtually universally used by power systems analysts. For starters, the sparsity of the system admittance matrix makes it possible to solve complicated issues quickly and effectively using sparsity approaches. Additionally, the nodal admittance formulation depicts the power system in accordance with how the majority of power engineers see it, with series and shunt components connected to buses where the voltage is monitored in relation to a single reference.

Transients programs discretize the differential equations using the appropriate numerical integration formula to produce conductances for elements specified by the equations. Although a variety of Runge-Kutta and other formulations are employed, it seems that the basic trapezoidal rule technique is the most popular. Iterative solution techniques are used to manage nonlinearities. While some programs, like those that use the EMTP technique, isolate the linear and nonlinear parts of the circuit to arrive at speedier answers, others incorporate nonlinearities in the general formulation. This limits the program's capacity to address certain types of nonlinear problems but often has little impact on most power system issues.

Harmonics: The Basics

A sound premise for the majority of American utilities is that the sine-wave voltage produced by centralized power plants is excellent. The voltage encountered on transmission networks is normally far less than 1.0 percent distorted in the majority of places. Closer to the load, however, the distortion increases. The present waveform hardly resembles a sine wave at certain loads. Electronic power converters have the ability to split the current into waveforms that seem arbitrary. Even if there are a few instances when the distortion is random, the majority of distortion is periodic or an integer multiple of the fundamental frequency of the power system. That is, the waveform of the current signal changes extremely slowly, if at all, and is essentially constant cycle after cycle. As a result, the word "harmonics" is now often used to refer to waveform distortion. To make sense, this concept has to be clearly defined.

In the late 1970s, when electronic power converters first started to be used often, many utility engineers started to worry about the power system's capacity to handle harmonic distortion. If these gadgets were allowed to exist, many frightening predictions were made concerning what would happen to power systems. Even though some of these worries were probably exaggerated, the field of power quality analysis owes a huge debt of gratitude to these individuals because their worry about this "new" harmonics problem ignited the research that ultimately produced a large portion of the knowledge about all aspects of power quality.

According to some, harmonic distortion continues to be the biggest issue with power quality. It is not difficult to see how an engineer who is presented with a challenging harmonics situation may have such perspective. Many of the traditional design and operating guidelines for power systems, which focus primarily on the fundamental frequency, are challenged by harmonics issues. The engineer is thus presented with novel phenomena that need for unfamiliar instruments to study and solve. While harmonic issues on utility systems might be challenging, they are not extremely common. In the United States, only a small percentage of utility distribution feeders have harmonics issues that are serious enough to warrant addressing.

The most frequent and important power quality aberrations, however, are voltage sags and interruptions, which affect practically every feeder. Harmonic issues affect the utility industry less than the end-user sector. Industrial users are far more likely to have issues caused by harmonic distortion if they employ adjust speed motors, arc furnaces, induction furnaces, and similar devices.

Harmonic distortion in electricity networks is not a recent occurrence. Throughout the history of ac electric power systems, concern regarding distortion has fluctuated. If one looks through the technical literature from the 1930s and 1940s, there are a lot of articles on the topic. Inductive interference with open-wire telephone networks was the main issue at the time, and the main causes were transformers. The precursors to current arc lighting were being introduced, and its harmonic configuration was creating quite a stir—much like the subsequent uproar produced by electronic power converters. Fortunately, there is a little likelihood that harmonics would affect the power system if the system is appropriately built to accommodate the load's power needs, albeit they could affect communications. Power system issues most typically occur when the system's capacitance causes resonance at a crucial harmonic frequency, which sharply elevates the distortion above background levels. Despite the fact that utility systems might experience similar issues, industrial power systems often experience more severe instances due to the greater degree of resonance attained.

Musical Distortion

The power system's nonlinear components are the source of harmonic distortion. Any device where the current does not follow the applied voltage is said to be nonlinear. An example of this is when a sinusoidal voltage is applied to a straightforward nonlinear resistor, and the voltage and current change in accordance with the curve. The resultant current is distributed even though the applied voltage is sinusoidal. A little percentage increase in voltage may result in the current doubling and changing the waveform. The majority of harmonic distortion in a power supply originates from this. Sinusoids may be used to represent distorted waveforms. The frequency of each sinusoid in a waveform that is constant from cycle to cycle may be thought of as a sum of pure sine waves, where each sinusoid's frequency is an integer multiple of the fundamental frequency of the distorted wave. This multiple is referred to as a harmonic of the fundamental, therefore the name of the topic. A Fourier series, named after the renowned mathematician who introduced the idea, is the term used to describe the sum of sinusoids.

The Fourier series idea is universally employed in the analysis of harmonic issues due to the aforementioned feature. At each harmonic, the system may now be examined independently. Additionally, compared to calculating the system response of the full distorted waveforms, finding the system response of a sinusoid of each harmonic separately is significantly simpler. The output waveform may then be calculated, if needed, using the new Fourier series created by combining the outputs at each frequency. Frequently, just the harmonic magnitudes are of importance. The Fourier series only includes odd harmonics when a waveform's positive and negative half cycles have the same structure. Due to the fact that most typical harmonic-producing devices seem the same to both polari- ties, this provides a further level of simplicity for the majority of power system studies. In reality, the appearance of even harmonics is often a sign that there is a problem, either with the measuring transducer or the load equipment. There are no exceptions to this rule, including random arc furnaces and half-wave rectifiers.

Higher-order harmonics are often insignificant for power system analysis. Despite the possibility of interference with low-power electronic devices, they often do not harm the power system. Additionally, it is challenging to get precise enough data to simulate power systems at high frequencies. When system resonances are present in the frequency range, this is often an exception. In electronic power converters, notching or switching transients may be used to excite these resonances. Timing circuits become unreliable as a result of voltage waveforms with several zero crossings. These resonances often arise on systems without power factor correction capacitors but with subterranean cable.

The bulk of the nonlinearities in the power system are found in the shunt components if the power system is represented as series and shunt elements, as is the customary approach. The power supply system's series impedance is very linear. The shunt branch of the typical "T" model is the source of harmonics in transformers as well; the leakage impedance is linear. End-user loads will thus be the primary causes of harmonic distortion in the end. Not all end users that suffer harmonic distortion will have large sources of harmonics, but most harmonic distortion is caused by a load or combination of loads that some end user.

Voltage versus Current Distortion

The term "harmonics" is often used without any further context. For instance, it's common to hear that harmonics may cause an adjus-speed drive or an induction furnace to malfunction. Why does it matter? In general, it may refer to one of the following three things:

1. The control cannot accurately detect firing angles due to the excessive harmonic voltages.
2. The machine must be run at a lower power than recommended because the harmonic currents are too large for some component of the power supply system, such as a transformer.
3. The harmonic voltages are excessive because the device's harmonic currents are excessive for the current state of the system.

This list indicates that volt- ages and currents have different causes and effects in addition to some link. As a result, using the phrase "harmonics" by itself to explain an issue is insufficient. In addition to shunting with and injecting harmonic currents into the power system, nonlinear loads seem to be sources of harmonic current. It is sufficient to simply consider these harmonic-producing loads as current sources in almost all studies. This has certain exceptions, which will be discussed later. Although, assuming that the source bus is ultimately a pure sinusoid, a nonlinear load draws a distorted current, voltage distortion is caused by distorted currents flowing through the linear, series impedance of the power delivery system. Each harmonic voltage drop is brought on by the harmonic currents that are flowing through the system's impedance. Voltage harmonics arise at the load bus as a consequence. The current and impedance have an impact on how much voltage distortion occurs. The quantity of harmonic current generated by the load is typically constant, provided that the load bus distortion doesn't exceed acceptable bounds. It should be emphasized that although the voltage distortion is ultimately caused by the load current harmonics, the voltage distortion is not within the control of the load. When the same load is applied to the power system at two distinct places, the voltage distortion values will change. The end-use application is where the harmonic current injection into the system is controlled. The entity with control over the system impedance, which is often the utility, exerts control over the voltage distortion assuming that the harmonic current injection is within tolerable bounds. When explaining harmonic occurrences, one must be cautious to recognize that there are clear distinctions between the sources and consequences of harmonic voltages and currents.

The word "harmonics" should be used with appropriate qualification. By accepted practice in the power sector, the speaker usually refers to the harmonic cur- rents when the phrase is used by itself to describe the load equipment. The voltages are usually the topic while discussing the utility system. Make it a practice to seek clarification to be safe.

CONCLUSION

In summary,overhead electricity distribution cables may be shielded against lightning strikes and overvoltage surges using the Scout arrester system. It builds a protective network that directs the surge to the ground using metal-oxide surge arresters and a low-capacitance cable. Compared to previous surge protection strategies, the Scout arrester scheme provides better surge protection and is more affordable and simpler to install. It has been shown to greatly minimize the frequency and length of power outages brought on by lightning strikes and has been effectively installed in a number of sites throughout the globe. A number of areas throughout the globe have successfully implemented the Scout arrester technique, and it has been shown to drastically lower both the frequency and length of power outages brought on by lightning strikes. It works especially well in places with heavy lightning activity and in situations when conventional surge protection techniques are impractical because of cost or logistical issues.

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CHAPTER 11

A BRIEF DISCUSSION ON HARMONICS VERSUS TRANSIENTS

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ABSTRACT:

Harmonics and transients are two types of disturbances that can occur in electrical power systems. Harmonics are periodic disturbances that occur at integer multiples of the fundamental frequency, while transients are non-periodic disturbances that occur as sudden changes in voltage or current. Harmonics are caused by non-linear loads such as power electronics, which draw current in a non-sinusoidal manner. This can cause distortions in the voltage waveform and lead to issues such as overheating of equipment, increased losses, and interference with communication and control systems.

KEYWORDS:

Electromagnetic Interference, Harmonics, Harmonic Distortion, Power Factor Correction, Power Quality, Resonance.

INTRODUCTION

Many power qualities issues that are truly transients are attributed to harmonic distortion. A measurement of the incident can reveal a waveform that is distorted and clearly has high-frequency components. Despite the presence of high-frequency components in transient disturbances, transients and harmonics are totally separate phenomena that need different analyses. The high frequencies are only briefly visible in transient waveforms after an abrupt shift in the power supply. The frequencies, which are the system's inherent frequencies at the moment of the switching action, are not necessarily harmonics. These frequencies are unrelated to the fundamental frequency of the system[1], [2].

By definition, harmonics are integer multiples of the fundamental frequency that happen in the steady state. The harmonics are produced by a waveform distortion that is constant, or at least lasts for a few seconds. Typically, transients disappear within a few cycles. Transients are connected to system changes like switching a capacitor bank. Harmonics are connected to a load's ongoing operation. Transformer energization is one instance when the lines between the two are blurred. While this is a brief occurrence, it has been known to activate system resonances and cause significant waveform distortion for many seconds.

Quantities of the Power System in Nonsinusoidal Conditions

Traditional power system metrics including rms, power, power factor, and phase sequences are described in a pure sinusoidal context for the fundamental frequency range. Unfortunately, many of the simplifications power engineers utilize for the fundamental frequency analysis do not hold true when harmonic distortion is present since the power system no longer functions in a sinusoidal state.

The angle in phase between current and voltage at fundamental frequency. Equation shows that only the fundamental frequency values are a function of the average active power. Since the active power in the nonsinusoidal case must account for contributions from all harmonic components, it is the total of the active powers at all harmonics. Furthermore, regardless of how distorted the current is, a decent estimate may be made since voltage distortion is often quite minimal on power systems. When calculating apparent and reactive power, this approximation cannot be used. The distortion has a significant impact on these two numbers. The apparent power S is a gauge of the load's potential influence on the system's thermal capacity. Its calculation is simple, but a little more difficult than in the case of the sinusoidal current, and it is proportional to the maximum value of the distorted current. The real rms value of a distorted waveform may now also be directly reported by a large number of current probes[3]–[5].

Reactive components are often related to the reactive power, a sort of power that accomplishes no actual work. For instance, a motor's inductance causes the load current to lag behind the voltage. There is no net work created when power flowing through the inductance sloshes back and forth between the inductance itself and the power system source. Since no power is dissipated or consumed, it is known as fictitious or reactive power for this reason. It is specified in var unit terms. The connection between P, Q, and S in a sinusoidal situation is summarized by the simple definition of reactive power in the sinusoidal case as the percentage of power that is in quadrature with the active power. There is another intriguing quirk with the reactive power when distortion is present. In actuality, the term "reactive power" may not be relevant. Most power engineers have a strong understanding of var flow in the power system. Many people are unaware that this principle only applies in the sinusoidal steady state. The component of S that is left behind after P is removed is not conserved that is, it does not sum to zero at a node when distortion is present. Power amounts are assumed to move cautiously across the system. In other words, the power factor ratio calculates the proportion of energy used for the purpose for which it was designed. Power factor values vary from 0 to 1. When a load has a power factor of 0.9, it means that it can efficiently utilise 90% of the apparent power that is given and convert it to productive work. The fundamental current lags the fundamental voltage by 25.84°, which is indicated by the phrase "lagging.There is just one phase angle between the voltage and the current in the sinusoidal situation.

The cosine of the phase angle, as in Eq., cannot be used to derive the power factor in the non-sinusoidal situation. The actual power factor is the power factor that accounts for the contribution of all active power, including both fundamental and harmonic frequencies. The ratio of the utility's perceived power provided to the total active power for all frequencies is the actual power factor. Both displacement and actual power factors are now often reported by power quality monitoring equipment. Despite having a nearly unity displacement power factor, many devices, including switch-mode power supply and PWM adjus-speed drives, really have a 0.5 to 0.6 true power factor. Due to Q1 being zero, an ac-side capacitor won't have much of an impact on the real power factor in this scenario. In reality, if resonance occurs, the distortion can worsen and the power factor might decline. According to the actual power factor, a given load requires a power delivery system that is constructed to be as big as possible. In this case, relying just on the displacement power factor would lull you into thinking everything is OK. The end outcome of distortion is an increase in the number of current components flowing through the system, which does not produce any net energy other than losses in the components of the power system they travel through. As a result, the system must be constructed with a somewhat higher capacity than necessary to transmit the electricity to the load.

DISCUSSION

Harmonic Phase Sequences

Power engineers have long employed symmetrical components to explain the behavior of three-phase systems. The three-phase system is split into three smaller single-phase systems for easier analysis. As long as the essential presumptions of the approach are adhered to, the method of symmetrical components may be used to analyze how the system reacts to harmonic currents[6]–[8].

Tritone Harmonics

Triplen harmonics are the odd multiples of the third harmonic, as was already explained. They need particular attention since the system response for triplens often differs significantly from that for the other harmonics. For grounded-wye systems, triplens become a crucial problem when current is flowing in the neutral. Overloading the neutral and telephone interference are two common issues. On occasion, one learns about devices that malfunction because the triplen harmonic voltage drop in the neutral conductor has severely distorted the line-to-neutral voltage. It is assumed that fundamental and third harmonic components exist for the system with properly balanced single-phase loads. The third-harmonic current components are three times as large as the phase currents because they naturally coincide in phase and time, but the fundamental current components in the neutral are zero when the currents at node N are added.

Triplen harmonic currents from single-phase nonlinear loads flow significantly differently depending on how the transformer winding connections are configured. The triplen harmonic currents are entering the wye side of the wye-delta transformer. They include the neutral since they are in phase. They are able to flow because of the delta winding's ampere-turn balance, but they are imprisoned there and do not appear in the line currents on the delta side. The triplen harmonic currents behave exactly like zero-sequence currents, which is exactly what they are, when the currents are balanced. With the delta winding linked to the transmission feed, this style of transformer connection is the most often used in utility distribution substations. The transformer's grounded-wye windings on both sides enable balanced triplens to pass unhindered from the low-voltage system to the high-voltage system. They will be equally represented on both sides. In the US, this method of serving cargoes is common.

When supplying single-phase loads with a high third-harmonic content on the wye side, transformers, in particular the neutral connections, are prone to overheating. A transformer's triplens cannot be seen while measuring the current on its delta side, which makes it impossible to determine the real extent of the heating it is experiencing. The proper isolation transformer connection may stop the flow of triplen harmonic currents. The flow of triple harmonic current is stopped by removing the neutral connection from either one or both wye windings. Ampere-turn balance is not appropriate. A delta winding also prevents the line's flow. It should be noted that three-legged core transformers act as if a "phantom" delta tertiary winding exists. As a result, a wye-wye connection with only one grounded neutral point may nevertheless carry triplen harmonics from that side.

These guidelines for triple-harmonic current flow in transformers only apply to situations with balanced loads. Phase imbalance may result in currents with regular triplen harmonic frequencies manifesting themselves unexpectedly. Triplen harmonics often have a zero sequence mode. Triplen harmonics may also contain positive or negative sequence components during imbalances. A three-phase arc furnace is one example of this in practice. A delta-delta linked transformer almost usually supplies the furnace in order to prevent the passage of zero sequence currents. Many engineers are shocked to see significant third-harmonic current present in significant magnitudes in the line current because they mistakenly believe that third harmonics are identical with zero sequence. The furnace, however, often runs in an imbalanced state with just two electrodes transmitting current during scrap melting. Then, just as in a single-phase circuit, these two phases may freely conduct large third-harmonic currents. They are not zero-sequence currents, however. Positive and negative sequence currents are present in equal numbers in the third harmonic currents. However, triplens often operate in the way that is described to the degree that the system is mainly balanced.

Musical Indices

The total harmonic distortion and the total demand distortion are the two metrics most often employed to gauge a waveform's harmonic content. Both are measurements of a waveform's actual value and may be used with either voltage or current.

Distortion of all harmonics

The THD is a metric used to assess the usefulness of the harmonic components that make up a distorted waveform. In other words, it is the harmonics' potential heating value in relation to the fundamental. Although the THD has various uses, it has limitations that must be understood. When a distorted voltage is put across a resistive load, it may provide a fair indication of how much more heat will be generated. The extra losses brought on by the current passing through a conductor may also be shown. However, because the voltage stress inside a capacitor is tied to the peak value of the voltage waveform rather than its heating value, it is not a reliable indication of that stress. The most popular method for describing voltage harmonic distortion is the THD index. Harmonic voltages are virtually always measured in relation to the waveform's fundamental value at the moment of sampling. The voltage THD is almost usually a significant quantity since the basic voltage only fluctuates by a small percentage. THD variations over time often follow a recognizable pattern that represents nonlinear load actions in the system.

Distortion of Demand Overall

THD values may be used to indicate current distortion levels, however they are often deceptive. Even while a little current could have a high THD, it won't pose a serious harm to the system. For instance, while running under extremely low loads, many adjus-speed drives may display high THD values for the input current. The amplitude of harmonic current is modest, despite the fact that its relative current distortion is substantial, therefore this is not necessarily a serious worry. By referring to the fundamental of the peak demand load current rather than the fundamental of the current sample, some analysts have sought to get around this problem. Total demand distortion is what gives rise to the recommendations in IEEE Standard 519-1992, Recommended Practices and Requirements for Harmonic Power Systems, which forms the foundation for these standards.

IL, measured at the point of common coupling, is the peak, or maximum, demand load current at the fundamental frequency component. There are two methods for calculating IL. It may be estimated as the average of the greatest demand current for the 12 months before when a load is already present in the system. The computation may be completed by averaging the peak demand data over the previous 12 months. IL must be calculated for a new facility using the anticipated load profiles.

Sources of Harmonics from Commercial Loads

High-efficiency fluorescent lighting with electronic ballasts, adjustable-speed drives for the heating, ventilation, and air conditioning loads, elevator drives, and delicate electronic equipment powered by single-phase switch-mode power supplies are the norm in commercial buildings like office buildings, department stores, hospitals, and Internet data centers. A huge number of tiny, harmonic-producing loads make up commercial loads. These little harmonic currents may accumulate in phase or cancel each other depending on the variety of the various load types. The overall harmonic current distortion as well as the circuit impedances both affect the voltage distortion levels. The service entrance transformers and conductor impedances dominate the circuit impedance in commercial facilities since power factor correction capacitors are not often utilized there. As a result, it is easy to calculate the voltage distortion by dividing the current by the impedance adjusted for frequency. The next sections go into further depth on typical nonlinear commercial load characteristics.

Solitary-Phase Power Sources

The most significant type of nonlinear loads in the power system nowadays is made up of electronic power converter loads because of their ability to generate harmonic currents. Over the last ten years, advances in semiconductor device technology have driven a revolution in power electronics, and all signs point to this trend continuing. Battery chargers, electronic ballasts, adjus-speed motor drives, electronic power supply, and several more uses for rectifiers and inverters are among the equipment.

Power supply for single-phase electronic equipment in commercial buildings are a significant source of worry because they may generate too much harmonic current for the wiring. Modern electronic and microprocessor-based office equipment often uses single-phase full-wave diode bridge rectifiers to provide DC power. With the expanded use of personal computers in every industry, the proportion of load that comprises electronic power supply is rising dramatically. Two popular varieties of single-phase power supply are available. Older systems lower voltages to the level needed for the dc bus using ac-side voltage control techniques, including transformers. By lowering harmonic content and flattening the input current waveform, the transformer's inductance has a positive side effect. Modern switch-mode power supplies use dc-to-dc conversion methods in order to provide a smooth dc output with a minimum of bulky, heavy components. The transformer is not needed since the input diode bridge is directly linked to the ac line. As a consequence, the capacitor's dc voltage is only loosely controlled. The switcher then changes this direct current back into alternating current at a very high frequency, which is then rectified once again. Switch-mode power supply are currently used almost exclusively by personal computers, printers, copiers, and the majority of other single-phase electronic devices. The main benefits are the low weight, small size, effective functioning, and absence of a transformer. Large changes in input voltage may often be tolerated by switch-mode power supply.

The input current to the power supply occurs in extremely brief pulses when the capacitor C1 regains its charge on each half cycle since there is no significant ac-side inductance. the whole circuit's current waveform and spectrum, which is used to power a range of electronic devices using switch-mode power supplies. An extremely high third-harmonic content in the current is a defining property of switch-mode power supply. The growing usage of switch-mode power supply raises concerns about neutral conductor overloading since third-harmonic current components in a three-phase system's neutral are additive. This is particularly true in older structures where an inadequate neutral may have been placed. Due to a combination of harmonic current content, stray flux, and high neutral currents, transformer overheating is also a risk.

Fluorescent Illumination

In a business building, lighting generally makes up between 40 and 60 percent of the load. In 1995, the United States performed a research on the energy use of commercial buildings. According to the Energy Information Administration, fluorescent lighting was utilized in 77 percent of commercial floor areas, compared to just 14 percent of facilities that used incandescent lighting1.

Fluorescent lights need a ballast to provide a high initial voltage to start the discharge so that electricity may flow between two electrodes in the fluorescent tube. Fluorescent lights are discharge lamps, hence a ballast is necessary to do this. The voltage drops as the arc current rises after the discharge has been formed. Between the two electrodes, there is effectively a short circuit, and the ballast has to immediately lower the current to a level that will maintain the desired lumen output. Thus, in lighting applications, a ballast also serves as a current-limiting device. Ballasts come in magnetic and electrical varieties. An iron-core transformer and a capacitor enclosed in an insulating substance make up a conventional magnetic ballast. One or two fluorescent bulbs may be driven by a single magnetic ballast, which runs at the line fundamental frequency of 50 or 60 Hz. When compared to an electronic ballast, the iron-core magnetic ballast is less efficient due to higher heat losses.

To transform the incoming fundamental frequency voltage into a considerably higher frequency voltage that is generally in the range of 25 to 40 kHz, an electronic ballast uses a switch-mode type power supply. These high frequencies have two benefits. First, the arc current may be controlled using a tiny inductor. Second, the flicker associated with an iron-core magnetic ballast at 100 or 120 Hz is completely or significantly reduced by the high frequency. Up to four fluorescent bulbs may normally be driven by a single electronic ballast. A measured fluorescent lamp current and harmonic spectrum. Standard magnetic ballasts are often very innocuous generators of extra harmonics , as the predominant harmonic distortion originates from the behavior of the arc. The THD at the moment is a reasonable 15%. Comparatively, the harmonic output of electronic ballasts, which make use of switch-mode power sources, may be doubled or tripled. A fluorescent bulb with an electronic ballast and a current THD of 144. Compared to the typical magnetic ballast-lamp combination, some electronic ballasts may actually generate less harmonic distortion since they have been intentionally designed to reduce harmonics [6]–[8].

The majority of electronic ballasts use passive filtering to keep the input current harmonic distortion to about 20%. Fluorescent lighting is a substantial generator of harmonics in commercial buildings, and these harmonics are often spread throughout the phases in a fairly balanced way. This lessens the quantity of triplen harmonic currents coming into the power supply system when using a supply transformer with a delta connection. It should be observed that regardless of how well balanced the phases are, the typical wye-wye supply transformers will not obstruct the passage of triplen harmonics.

Drives with variable speeds for HVAC and elevators

Elevator motors, pumps, and fans in HVAC systems are a few common commercial loads for adjus-speed drives. The electrical power converter that converts ac voltage and frequency into variable voltage and frequency is the core component of an ASD. The ASD can change motor speed to meet application requirements, such as reducing the speed of a pump or fan, thanks to the variable voltage and frequency. ASDs are widely used in industrial loads.

Harmonic Sources from Industrial Loads

Nonlinear loads are often used in modern industrial facilities, which is one of their distinguishing features. These loads, which may account for a significant part of the total facility loads, introduce harmonic currents into the power system and result in harmonic voltage distortion. The comparatively low power factor of these nonlinear loads makes this harmonic issue worse. Capacitor banks are often used in industrial facilities to increase the power factor and reduce penalty costs. When power factor correction capacitors are used, harmonic currents from nonlinear loads may be amplified, leading to resonance conditions within the facility. The facility's low-voltage bus, where the capacitors are applied, often experiences the greatest voltage distortion level. Resonance situations lead to the overheating of motors and transformers as well as the malfunction of delicate electrical devices.

Converters For Three-Phase Electricity

The fundamental way that three-phase electronic power converters vary from single-phase converters is that third-harmonic currents are not produced. This is a huge benefit as the third-harmonic current makes up the majority of harmonics. At their typical frequencies, they may nevertheless be major harmonic sources. This kind of adjustable-speed drive uses a normal current source.

PWM-type current and harmonic spectrum ASD

Typically, the switch-mode power supply used in computers is a three-phase version of the input to the PWM drive. A sizable capacitor on the dc bus receives a direct input from the rectifier on the ac line. The capacitor is charged in brief pulses with little intended inductance, resulting in the recognizable "rabbit ear" ac-side current waveform with extreme distortion. In contrast, the switch-mode PWM drives are currently being used for loads up to 500 horsepower, while power supplies are typically for extremely modest loads. Power engineers have reason to be concerned about this.

DC motors. For DC drives, simply rectification is needed. They benefit from comparatively simple control systems as a result. The dc drive provides a larger speed range and more beginning torque as compared to ac drive systems. However, the cost of power electronic devices has been declining year after year while the cost of purchasing and maintaining dc motors has remained high. Because of this, only applications that need the speed and torque characteristics of a dc motor may utilize the dc drive. Six-pulse rectifiers are used by most dc drives. A 12-pulse rectifier may be used with large drives. This lowers some of the bigger ac current harmonics and lowers thyristor current responsibilities. The fifth and seventeenth harmonic currents are the two biggest harmonic currents for the six-pulse drive. In terms of how the system reacts, they are also the most problematic. Depending on system imbalances, a 12-pulse rectifier in this application may be predicted to remove around 90% of the fifth and seventh harmonics. The 12-pulse drive has drawbacks including higher electronics costs and often requiring a second transformer[9]–[11].

CONCLUSION

In summary,two different sorts of disruptions that might happen in electrical power systems are harmonics and transients. They may disrupt communication and control systems, harm machinery, and increase losses. Utilizing filters, surge protectors, and voltage stabilizers are examples of mitigation techniques. Adherence to relevant standards and laws, as well as routine equipment testing and maintenance, are necessary for the proper control of harmonics and transients. For electrical power systems to operate safely and reliably, harmonics and transients must be managed properly. This calls for the observance of relevant standards and laws as well as routine equipment testing and maintenance.

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CHAPTER 12

A BRIEF DISCUSSION ON CLASSIFICATION OF AC DRIVES

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ABSTRACT:

AC drives, also known as variable frequency drives (VFDs), are devices that control the speed of an electric motor by varying the frequency and voltage of the power supplied to it. They are widely used in industrial and commercial applications to control the speed and torque of pumps, fans, compressors, conveyors, and other types of machinery. AC drives work by converting the incoming AC power into DC power, which is then converted back into AC power at a variable frequency and voltage. This allows the motor to be run at different speeds and torques, depending on the requirements of the application. The use of AC drives can lead to significant energy savings, as they allow for more efficient operation of the motor.

KEYWORDS:

AC Drives, Motor, Power Electronics, Variable Frequency Drive.

INTRODUCTION

The rectifier output is reversed in ac drives to provide the motor a variable-frequency ac voltage. Voltage source inverters and current source inverters are the two categories that inverters fall under. For a VSI, the inverter stage needs a steady dc voltage input. A capacitor or an LC filter in the dc link is used to do this. The dc link has a series inductor since the CSI needs a steady current input[1], [2]. Induction motors with a standard squirrel cage are often used in AC drives. These motors are durable, reasonably priced, and need minimal maintenance. In situations where precise speed control is essential, synchronous motors are employed.

An AC waveform is synthesized as a train of variable-width dc pulses using a VSI and PWM techniques in a common ac drive arrangement. This is accomplished by the inverter using either SCRs, gate turnoff thyristors, or power transistors. For drives up to at least 500 hp, the VSI PWM drive currently delivers the highest energy efficiency for applications across a broad speed range. Another benefit of PWM drives is that, in contrast to other drive types, motor speed may be controlled without changing the rectifier output voltage. This enables the thyristor control circuitry to be removed and the rectifier thyristors to be swapped out for diodes.

Drives with very high power need inverters and SCRs. These might have six pulses or twelve pulses, like big dc drives. Applications that do not call for abrupt speed changes cannot use VSI drives. The inverter thyristors in CSI drives must be commutated, which requires a motor with a leading power factor or additional control circuitry. CSI drives offer strong acceleration/deceleration characteristics. In either scenario, the CSI drive has to be built to work with a particular motor. The need for thyristor protection against inductive voltage spikes in current source inverters raises the price of this kind of drive[3], [4].

Effect of the working environment. In adjus-speed drives, the harmonic current distortion is not constant. For various speed and torque levels, the waveform significantly changes.

The two operational scenarios for a PWM variable-speed drive. The drive injects much greater magnitude harmonic currents at rated speed even though the waveform is proportionally much more de- torted at 42 percent speed. The current injection quantity is shown on a bar graph. Instead of the greatest THD, this will be the limiting design element. Before making design choices, engineers should take care to comprehend the underlying data and measurements pertaining to these drives. Arc welders, arc furnaces, and magnetic ballast-equipped discharge lights all fall under this category. The arc is fundamentally a voltage clamp connected in series with a reactance that reasonably restricts current.

Electric arc voltage-current characteristics are nonlinear. After arc ignition, the power system's impedance is the only thing stopping the voltage from falling as the arc current rises. As in applications for fluorescent lighting, this gives the arc the appearance of having a negative resistance for a portion of its operational cycle. With some assistance from the power system and furnace transformer, the furnace cable and leads serve as the limiting impedance in applications using electric arc furnaces. Actually, the best way to describe the electric arc itself is as a generator of voltage harmonics. If a probe were to be positioned exactly across the arc, a waveform that resembled a trapezoid would be seen. Its size mostly depends on how long the arc is. But furnace leads or ballasts' impedance serves as a buffer and only slightly distorts the supplied voltage.

Thus, it seems that the arcing load is a rather weak current source, which is sufficient for the majority of studies. The system is an exception when it is close to resonance, in which case a Thevenin equivalent model employing the arc voltage waveform provides more accurate results. Similar to magnetic ballasts, arc furnace loads and other arcing devices have harmonic content. Through the transformer connection, three-phase arcing devices may be set up to cancel the triplen harmonics. In three-phase arc furnaces, however, this cancellation may not function due to the frequent unbalanced operation during the melting phase. The cancellation is improved throughout the refining process when the arc is more consistent.

DISCUSSION

Saturable Devices

Transformers and other electro-magnetic devices having a steel core, such as motors, fall under this category of equipment. Due to the steel's nonlinear magnetizing properties, harmonics are produced. Normal operation for power transformers is limited to the "knee" position of the magnetizing saturation characteristic. A complex optimization process that takes into account noise, no-load losses, steel cost, and a variety of other parameters is used to determine a transformer's operating flux density.

In order to achieve the standard, the vendor will attempt to use the transformer with the lowest assessed cost since many electric utilities would punish transformer suppliers in different ways for no-load and load losses. There will typically be more steel in the core and a larger saturation curve as a consequence of a high cost penalty on the no-load losses or noise, which will provide lower harmonic currents[5], [6].

Property of Magnetizing Transformers

At normal operating voltage, transformer exciting current has a high harmonic content, however it normally represents less than 1% of the rated full load current. Transformers are less of an issue than electronic power converters and arcing apparatuses, which may generate harmonic currents of at least 20% of their rated value. However, they will have considerable impact, especially on utility distribution networks, which include a large number of transformers. During the early morning hours, when the load is light and the voltage is rising, it is typical to see a noticeable increase in triplen harmonic currents. Because there isn't enough load to hide it and more current is created due to the higher voltage, the transformer stimulating current is then more apparent. Only at these low load levels would harmonic voltage distortion from transformer overexcitation typically be noticeable.

Some transformers are intentionally used in saturated areas. A triplen transformer is one example, which is used to produce 180 Hz for induction furnaces. When overexcited, motors also display some current distortion, albeit it usually has minimal impact. However, there are several single-phase, fractional horsepower motors with a roughly triangular waveform and sizable third-harmonic currents. For single-phase or wye-grounded three-phase transformers, the waveform is intended. There is clearly a lot of third harmonic in the current. The flow of triplens, which often have zero-sequence harmonics, is prevented by ungrounded-wye connections and delta connections. Thus, barring a system imbalance, the line current will be free of these harmonics.

Searching for Harmonic Sources

The harmonic currents often travel from the harmonic-producing load to the power system source on radial utility distribution feeders and industrial plant power systems. The power system's impedance is often the lowest impedance that harmonic currents encounter. As a result, the source receives the majority of the current.

To find harmonic sources, one might utilize the overall trend of harmonic current flows. Simply measure the harmonic currents in each branch beginning at the circuit's main branch and follow the harmonics to the source using a power quality meter that can provide the current's harmonic content. For at least one of the harmonics, power factor correction capacitors may change this flow pattern. For instance, adding a capacitor to the previous circuit as shown in may cause a significant increase in the harmonic current flowing through that area of the circuit. In this case, following the harmonic current's course will result in a capacitor bank rather than the real harmonic source. Therefore, in order to accurately identify the harmonic sources, all capacitors must typically be momentarily disconnected.

Harmonic currents that are simply caused by maintenance involving a capacitor bank are typically easy to distinguish from harmonic currents that are attributable to genuine sources. On top of the basic sine wave in a resonance current, there is normally just one dominant harmonic present. It is important to note that none of the harmonic sources previously discussed in this article emit any additional harmonic frequencies. Each of these generates several harmonic frequencies. Depending on the distortion mechanisms, the waveforms of these harmonic sources may have fairly random wave patterns, but they nonetheless include a number of harmonics in appreciable amounts. Resonance is almost often indicated by a single, big, substantial harmonic. This information may be used to assess the likelihood of harmonic resonance issues in a capacitor-based system. Simply check the capacitors' current. It is most probable that the capacitor is taking part in a resonant circuit inside the power supply if it has a very high concentration of one harmonic other than the fundamental. When there is a suspicion of harmonic problems, always check the capacitor currents first.

Correlating the temporal changes of voltage distortion with particular customer and load characteristics is another way to identify harmonic sources. Certain forms of intermittent loads, such as arc furnaces, mill drives, and mass transits, may be compared to patterns from the harmonic distortion data. The harmonic source may be identified by comparing the time from the measurements and the actual operating time.

Features of System Response

Both the origins of harmonics and the system reaction are significant in power systems. In reality, unless there is a negative interaction with the system's impedance, power systems are relatively forgiving of the currents injected by harmonic-producing loads. Harmonic analysis requires more work than just determining the sources. The real effect of the nonlinear load on harmonic voltage distortion is determined by the power system's reaction to each harmonic frequency. The system impedance, the existence of a capacitor bank, and the quantity of resistive loads in the system are the three main factors that influence the system response characteristics.

System Resistance

Power systems are largely inductive at the fundamental frequency, and the analogous impedance is frequently referred to as the short-circuit reactance. Capacitive effects on utility distribution systems and industrial power systems are commonly disregarded. The short-circuit impedance to the point on a network where a capacitor is placed is one of the most often used metrics in the investigation of harmonics on power systems. The impedance's inductive reactance component varies linearly with frequency. Beginners in harmonic analysis often neglect to adjust the reactance for frequency, which is a common blunder. From the fundamental impedance reactance reactance X1, the reactance at the third harmonic is calculated by:

$$Xh = hX1$$

When examining the impact of harmonics smaller than the ninth, one may often assume that the resistance does not vary considerably in most power systems. Once the skin effect in the conductor becomes substantial at a higher frequency, the resistance for lines and cables changes roughly by the square root of the frequency. With certain transformers, this rule is an exception. Larger transformers' apparent resistance may change almost proportionally with frequency due to stray eddy current losses. As we shall see later, this may have a very positive impact on damping of resonance.

There is no change in the overall apparent resistance until the frequency reaches around 500 Hz in smaller transformers (less than 100 kVA), when the resistance of the winding is often so great compared to the other impedances that it swamps out the stray eddy current effects. Obviously, at fundamental frequency, these smaller transformers may have an X/R ratio of 1.0 to 2.0, while huge substation transformers may often have a ratio of 20 to 30. The system impedance model should thus be given greater thought if the bus under study is dominated by transformer impedance rather than line impedance. Neglecting the resistance will often result in a conservatively high harmonic distortion forecast.

Battery Impedance

Shunt capacitors significantly change the system impedance variation with frequency, whether they are installed at the customer site for power factor correction or on the distribution system for voltage management. Although capacitors don't produce harmonics, their presence may sometimes be blamed for severe harmonic distortion.

Similar Resonance

There are at least one or more natural frequencies in any circuit that includes both capacitances and inductances. A resonance may form when the voltage and current at that frequency continue to exist at very high levels when one of those frequencies coincides with a frequency that is being generated on the power supply. The majority of issues with harmonic distortion in power systems originate from this. A distribution system that could have issues with parallel resonance. The shunt capacitor looks parallel to the equivalent system inductance when seen from the standpoint of harmonic sources, as shown by the equation. Furthermore, the power system voltage source seems short-circuited in the image because it is believed that the power system has an analogous voltage source that exclusively emits fundamental frequencies. When the reactance of XC and the distribution system cancel each other out, parallel resonance develops. The parallel resonant frequency is the frequency at which this phenomenon occurs.

Resonance in series

In certain cases, a series LC circuit to a source of harmonic currents may seem like a shunt capacitor and the inductance of a transformer or distribution line. A significant amount of the harmonic current generated in the distribution system will be drawn to the LC circuit if the resonant frequency matches a typical harmonic frequency of the nonlinear load. In this approach, a customer who uses power factor correction capacitors but has no nonlinear load may experience excessive harmonic voltage distortion brought on by nearby harmonic sources. The transformer, harmonic sources, and the power factor correction capacitor create a series circuit when resonance is occurring. The straightforward circuit. The total number of harmonics generated by other loads is represented by the harmonic source in this figure. The service entry transformer's inductance is connected in series with the capacitor. The only factor limiting the series combination of the capacitor bank's resistance and the transformer's inductance is how tiny it is. As a result, the harmonic current associated with the resonance frequency will easily flow across this circuit. The power factor adjustment capacitor's voltage is greatly distorted and amplified.

Effects of resistive load and resistance

It's not always a reason for concern when the resonant harmonic coincides with another harmonic source. Often, the system's resistance-based damping is sufficient to stop catastrophic voltages and currents. In parallel with the capacitance, it displays the parallel resonant circuit impedance characteristic for different resistive load densities. Peak impedance may benefit significantly from resistive loading as low as 10%. The resonance will also be reduced if there are a lot of lines or cables between the capacitor bus and the closest upline transformer. Lines and cables may significantly increase the corresponding circuit's resistance.

Catastrophic harmonic issues from capacitors on utility distribution feeders are often seen due to loads and line resistance. Although resonance-related harmonic issues are possible, they often do not result in physical harm to the electrical system's components. When capacitors are mounted on sub-station buses, whether in utility substations or industrial facilities, the most problematic resonance situations develop. The relative resistance is low and the corresponding parallel resonant impedance peak is highly abrupt and strong in certain situations, when the transformer dominates the system impedance and has a high X/R ratio. This is a typical reason why equipment like capacitors, transformers, or loads malfunction. Utility distribution engineers may be able to put feeder banks without too much care for resonance, but studies should always be done for utility support applications and for industrial capacitor uses. According to utility experts who are knowledgeable with the issues, resonance causes significant operational interruptions or equipment failure in around 20% of industrial facilities for which no studies have been conducted. In reality, choosing the appropriate capacitor size from the manufacturer's selection based on typical monthly billing data tends to tune the system close to the fifth harmonic. Because it typically makes up the bulk of the system, this harmonic is among the hardest to tune.

Contrary to popular belief, resistive loads have minimal effect on harmonic currents and the associated voltage distortion in the absence of resonance. The majority of the current will return to the power source. To state that resistive loads will damp resonance, which will result in a large decrease in harmonic distortion, is extremely appropriate. The majority of motor loads are inductive and provide negligible damping. In fact, by bringing the system's resonance frequency closer to a large harmonic, they may even exacerbate distortion. Due to the apparent X/R ratio of small, fractional-horsepower motors being lower than that of big, three-phase motors, these motors may considerably contribute to damping.

Harmonic Distortion's Effects

Nonlinear loads cause harmonic currents to be fed back into the supply systems. These currents may negatively interact with a variety of losses, overheating, overloading, interference with communications connections, and inaccuracies in power metering. effects of harmonic distortion on different elements of the power system.

Transformers are affected

Transformers are designed to give the necessary power to connected loads while experiencing the fewest losses possible at fundamental frequency. Harmonic distortion of the voltage and current in particular will cause a large amount of extra heating. Different design decisions are made by designers when creating a transformer to support higher frequencies, such as employing constantly transposed cable rather of a solid conductor and adding extra cooling ducts. A transformer that has a current distortion of more than 5% is often a candidate for harmonic derating.

When harmonic components are present in the load current, there are three consequences that lead to increased transformer heating:

Current RMS: Harmonic currents may cause the transformer's rms current to exceed its capacity if the transformer is solely designed for the load's kVA requirements. Increased conductor losses are a consequence of the higher total rms current.

Loss due to eddy currents: These are the magnetic flux-induced currents in a transformer. These induced currents flow through the transformer's windings, core, and other conducting bodies that are exposed to its magnetic field, which results in extra heating. With the square of the frequency of the current creating the eddy currents, this component of the transformer losses rises. So, for harmonic heating, this becomes a crucial part of transformer losses.

Loses at the core: The impact of the harmonics on the applied voltage and the transformer core's design will determine how much core losses rise when harmonics are present. Eddy currents in the core laminates may grow with an increase in voltage distortion. Depending on the thickness of the core laminations and the caliber of the core steel, this will have a different effects overall. In general, the rise in these losses brought on by harmonics is not as serious as the ones in the prior two.

Exceptions

Transformers often fail or run hot despite not seeming to have a harmonics issue based on the parameters above, perhaps owing to overload. One typical scenario with grounded-wye transformers is when the transformer overheats at less than rated load and the line currents include an 8 percent third harmonic, which is a comparatively modest amount. Why would this transformer pass a heat run test and maybe an over-load test at the factory yet not function as intended in use? Leaving aside issues with mechanical cooling, there is likely some conducting component in the magnetic field that is being impacted by the harmonic fluxes. Three options among many are as follows:

On three-legged core designs, zero-sequence fluxes will "escape" from the core. Most of the harmonics in the third, ninth, fifteenth, etc., are zero-sequence. Therefore, these harmonic fluxes might result in extra heating in the tanks, core clamps, etc. that would not necessarily be present during balanced three-phase or single-phase testing provided the winding connections are suitable to enable zero-sequence current flow. The previously indicated 8 percent line current corresponds to a neutral third-harmonic current that is 24 percent of the phase current. The leakage flux in the tank, as well as in the oil and air space, might increase significantly as a result. Burned or bled paint on the tank and signs of heating on a bayonet fuse tube or bushing end are two signs[7]. Additionally, flux may "escape" the boundaries of the core due to DC offsets in the current. For instance, the core will stay normal during the negative half cycle but become significantly saturated during the positive half cycle. Numerous electrical power converters may generate current waveforms that are asymmetrical either unintentionally or on purpose. This may cause a little dc offset on the transformer's load side. The majority of power transformers may have issues with only a little bit of dc offset. There can be a bushing end, clamping structure, or other conducting component that is too near to the magnetic field. It may be so little that it has no impact on stray losses at fundamental frequencies, yet it might nevertheless result in a hot spot when exposed to harmonic fluxes[8], [9].

CONCLUSION

In summary,by adjusting the frequency and voltage of the electricity sent to electric motors, AC drives are devices that regulate the speed and torque of such motors. They have a number of benefits over conventional motor control techniques, such as increased energy efficiency and process control. However, they are costlier and sophisticated than conventional approaches and have the potential to produce harmonics into the electrical system. Compared to conventional motor control techniques like mechanical speed controllers and fixed-speed motors, AC drives provide a number of benefits. They provide accurate motor speed and torque control, enhancing process control and energy efficiency. By lessening the strain and wear brought on by frequent starting and stopping, they may also lengthen the life of the engine. However, there are several drawbacks to using AC drives. They may induce harmonics into the electrical system, which may result in issues including equipment damage and overheating. Additionally, they may be costlier and complicated than conventional forms of motor control.

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CHAPTER 13

A BRIEF DISCUSSION ON APPLIED HARMONICS

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ABSTRACT:

Applied harmonics refer to the study and analysis of harmonic distortion in electrical systems, as well as the methods used to mitigate its effects. Harmonic distortion is a common problem in electrical power systems, caused by non-linear loads that draw current in a non-sinusoidal manner. These distortions can lead to issues such as equipment damage, overheating, and interference with communication and control systems. Applied harmonics involves the use of various tools and techniques to identify and analyze harmonic distortions in electrical systems, such as power quality meters, spectrum analyzers, and computer simulations. It also involves the implementation of measures to mitigate the effects of harmonics, such as the use of filters, harmonic suppression transformers, and active harmonic filters.

KEYWORDS:

Distortion, Filter, Harmonic, Mitigation.

INTRODUCTION

The harmonic voltage distortion may have a big influence on motors. Harmonic fluxes occur within the motor as a result of harmonic voltage distortion at the motor terminals. Harmonic fluxes essentially induce high-frequency currents in the rotor even if they do not substantially contribute to motor torque since they spin at a frequency other than the rotor's synchronous frequency. Similar to negative-sequence currents at fundamental frequency, the extra fluxes have no influence on motor performance other than to cause greater losses. High-pitched sounds, warmth, vibration, and decreased efficiency are all signs of harmonic voltage distortion[1], [2].

Typically, a blocked rotor reactance linked across the line may be used to represent motors at harmonic frequencies. The most significant harmonic voltage components for motors are often those of lower order, with greater magnitudes and lower apparent motor impedance. If the voltage distortion stays under the IEEE Standard 519-1992 limitations of 5% THD and 3% for any particular harmonic, derating motors is often not necessary. When the voltage distortion reaches 8 to 10 percent and above, excessive heating issues start to appear. For a long motor life, such distortion should be addressed. Regarding the harmonic current flow, motors seem to be in parallel with the power system impedance, and they typically raise the system resonance by lowering net inductance. Depending on where the system resonance is before igniting the motor, this might be harmful to the system. Depending on the X/R ratio of the blocked rotor circuit, motors may also contribute to the dampening of certain of the harmonic components. This could aid in reducing harmonic resonance in systems with lots of tiny motors and a low X/R ratio. Large motors, however, cannot rely on this.

Telecommunications-Related Effects

Harmonic currents may cause interference in communication circuits that share a shared channel whether they flow on the utility distribution system or within an end-user facility. Common harmonic currents often produce voltages in parallel conductors that are within the range of what is typically used for voice communications. Particularly bothersome harmonics are those between 540 and 1200 Hz. With frequency, the induced voltage per ampere of current rises. Triplen harmonics are particularly problematic in four-wire systems because they add directly to the neutral circuit, which is most exposed to the communications circuit and is in phase with all conductors of a three-phase circuit.

Direct conduction or induction are the two methods used to link harmonic currents from the power supply into communication lines. Using induction to connect to the neutral of an overhead power line. In the days of open wire telephone systems, this was a serious issue. This kind of coupling is now less relevant due to the widespread use of shielded, twisted-pair conductors for telephone connections. There is no net voltage in the loop that the conductors create since the direct inductive coupling is equal in both conductors. If large currents are produced in the shield that surrounds the telephone cables, inductive coupling may still be an issue. A potential difference in the ground references at the ends of the telephone wire is caused by an IR drop caused by current flowing in the shield. Direct conduction may also result in shield currents. The ground route of the power system and the shield are parallel. High shield IR drop will once again potentially result in a discrepancy in the ground references at the ends of the phone wire if local ground conditions are such that a substantial amount of current flows through the shield.

Effect on Demand and Energy Metering

Electric utility providers typically track two types of energy usage: the maximum power utilized during a certain time period and the overall cumulative energy spent. For bigger industrial clients, there are thus two costs in any given billing period: energy charges and demand charges. Typically, residential consumers only pay for the energy they use. The energy charge, which is expressed in kilowatt-hours, is what it costs to produce and provide all the energy used during a billing period. The demand fee, which makes up the second portion of the bill, is what it costs to have enough electricity available at all times to fulfill the peak demand for energy usage from each client. The demand fee accounts for the utility's fixed costs associated with meeting peak electricity demands. The demand fee, which is calculated in kilowatts, is often determined by the greatest 15- or 30-min peak demand of usage within a billing period[3]–[5].

The so-called watthour and demand meters are used to calculate both energy and demand costs. The demand pointer is often reset to zero at the conclusion of each timing interval and a demand meter is typically integrated to a watthour meter with a timing device to record the peak power usage. Watthour and demand meters' accuracy may be negatively impacted by harmonic currents from nonlinear loads. The induction motor idea is the foundation of conventional watthour meters. Inside the meter, a revolving disk or rotor element rotates at a rate corresponding to the rate of power flow. This disk then powers a set of gears, which in turn turns dials on a register. At harmonic frequencies, conventional magnetic disk watthour meters often exhibit a negative inaccuracy. In other words, if they are correctly calibrated for the fundamental frequency, they report little power at harmonic frequencies. This mistake happens more often now. Due to the distortion in the voltage, nonlinear loads often inject harmonic power back into the supply system, while linear loads absorb harmonic power. By displaying the directions of the currents, this is shown.The extra energy is absorbed by the linear load, but the meter does not measure the full amount that is really used. Is the increased energy something the consumer genuinely wants? The answer is no if the load is made up entirely of motors because the additional energy causes losses in the motors due to harmonic distortion. If the load is resistive, the energy will probably be used effectively.

Fortunately, the mistake is quite modest in the majority of real situations when the voltage distortion is within the permissible limits for the energy supply. Modern electronic meters that are in use today are time-division and digital sampling based. Compared to traditional watthour meters based on the induction motor concept, these electronic meters are far more precise. Despite having the ability to monitor harmonic components, these electronic watthour meters may also be configured to measure solely the basic power. To ensure that the meters are measuring the proper amount, the user should use caution. The demand metering process has the most potential for mistakes. The apparent power that is purely attributable to harmonic distortion is ignored, which leads to the metering inaccuracy. While D is often disregarded, certain metering techniques precisely measure the active and reactive power. The D term is often ignored and only Q at the fundamental is recorded if Q is calculated by a second watthour meter supplied by a voltage phase-shifted from the energy meter. Although many contemporary meters are certified to appropriately account for harmonics, even some electronic meters do not adequately account for the total perceived power. The measured kVA demand is thus smaller than the real due to the flaws in the metering mechanism. The consumer would benefit from the mistake.

When the total current at the metering site is significantly skewed, the worst mistakes happen. There is a 10- to 15% margin of error for the overall kVA demand. Fortunately, the current distortion is not as severe at the metering point for total plant load as it is for individual load currents. The metering inaccuracy is typically rather modest as a result. There are a few exceptions to this rule, such as pumping stations where the only load on the meter is a PWM motor. Given that the voltage has little distortion, the energy meter should be accurate enough, but the demand metering may be significantly off.

DISCUSSION

Interharmonics

The Fourier theory states that a periodic waveform may be represented as the sum of pure sine waves of various amplitudes, where each sinusoid's frequency is an integer multiple of the periodic waveform's fundamental frequency. The term "harmonic frequency" refers to a frequency that is an integer multiple of the fundamental frequency, where f0 and h are the fundamental frequency and an integer number, respectively[6]–[8].

On the other hand, a periodic waveform is not always produced by adding two or more pure sine waves with different amplitudes when each sinusoid's frequency is not an integer multiple of the fundamental frequency. This fundamental frequency's noninteger multiple, fih = hif0, where hi is a noninteger value greater than unity, is referred to as an interharmonic frequency. Interharmonic frequencies are thus, practically speaking, frequencies between two adjacent harmonic frequencies. The extensive usage of electronic power converter loads, which may produce current distortion across a broad range of frequencies, including characteristic and noncharacteristic frequencies, is one of the main causes of interharmonics.Adjus-speed drives in industrial applications, PWM inverters in UPS applications, active filters, and specialized power conditioning gear are a few examples of these loads. An adjus-speed drive's front end generally consists of a diode rectifier, which changes the input ac voltage to a dc voltage. The dc voltage is then transformed by an inverter into variable ac voltage with variable frequency. Particularly when using an asynchronous switching strategy, the inverter may cause interharmonics in the current. When the power electronic switches' switching frequency is an integer multiple of the fundamental frequency of the inverter voltage output, the switching system is said to be asynchronous.5 Interharmonic issues might develop if the harmonic current propagates via the dc connection and into the supply system. Rapidly shifting load current, as that in induction furnaces and cycloconverters, is a substantial cause of interharmonic distortion. Side-band frequencies surround the fundamental or harmonic frequencies as a result of the load current's fast fluctuations. The easiest way to explain interharmonic generation is using an example from an induction furnace.

In the forging and extruding industries, induction furnaces have been extensively utilized to heat ferrous and non-ferrous materials. Electronic power converters are used by contemporary induction furnaces to provide a changeable frequency to the furnace induction coil. According on the kind of material being melted and the volume of that material in the furnace, the frequency at the melting coil changes. The dc-to-ac inverter powers the resonant circuit made up of the furnace coil and capacitor to maintain resonance. The kind, temperature, and quantity of the material affect the coil's inductance when the furnace transitions from one cycle to another, such as from a melt to pour cycle. The furnace operates at a fluctuating frequency as a consequence of this circumstance. Induction furnaces typically operate between 150 and 1200 Hz. We'll give you one now. A 12-pulse current source is used in an induction furnace, and reactors on the dc link soften the current before it enters the inverter. The 11th, 13th, 23rd, 25th, and so on are typical characteristic harmonics in ac-side line currents. Noncharacteristic harmonics like the 5th and 7th are also potentially present. As the furnace transitions from one cycle to the next, there are additional currents at noninteger frequencies as a result of the interaction with the inverter output frequency. Through little changes in the dc link current, the inverter's switching reflects the furnace circuit's frequency to the ac-side power. Inter-harmonic frequencies are produced by this interaction on the ac side, which have no bearing on the power supply frequency.

Evaluations of Harmonic Distortion

Harmonic currents generated by nonlinear loads may negatively affect the utility supply system. Voltage and current harmonic distortion are often caused by the interactions and may be seen throughout the system. So as to ensure that harmonic voltage levels on the overall power system are acceptable if the power system does not excessively accentuate the harmonic currents. End users have control over this amount. Both individual harmonic components and the overall demand distortion have recommended upper bounds. The idea behind PCC. Instead of being represented as a percentage of the fundamental, these restrictions are expressed as a percentage of the greatest current demand level of the end user. This is meant to provide a standard framework for review throughout time. The utility is primarily responsible for limiting the voltage distortion at the PCC because the harmonic voltage distortion on the utility system results from the interplay between distorted load currents and the utility system impedance. The highest individual harmonic component and overall harmonic distortion upper bounds are provided. The percentage of the fundamental voltage is used to indicate these values. The THD should be less than 5% for systems 69 kV. The resonance of power factor correction capacitor banks may sometimes be used to calculate the impedance of a utility system at harmonic frequencies. High harmonic voltages and an extremely high impedance are the effects of this. The utility must often make sure that system resonances do not coincide with harmonic frequencies present in the load currents in order to comply with IEEE Standard 519-1992[9].

Therefore, in theory, utilities and end users are equally accountable for limiting harmonic current injections and voltage distortion at the PCC. The assessment of harmonic distortion is split into two sections because there are two parties engaged in limiting harmonic distortions: measurements of the currents being injected by the load and estimates of the frequency response of the system impedance. In order to adequately depict temporal fluctuations and statistical properties of the harmonic distortion, measurements should be made continuously for an adequate amount of time. Since harmonics are a continuous phenomenon, sporadic measurements should be avoided since they do not accurately capture harmonic features. Since this offers a realistic loading cycle for the majority of industrial and commercial loads, the minimum measurement time is typically 1 week.

Point of Common Coupling Theory

Harmonic distortion tests are often conducted at a point where another customer may be serviced, in between the end user or customer and the utility system. The point of common connection is where this occurs. Depending on whether the service transformer supplies power too many customers, the PCC may be placed on either the main side or the secondary side of the transformer. In other words, the PCC is situated at the main of the transformer if several customers are supplied from it. On the other side, the PCC is situated in the secondary of the transformer if several consumers are fed from it.

It should be noted that current measurements for verification may still be made at the transformer secondary while the PCC serves as the transformer's primary. The turn’s ratio of the transformer should be used to translate the measurement data to the high side of the transformer, and the impact of the transformer connection on the zero-sequence components must be taken into consideration. For example, a transformer with a delta-wye connection will prevent zero-sequence current components from moving from the secondary to the main system. The principal delta winding will have these auxiliary components. Therefore, the assessment of a PCC on the main side would not take into account zero-sequence components observed on the secondary side.

Assessments of the Electricity System's Harmonics

Procedures to assess the acceptability of the voltage distortion for each customer are part of harmonic assessments of the utility system. Corrective measures will be conducted to lower the distortion to a level within limitations if the voltage distortion exceeds the suggested limits. Guidelines for acceptable amounts of voltage distortion on the utility system are provided by IEEE Standard 519-1992. Note that both the maximum individual harmonic component and the THD have suggested limitations indicated. It should be noted that the concept of total harmonic distortion differs somewhat from the traditional definition. Instead of the magnitude of the fundamental frequency voltage at the moment of the measurement, the THD value in this is presented as a function of the nominal system rms voltage. According to the terminology employed here, voltage distortion may be evaluated in relation to set limitations rather than limits that change depending on the system voltage. The current limitations are imposed using a similar approach. Limiting voltage distortion levels on the whole utility system involves two key elements:

Harmonic currents introduced into the system by certain end users need to be kept to a minimum. Through the system impedance, these currents spread toward the supply source, causing voltage distortion. So, it is possible to restrict both the voltage distortion and the quantity of injected harmonic currents. Even if the harmonic current injection levels are within acceptable bounds, the total voltage distortion levels may be severe. A harmonic current frequency that is near to a system resonance frequency is the main cause of this phenomenon. This may cause unacceptably high amounts of voltage distortion in particular system locations. The capacitor bank that is a component of the resonance will often experience the most voltage distortion. The site of injection may be far from this place. Procedure for evaluating voltage limits. Here is a description of the utility system harmonic assessment process as a whole. This process is applicable to installations that are both current and upcoming. It is advisable to use measurements for existing installations to establish the characteristics of harmonic sources on the system. These tests should be carried out at locations where nonlinear loads are thought to be the culprit. In order to capture all cycle load fluctuations, tests typically last at least a week. Manufacturer-provided harmonic characteristics may be sufficient for recent or future installations.

Modeling a system: By creating a computer model of the system, it is possible to predict how the system will react to harmonic currents injected at end-user sites or by nonlinear devices on the power system. Models of the distribution and transmission systems are created as mentioned.

System reaction to frequency: A frequency scan of the whole power delivery system should be performed in order to identify any potential system resonances. Since the key factor that would affect the resonant frequencies is the capacitor configuration, frequency scans are carried out for all capacitor bank configurations of interest.

Analyze the amounts of predicted distortion: The voltage distortion levels surrounding the system may be acceptable, even if the system resonance is near to the characteristic harmonics. The majority of resistances on distribution systems are greatly damped by the system's resistances, which lowers the harmonic currents' magnifying power. To calculate the maximum anticipated harmonic distortion, the predicted harmonic sources are combined with the system design that produces the worst-case frequency-response characteristics. This will show whether harmonic mitigating actions are required or not.

Analyze a Harmonic Control Strategy: Changing the system's frequency-response properties, managing the harmonic injection from nonlinear loads, or adding harmonic filters may all be used to regulate harmonics. Because the characteristics of certain systems are continually changing due to shifting capacitor banks and varying loads, designing passive filters for such systems may be challenging.

Harmonic evaluation for end-user facilities

End-user facilities experience harmonic issues more often than the utility supply system does. The majority of nonlinear loads are found in end-user facilities, and the closest proximity to harmonic sources is where the greatest voltage distortion levels are found. The biggest issues arise when resonant circumstances are caused by power factor correction capacitors and nonlinear loads. In certain cases, it is not possible to get the average maximum demand load current at the PCC during the past 12 months. In these circumstances, it is necessary to determine this number based on the anticipated load profiles. The average for seasonal loads should exceed the maximum loads alone.

In this process, the restrictions of IEEE Standard 519-1992 are used to evaluate the harmonic production characteristics of certain end-user loads. However, while thinking about power factor correction equipment, more care must be used. The PCC is often at the main side of a service transformer serving the facility for industrial and commercial end customers. Find the corresponding limitations on each harmonic and the TDD after calculating the short-circuit ratio at the PCC. Describe the harmonic sources in detail. The total amount of harmonic current production in the facility is formed by the sum of all of the facility's nonlinear loads. Measurements taken at the PCC over time are the most effective approach to describe harmonic current in an existing plant. Knowing the characteristics of various nonlinear loads and what proportion of the overall load is made up of these nonlinear loads allows one to estimate the harmonic current for planning studies. There were listed the typical characteristics of each harmonic sources. Consider current restrictions while evaluating harmonic current levels. If these values are over thresholds, the facility does not comply with the IEEE Standard 519-1992 limit, and mitigating measures could be needed.

Harmonic Control

All power systems exhibit harmonic distortion to some extent. Fundamentally, harmonics should only be controlled when they pose a threat. Three main factors lead to harmonic issues:

1. There is an excessive supply of harmonic currents.
2. The currents have a route that is excessively lengthy and cause high voltage distortion or telephone interference.
3. The system's reaction amplifies one or more harmonics to a larger extent than is acceptable.
1. When an issue arises, the following are the standard options for controlling harmonics:
1. Reduce the load's harmonic current output.
2. Include filters to remove harmonic currents from the system, prevent harmonic currents from entering the system, or locally supply harmonic currents.
3. Alter the system's frequency response using filters, inductors, or capacitors.

Harmonic Current Reduction in Loads

Unless a load is being operated improperly, there is often nothing that can be done to considerably lower the amount of harmonic current it is generating. Arcing devices and the majority of electronic power converters are locked into their specified characteristics, but an overexcited transformer may be brought back to normal performance by reducing the applied voltage to the appropriate range. One exception to this rule is PWM drives, which immediately charge the dc bus capacitor from the line without adding any deliberate resistance. Harmonics will be significantly reduced, and improvements for transient protection will result from adding a line reactor or transformer in series. In three-phase systems, transformer connections may be used to minimize harmonic currents. By significantly lowering the fifth and seventh harmonics, phase-shifting half of the 6-pulse power converters in a plant load by 30° may approach the advantages of 12-pulse loads. Transformers with delta connections may prevent zero-sequence harmonics from leaving the line. Transformers that grind and zigzag may shunt triples off the line.By punishing bids from suppliers with excessive harmonic content, purchasing criteria may significantly reduce harmonic issues. This is especially crucial for loads like high-efficiency lighting[10], [11].

CONCLUSION

In summary,the study and analysis of harmonic distortion in electrical systems, as well as the strategies used to lessen its impacts, are referred to as applied harmonics. This entails identifying and analyzing harmonic distortions using a variety of tools and methodologies, as well as putting policies in place to lessen their consequences. For electrical power systems to run safely and reliably, harmonics must be managed properly. With the rise of non-linear loads in electrical systems, such as variable frequency drives, uninterruptible power supplies, and electronic ballasts, the significance of applied harmonics has increased. For electrical power systems to operate safely and reliably as well as to comply with all applicable standards and regulations, harmonics must be managed properly.

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CHAPTER 14

A BRIEF DISCUSSION ON FILTERING OF HARMONIC

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ABSTRACT:

Filtering of harmonic refers to the process of removing or reducing harmonic components from the electrical power system. Harmonic distortion is a common problem in electrical systems, caused by non-linear loads that draw current in a non-sinusoidal manner. These distortions can lead to issues such as equipment damage, overheating, and interference with communication and control systems. Filters can be used to remove or reduce harmonic components from the electrical system. There are several types of filters, including passive filters, active filters, and hybrid filters. Passive filters use passive components such as resistors, capacitors, and inductors to attenuate harmonic currents, while active filters use electronic circuits to actively cancel out harmonic currents. Hybrid filters combine both passive and active components to provide a more effective solution.

KEYWORDS:

Capacitor Bank, Hybrid Filters, Harmonic Current.

INTRODUCTION

The shunt filter operates by cutting off harmonic currents as near to the distortion source as is practicable. As a result, the supply system is kept free of currents. Due to its economic viability and propensity to both reduce harmonic current and adjust load power factor, this form of filtering is used the most often[1]–[3]. Applying a series filter that stops the harmonic currents is another strategy. This circuit is tuned in parallel and has a high impedance for the harmonic current. Because it is difficult to insulate and the load voltage is significantly distorted, it is not often employed. One typical use is to stop the flow of triplen harmonics while maintaining a solid ground at fundamental frequency in the neutral of a grounded-wye capacitor. Active filters function by electrically feeding a nonlinear load with the current's harmonic component. More details on filtering are provided.

Changing the Frequency Response of the System

There are many ways to change the way that harmonics make a system react negatively. This not only removes a problematic harmonic current from the system, but it also radically alters its response, usually for the better. Shunt power factor correlation capacitors and system inductance often experience harmful resonances. Between the capacitor and the supply system source, the reactor must be attached. To shift the system resonance without actually adjusting the capacitor to produce a filter, one technique is to simply connect a resistor in series with the capacitor. Another is to increase the line's reactance. For people that use utilities as well as businesses, this is often one of the least costly choices. Transfer a capacitor to a location in the system with larger losses or a different short-circuit impedance. Moving the bank to a different branch of the feeder may very well fix the issue for utilities when a new bank interferes with telephone service. Because the capacitor cannot be moved far enough to make a difference, this is generally not an option for industrial usage[4], [5]. Simply accept the increased losses, lower voltage, and power factor penalty by removing the capacitor. This is sometimes the best financial option, if it is physically possible.

Where Harmonics are Controlled

The methods for reducing harmonic distortion issues vary a little depending on the area. The utility distribution feeder and end-user power systems may both be controlled for harmonic distortion using the following strategies.

The distribution feeders for utilities

A utility distribution feeder often has a low X/R ratio. Therefore, compared to what may be observed within an industrial plant, the harmonic amplification caused by resonance with feeder banks is often small. Engineers in charge of utility distribution are used to locating feeder banks without thinking about harmonics. However, in a rare instances, voltage distortion caused by feeder bank resonance may exceed limitations and call for mitigation. When issues do arise, the typical approach is to move the problematic bank, alter the capacitor's size, or adjust the neutral connection as a first step toward a resolution.

Increased triplen harmonics in the feeder's neutral circuit are the cause of certain harmonic issues with feeder capacitor banks. Changes are made to the neutral connection of wye-connected banks to alter the flow of zero-sequence harmonic currents. The neutral is allowed to float in order to stop the flow. In certain circumstances, it is preferable to facilitate the flow by inserting a reactor in the neutral to transform the bank into a tuned resonant shunt for a zero-sequence harmonic. On distribution feeders, harmonic issues often only appear at low loads. There is less load to dampen out resonance as the voltage increases, forcing the distribution transformers to produce higher harmonic currents. This is a common moment to turn off the capacitors to remedy the issue.

The fundamental concept is to spread a few filters nearer the feeder's ends should harmonic currents from far separated sources need to be filtered on distribution feeders. Although it is not done often, more feeder filters are being installed. a distribution feeder equipped with a filter as an example. As a result, the average route of the harmonic currents is shortened, which lowers the likelihood of telephone interference and the harmonic voltage drop in the lines. With regard to at least one harmonic component, the filters seem to be almost a short circuit. As a result, there is little voltage distortion on the feeder. It is harder for the voltage distortion to exceed restrictions elsewhere when the ends of the feeder are "nailed down" by filters with regard to the voltage distortion. Large capacitor banks should always be put in distribution substations after conducting harmonic flow analyses. At this stage of the system, it is impossible to rely on system losses to completely eliminate resonance, and resonance amplification may be quite damaging.

DISCUSSION

In End-User Facilities

Determine if resonance with the facility's power factor capacitors is the primary source of harmonic issues when they occur in an end-user facility. When it is, try a simple fix by switching the size of the capacitor first. It could be conceivable to use a control strategy using automated power factor controllers to stay away from the problematic setup. In some situations, it won't be able to prevent persistent circumstances due to the sheer number of capacitors being randomly swapped with loads. It will be essential to filter[6].

Filter installation is often more practicable and cost-effective on end-user low-voltage systems than on utility distribution systems. Both the requirements for filter installation and the accessibility of filtering equipment on the market have improved. Industrial users can also look at ways to reduce harmonic currents by employing various transformer connections and line chokes when the amount of harmonic currents injected by loads is excessive. Zigzag transformers and triplen harmonic filters may lessen the effect of triplen harmonic currents on neutral circuits in office buildings. All capacitors put on the main bus of industrial systems should be the subject of studies. There are not enough line losses here to prevent resonance. As a consequence, the voltage distortion that results when resonance occurs at a harmonic frequency that plays a significant role in the load current is often severe.

When capacitors are positioned outside on the factory floor, on motors and in motor control centers, resonance issues are often less severe. Comparing this to merely mounting the capacitor on the main bus has the added advantage of lowering system losses. Of course, owing to the various installations needed, this method may be more expensive than using a single capacitor on the main line. In order to attenuate the resonance, the cables must be long enough to inject adequate resistance into the circuit. It may not be possible to provide a large harmonic reduction advantage in plants with short connections.

Harmonic Research

Harmonic studies are crucial for defining and comprehending the scope of harmonic issues. Harmonic investigations are often carried out when.

1. Finding a fix for a current harmonic issue
2. Putting in massive capacitor banks for industrial power systems or utility distribution systems
3. Putting in massive nonlinear loads or devices
4. The creation of a harmonic filter
5. Transforming a capacitor bank for power factor into a harmonic filter

Before adopting a final solution, harmonic studies provide a way to assess multiple potential solutions and their efficacy under diverse settings. Methods for conducting harmonic investigations are described in this section.

Harmonic Research Methodology

An overview of the optimum method for conducting a power systems harmonics investigation is provided below:

This is crucial to the ongoing inquiry. For instance, figuring out what is causing a current issue and fixing it can be the goal. Another may be to assess the likelihood of issues with a new plant expansion that includes components such adjus-speed drives and capacitors. Create a premeasurement computer simulation based on the best knowledge available if the system is complicated. Measurements are costly in terms of manpower, equipment, and potential plant operations disturbance. Before starting the measures, it will often be more cost-effective to have a strong notion of what to look for and where to search.

1. Measure the present harmonic circumstances, identifying the harmonic current's source and the system bus' voltage distortion.
2. Utilize the measurements to calibrate the computer model.
3. Examine the current issue or the state of the new circuit.
4. Create solutions and look at any potential negative system interactions. Check the findings' sensitivity to significant factors as well.
5. Monitor the system after installing the suggested fixes to ensure it is running properly.

To be honest, it's not always feasible to carry out each of these stages exactly. Due to the expense of engineering time, travel, and equipment costs, one or both measurement phases are the procedures that are most often skipped. However, it is highly advised that the first measurements be done if at all feasible since there are several nasty surprises hiding in the shadows of harmonics analysis. An expert analyst may be able to address a problem without measurements.

The creation of a system model

When developing a system model for harmonic simulation research, two key problems must be taken into account. The size of the system model to be included in the simulation is the first problem. Second, one must choose whether to describe the model as a complete three-phase model or as a single-phase equivalent.

Consider a utility that wants to assess the frequency response linked to the installation of a large capacitor bank on a distribution feeder as an example of model extent. It is often impractical to represent the complete distribution system since doing so would need a lot of time for model development and processing power to perform simulations. Starting with a model that is one or two buses away from the bus of interest and include everything in between is one strategy. Another strategy would be to begin with a tiny, simple circuit that properly captures the phenomenon before adding additional system information to assess the influence on the outcome of the solution. The physical system is appropriately represented by the simulation model when adding more system details does not alter the analytical findings.

It is often adequate to represent the upstream transmission system with a short-circuit equivalent at the high-voltage side of the substation transformer when modeling distribution systems for harmonic research. For many investigations, the transmission and distribution are effectively isolated because the transformer's leakage impedance outweighs the short-circuit equivalent. However, a portion of the transmission system must be modeled to incorporate the capacitor bank if one is present close to the high-voltage side of the transformer. From the low-voltage side of the transformer, the combination of the transformer and the capacitor bank may act as a filter for a certain frequency. Feeder lines, capacitor banks, critical service transformers, and end-user capacitor banks are examples of distribution system components that are located after the substation transformer. It is common practice to disregard the capacitance from overhead feeder wires since the feeder capacitor banks predominate the system capacitance. However, cable capacitance should be reflected if there is a significant piece of UD cable, particularly if the investigation is focused on higher-order harmonics. Next, the analyst must choose whether to describe the model as a full three-phase model or as a single-phase equivalent. Comparatively to a three-phase model, a single-phase equivalent model is often easier and less challenging to create. Analyzing imbalanced events or systems with several single-phase loads, however, is sometimes insufficient.

For many three-phase industrial loads, there is a rule that allows for the simpler positive- series modeling. It is simple to determine how the system will react to positive-sequence harmonics since utility and industrial power engineers are both held accountable for doing such modeling in their load flow and voltage drop calculations. The rule may be expressed as follows: Only the positive-sequence circuit has to be represented in order to calculate the system reaction when there is a delta winding in a transformer located anywhere in series with the harmonic source and the power system. Zero-sequence harmonics are not possible since they are blocked. In general, it is believed that the positive and negative sequence networks react to harmonics similarly. Triplen harmonics may sometimes be seen in measurements upstream of a delta winding. Typically, the zero sequence of these harmonics is assumed. Depending on the other sources in the system, they could be. However, they may also result from imbalanced harmonic sources. An arc furnace is one such instance. The delta winding only blocks triplens that are in phase and are in zero sequence. As a result, triplen harmonics are often taken into account while undertaking analysis using a positive-sequence model.

When assessing four-wire utility distribution feeders with several single-phase loads, the symmetrical component approach is unable to provide a benefit. Networks with both positive and zero sequences are used. Manual system analysis is often impractical, and the majority of computer programs that are capable of effectively simulating complex systems simply build up the linked three-phase equations and solve them immediately. Fortunately, there are now several computer tools that make creating a three-phase model virtually as simple as creating a single-phase equivalent. Because the sequence networks would also need to be connected, the whole three-phase model can be solved in the same amount of time as the sequence networks. The symmetrical component strategy not only fails to provide a benefit in this instance, but analysts often commit mistakes and unintentionally break the assumptions of the method. Harmonic analysis of unbalanced circuits employing symmetrical components is typically not advised. Only those who are completely certain in their comprehension of the approach and its underlying premises should try it.

Harmonic Source Modeling

The majority of power system harmonic flow analysis is carried out utilizing steady-state, linear circuit solution methods. Nonlinear components known as harmonic sources are often thought of as injection sources for linear network models. They may be depicted as voltage or current injection sources. It is Sui to approach harmonic sources as straightforward sources of harmonic currents for the majority of harmonic flow research. When a current source is used in lieu of an electronic power converter in the corresponding circuit. Less than 5% of the time, the voltage distortion at the service bus is typically considered to be minimal. As a result, the current distortion for many nonlinear devices is essentially constant and unaffected by supply system distortion.

Simple Diagram

Measurements should be used to ascertain the values of the injected current. It is typical to presume that the harmonic content is inversely related to the harmonic number in the absence of observations and published data. In other words, the fundamental current makes up 20% of the fifth-harmonic current, etc. The basis for many nonlinear devices, the Fourier series for a square wave, is where this is generated. But because of their considerably larger harmonic content, modern technologies like PWM drives and switch-mode power supply, it does not really apply to them. 6.3 displays common values to use while analyzing various device kinds.

A straightforward current source model would predict voltage distortion with an extremely high accuracy when the system is close to resonance. The model attempts to continuously inject current into a system with a high impedance, which is an invalid approximation of reality. When there is significant voltage distortion, the harmonic current will not stay constant. Most of the time, this is irrelevant since it is obvious from the simple model that the system cannot be efficiently controlled in resonance. The model will provide a reasonable response after the resonance has been removed, maybe by adding a filter.

A more complex model must be utilized in situations when a more precise response is needed under real-world circumstances. A Thevenin or Norton equivalent is sufficient for the majority of power system equipment. The added impedance modifies the parallel resonant circuit's response. For many nonlinear loads, a Thevenin equivalent may be found in a simple method. For instance, a square-wave voltage with a peak magnitude that is around 50% of the nominal ac system voltage is a good representation of an arc furnace. The furnace transformer and leads' short-circuit impedance is the only source of the series impedance. For many nonlinear devices, it is unfortunately impossible to determine precise equivalent impedances. In these situations, a thorough modeling of the harmonic-producing load's internals is required. A thorough time-domain study or iterative computer algorithms may be used to accomplish this. Fortunately, obtaining such high precision during resonance is seldom necessary, therefore analysts rarely need to take these precautions. Regardless of requirement, it is advised to model arcing devices using a Thevenin model.

Computer programs for analyzing harmonics

The reader now has a better understanding of the kinds of tasks required for power system harmonics analysis thanks to the discussion that came before it. It should be quite evident that a sophisticated computer program is needed for circuits other than the simplest of circuits. These programs' characteristics and the history of various well-known analytical tools are explained.One circuit that usually arises in simple industrial systems may be calculated manually, it should be highlighted from the outset. Essentially, it is a one-bus circuit with a single capacitor. Two tasks are doable rather quickly. Discover the resonance frequency. Either the capacitor has to be replaced or a filter needs to be constructed if the resonant frequency is close to a potentially harmful harmonic.

Compatible Circuit

Unfortunately, such a simple circuit cannot reflect all real-world scenarios. In fact, even the most experienced analysts would find the issue challenging after adding only one extra bus with a capacitor to the straightforward circuit. However, a machine can do the task in a matter of milliseconds. The analyst must define the circuit configuration, loads, and sources for the program in order to utilize the generally used computer tools. Information that must be gathered includes

1. Impedances of lines and transformers
2. Connectors for transformers
3. Values and placements of capacitors
4. Spectra of harmonics for nonlinear loads
5. Voltages at power sources

When these numbers are input into the application, it automatically corrects impedances for frequency and calculates the system's harmonic flow. capabilities for programs that analyze harmonics. Acceptable computer software for power systems harmonics analysis should have the following qualities:

1. It must be able to manage big networks with at least a few hundred nodes.
2. It must to be able to manage multiphase models with any kind of structure. Not all circuits can be accurately solved by balanced, positive-sequence models, especially those on utility distribution feeders.
3. It need to have the ability to model systems using positive-sequence models. There is no need to construct a complete three-phase model when there cannot be zero-sequence harmonics.
4. To build the system frequency-response characteristics required to locate resonances, it should be able to conduct a frequency scan at low frequency intervals.
5. It should be able to assess the real current and voltage distortion by performing simultaneous solution of various harmonic sources.
6. It need to include internal models of typical harmonic sources.
7. It should be possible to represent harmonic sources as both current and voltage sources.
8. Based on the phase angles of the basic frequencies, it should be able to automatically change the phase angles of the sources.
9. It need to have the ability to simulate any transformer connection.
10. The findings should be presented in a clear and user-friendly way.

Computer-Based Harmonic Analysis: A Historical Viewpoint

Power flow calculations are now the most prevalent sort of computer study of power systems. The majority of power engineers have some knowledge of this kind of equipment. Short-circuit programs and, at least for mission-critical systems, dynamics programs are further typical computer techniques. Due to the complexity of the modeling, harmonics and electromagnetic transients' tools have always been the purview of professionals. Even while power flow analysis tools are common, their formulation is often inappropriate for harmonics analysis. The circuit model used in short-circuit programs is the most similar to the one required for harmonic flow analysis in networks of the tools that are often used. In reality, many analysts would utilize short-circuit programs to calculate harmonic distortion in the past, manually modifying the impedances for frequency. This was before the development of specialized power systems harmonic analysis tools. Although the practitioner won't want to repeat this experience often, it is an intriguing learning opportunity for the learner. Of course, employing electromagnetic transients' programs to do the study in the time domain is also an option, but this method is often too time-consuming and complex for most issues.

Today, the majority of power system harmonics analysis is carried out using computer programs created specifically for the task in the sinusoidal steady state. Although the primary application in the package may be a power flow tool, it is good to note that many suppliers of power system analysis software are include some harmonics analysis capabilities in their packages. Understanding how something has changed is helpful. Few of the developers have produced technical publications describing their work, in contrast to power flow algorithms. As a result, it is challenging to track the development of harmonics analysis in power systems via the written word. As we recognize the achievements of numerous of the industry's pioneers in this book, the reader will better comprehend the background of some of the most important computer technologies in use today.

Power systems harmonic studies were typically carried out using analog simulators, such as a transient network analyzer, before computers were widely used for harmonics analysis. Midway through the 1970s, there weren't many TNAs in the United States; they were mostly found at big equipment producers like General Electric Co., Westinghouse Electric, and McGraw-Edison Power Systems. Harmonic studies were often only carried out on extremely unusual circumstances, such as big arc furnace installations that might affect utility transmission networks, due to the inconvenience and expensive expense. At least two variable-frequency sources were often present in TNAs. As a result, the standard practice was to utilize one source to represent the nonlinear load and a second source to represent the power frequency. The challenging element of this process was to sweep the frequency across the system resonances quickly enough to prevent harming the inductors, capacitors, and power supply. We became involved in harmonics analysis in 1975 when author Dugan, who was working at McGraw-Edison at the time, built the first electronic arc model for a TNA to do away with the second source.4 In the same year, Dugan collaborated with William and Dr. Sarosh N. Talukdar in order to get over the restrictions of harmonic analysis through analog simulator. The Virginia Electric Power Company's Frequency Response Analysis Program was created to evaluate the effects of installing 220-kV capacitor banks on the transmission system. At this voltage level, they were some of the first capacitors used.

The NFRAP program approaches, which treat nonlinearities as sources and use direct nodal admittance matrix solution techniques, have developed into what is perhaps the most widely used family of harmonic analysis programs. EPRI funded a study on harmonics on utility distribution feeders from 1977 to 1979.5,6 The Distribution Feeder Harmonics Analysis program is one of the results of this study. It was the first software created especially for evaluating harmonics on imbalanced distribution systems, and it included detailed models of the components of power systems to aid in model development. It ended up serving as the model for the current harmonic analysis software. Robert E. Owen and the project's creator, McGranaghan, served as the project's principal investigators, while Dugan and Sponsler once again served as the project's principal software designers. The McGraw-Edison Harmonic Analysis Program, developed between 1980 and 1984, was the next generation of software tool based on the NFRAP program approach. It was unique in that it was interactive with graphical output and was built in Fortran for minicomputers. Prior attempts had all used batch-mode programs that produced tabular data. It was user-friendly in the traditional sense at the time. The creators comprised Dugan, Jack, and McGranaghan[7]–[9].

CONCLUSION

In summary,the technique of eliminating or lowering harmonic components from the electrical power supply is referred to as harmonic filtering. Passive, active, and hybrid filters are just a few of the numerous kinds of filters that may be chosen depending on a number of variables.

Harmonics must be properly filtered in order for electrical power systems to operate safely, reliably, and in accordance with all applicable standards and laws. Harmonics must be properly filtered in order for electrical power systems to operate safely, reliably, and in accordance with all applicable standards and laws. It may result in higher energy efficiency, less losses, and better equipment performance.

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CHAPTER 15

DEVICES FOR CONTROLLING HARMONIC DISTORTION

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ABSTRACT:

Devices for controlling harmonic distortion are used in electrical power systems to reduce the effects of harmonic distortion caused by non-linear loads. Harmonic distortion is a common problem in electrical systems, caused by non-linear loads that draw current in a non-sinusoidal manner. These distortions can lead to issues such as equipment damage, overheating, and interference with communication and control systems. There are several types of devices used for controlling harmonic distortion in electrical power systems, including passive filters, active filters, and harmonic suppression transformers. Passive filters use passive components such as resistors, capacitors, and inductors to attenuate harmonic currents, while active filters use electronic circuits to actively cancel out harmonic currents. Harmonic suppression transformers are designed to isolate the harmonic-producing load from the power source, reducing the level of harmonic distortion.

KEYWORDS:

Active Filter, Distortion, Harmonic, Mitigation, Harmonic Reduction.

INTRODUCTION

To reduce harmonic distortion, a variety of tools are available. They might be complex as an active filter or as simple as a capacitor bank or line reactor.A simple mitigation measure like moving, resizing, or adding a shunt capacitor bank may successfully alter a poor system frequency response and reduce harmonic distortion to an acceptable level. Similar results may be achieved by a reactor by detuning the system from dangerous resonances. Prior to adopting a more sophisticated device, it is important to investigate the efficacy of such simple techniques for controlling harmonic distortion[1], [2]. The first section of the text examines how well a simple in-line reactor, or choke, can reduce harmonic distortion. The discussion of passive and active harmonic filters, two broad kinds of harmonic filters, follows. While the latter are based on power electronic devices, the earlier are based on passive components.

Chops or in-line Reactors

A relatively modest resistor, or choke, is added at the line input side of the drive as a simple yet often effective approach to reduce harmonic distortion produced by adjustable-speed drives. Particularly useful for drives of the PWM kind. The inductance makes the drive draw current over a longer length of time because it reduces the pace at which the capacitor on the dc bus can be charged. The end result is an energy-equal current of lower amplitude and much reduced harmonic content. For a PWM-type drive, a standard 3 percent input choke may cut the harmonic current distortion from 80 to 40 percent. In 6.8, this striking harmonic decrease is seen. Once the choke size has been raised by more than 3 percent, there is not much further harmonic reduction possible. Based on the driving kVA basis, the choke size is calculated. Examines how well a 3 percent choke reduces harmonic current distortion as compared to no choke, for different ASD sizes. The following waveforms are examples for either end of the range[3]. The choke is absent from the broader waveform. As can be seen from 6.10, adding a choke to the ASD line results in a significant improvement. The present THD decreases from a range of 80 to 120 percent to around 40 percent. When the ASD is substantially smaller than the service transformer, the decrease is better. The present THD decreases from 125 to 40 percent when the ASD is 5 percent of the transformer's size. It's also vital to remember that the choke has additional benefits in ASD applications[4], [5]. The choke is highly effective in blocking some high-frequency transients due to the impact of slowing the dc capacitor charging rate. This reduces the likelihood of annoying drive tripping when the utility system is energizing capacitors. Although they could be more expensive, isolation transformers can provide the same advantage as a choke. But isolation transformers with several drives have the benefit of producing a 12-pulse operation that works. One drive may be supplied by a delta-wye connected transformer, and another drive can be supplied using a delta-delta connected transformer to provide a 12-pulse setup.

Zipping Transformers

Commercial facilities often use zigzag transformers to control zero-sequence harmonic components. A zigzag transformer provides a low-impedance route to neutral, acting as a filter to the zero-sequence current. By giving the current a shorter route, this lowers the amount of current that flows in the neutral back toward the supply. The transformer has to be situated close to the load on the circuit that is being protected in order to function properly. Transformer heating and overloaded neutral conductors are the two main issues in commercial buildings. It is possible to resolve both of these issues by placing zigzag transformers correctly. To avoid transformer overheating, several recently constructed commercial structures use zigzag transformers on the 480/208-V supply transformer secondaries. Neutral wires feeding the loads are not benefited by a zigzag transformer placed at the supply transformer secondary.

A zigzag transformer may shunt around 50% of the third-harmonic current away from the neutral conductors of the main circuit, according to typical findings. As a result, the zigzag transformer can nearly always achieve accep levels of neutral current reduction caused by zero-sequence harmonics. In office buildings with plenty of computers and associated equipment, the third harmonic will almost invariably be the biggest zero-sequence harmonic. If there is a handy location to situate the transformer between the problematic neutral circuit and the real loads, zigzag transformers are a great option for existing facilities where neutral conductor issues and potential transformer heating are worries. It may be preferable to simply construct the circuits in new facilities with enough current carrying capacity in the neutrals and larger capacity transformers.

DISCUSSION

Passive Filters

Inductance, capacitance, and resistance components are adjusted and set to control harmonics in passive filters. They are often used and reasonably priced when compared to other methods of eliminating harmonic distortion. They might, however, interact negatively with the power system, therefore it is crucial to consider all potential system interactions while designing them.

By setting the components to produce a resonance at a certain frequency, they are used to either shunt the harmonic currents off the line or to stop their passage amongst system components. passive shunt filters. The single-tuned "notch" filter is the most popular kind of passive filter. This kind is the most affordable and often meets the needs of the application. The notch filter is connected in shunt with the power supply and is series-tuned to provide a low impedance to a certain harmonic current. As a result, harmonic currents on the line that pass through the filter are diverted from their usual flow route.

In addition to harmonic suppression, notched filters may also offer power factor adjustment. In reality, notch filters may be created using power factor correction capacitors. Any major harmonic or other frequency component that the load could create must be securely far from this resonance frequency. In order to give a margin of safety in the event that any change in system characteristics might cause the notch frequency to increase, filters are often set slightly lower than the harmonic to be filtered. Fluctuations in capacitance or inductance due to temperature fluctuations or failure may cause the parallel resonance to move higher into the harmonic that is being filtered if they were precisely tuned to the harmonic. The fact that the resolution is often fairly crisp suggests that this could provide a condition that is worse than one without a filter. Filters are added to the system beginning with the lowest significant harmonic to prevent issues with this resonance. For instance, installing a seventh-harmonic filter often necessitates the installation of a fifth-harmonic filter as well. With a seventh-harmonic filter alone, the new parallel resonance is often quite close to the fifth, which is usually fatal.

Because the capacitor is delta-connected, the filter arrangement prevents the admission of zero-sequence currents, rendering it ineffective for filtering zero-sequence triplen harmonics. When it becomes required to manage zero-sequence third harmonic currents in many industrial and commercial building facilities, other methods must be used since 480-V capacitors are often delta-configured. On utility distribution systems, however, capacitors are more often wye-connected. By adjusting the neutral connection, it is possible to modify the triplen harmonics of the zero-sequence. It is standard practice to compel a capacitor's bank to filter only zero-sequence harmonics by inserting a reactor in the neutral. This method is often used to get rid of telephone interference. The tap is modified to reduce the telephone and a tapped reactor is inserted in the neutral. On a bus where it is anticipated that the short-circuit reactance XSC would stay constant, passive filters should always be installed. The parallel resonance will change with system impedance while the notch frequency stays constant. For instance, since the generator impedance is far larger than the utility impedance, the parallel resonance frequency for running with standby generation alone is likely to be substantially lower than when linked to the utility. This could make a little harmonic seem more important. As a result, filters are often deleted while using standby generation.

Additionally, filters need to be made with the bus's capacity in mind. The temptation is to just consider the load that is causing the harmonic when sizing the current-carrying capacity. On the other hand, a very powerful bus with a little bit of background voltage distortion could force the filter to work too hard. A series passive filter is connected in series with the load, as opposed to a notch filter, which is linked in shunt with the power supply. At a certain harmonic frequency, the inductance and capacitance are set to give a high impedance via a parallel connection. The high impedance subsequently prevents harmonic currents from flowing outside of the tuned frequency. The filter would be made to have a low impedance at fundamental frequency, enabling the fundamental current to follow with very little extra resistance and losses.

When using a single-phase circuit, where it is not feasible to take advantage of zero-sequence characteristics, series filters are employed to block a single harmonic current. The ability of the series filters to prevent numerous harmonic currents is restricted. A series filter set to that harmonic is necessary for every harmonic current. The fundamental frequency may suffer severe losses as a result of this configuration. A series filter must also have an overcurrent safety mechanism and be designed to handle the entire rated load current, much like other series components in power systems. Series filters are thus used far less often than shunt filters.

A Passive Series Filter

In real applications, many stages of both series and shunt filters are often needed. For instance, in shunt filter applications, the seventh-harmonic filter itself and the lower fifth-harmonic filter are often required as the two stages of the shunt filter. Similar to this, numerous levels of filters are required to block different frequencies in series filter applications since each frequency needs its own series filter. Harmonics may manifest not only in a single frequency but also throughout a broad spectrum of frequencies in a variety of power system circumstances. A six-pulse converter produces typical harmonics of the fifth, seventh, eleventh, thirteenth, etc. In essence, electronic power converters may generate time-varying interharmonics with a broad frequency range. It would be exceedingly challenging to use shunt filters to design a series or shunt filter to minimize or remove these widely dispersed and time-varying harmonics. As a result, a different harmonic filter has to be developed.

A low-pass broadband filter is the perfect tool for preventing numerous or common harmonic frequencies. However, current with frequency components above the cutoff frequency is filtered out. Current with frequency components below the filter cutoff frequency may pass. It is referred to as a low-pass broadband filter because this kind of low-pass filter is often created to attain a low cutoff frequency. Installing a capacitor bank on a transformer's low-voltage side will provide distribution system applications the effect of low-pass broadband filters. When taken into account together with the transformer leakage inductance and the system impedance, the size of the capacitor bank would need to be chosen in such a way as to produce the necessary cutoff frequency. The high-voltage side of the transformer may then be protected against harmonics over the cutoff frequency. The size of the capacitor bank may be relatively big since the cutoff frequency might sometimes be extremely low. There will be a noticeable voltage increase as a consequence. If the voltage doesn't drop to an acceptable level, a voltage regulator or transformer load tap changer has to be utilized.

To isolate the area of the system vulnerable to high voltage at a substation that serves numerous feeders, a line reactor and voltage regulator might be put at the feeder's start. This design will make it possible to maintain normal voltage levels at other feeds. The required cut-off frequency is produced by combining the transformer leakage inductance, the line rectifier, the voltage regulator, and the capacitor bank. Commercial low-pass broadband filters have been utilized in industrial system applications to block harmonics created by nonlinear loads from entering the ac system. The setup shows the usual design. A buck transformer is required to lower the voltage at the line reactor output to a point where the voltage at the capacitor is enough since the presence of the capacitor bank raises the voltage at the ASD's input. When there is no series inductor between the filter capacitor banks and the ASD dc bus capaci- tor, the low-pass broadband filter performs at its best in ASD applications. Since the dc bus capacitor receives its charge from the filter capacitor, any impedance in the middle diminishes its charging capacity.

A low harmonic frequency, such as 100 to 200 Hz on a 60-Hz system, is often used as the cutoff frequency for a low-pass broadband filter for ASD applications. With such a low tuning frequency, the filter can effectively filter out most harmonic currents and is less likely to cause any unintended resonances with the rest of the system. Under rated load circumstances, the filter can often decrease the total current harmonic distortion in ASD applications from the 90 to 100% range down to the 9 to 12% range. This performance is unquestionably far better than a straightforward ac line choke, which only brings down the total current distortion to the region of 30 to 40%. An ac line choke, however, is less expensive than a low-pass broad-band filter. In industrial and utility systems, C filters are an alternative to low-pass broadband filters for concurrently decreasing various harmonic frequencies. Numerous steady-state and time-varying harmonic and interharmonic frequencies produced by electronic converters, induction furnaces, cycloconverters, and similar devices may be attenuated by them. A C filter's impedance frequency response is also quite similar to a second-order high-pass filter's. The reactance of Ca is minimal at high-order harmonic frequencies whereas that of Lm is significant. As a result, the reactance of Lm dominates the impedance of the series Lm and Ca branch. The C filter and second-order high-pass filters both have comparable high-frequency responses.

Current Filters

The use of active filters to get rid of harmonics is relatively recent. They are far more costly than passive filters and are built on sophisticated power electronics. They do not resonate with the system, which is a distinctive benefit. The features of the system impedance may be ignored using active filters. They may thus be employed in very challenging situations where passive filters cannot function effectively due to parallel resonance issues. They can also deal with many harmonics at once and solve other power quality issues like flicker. They are especially helpful for heavy loads that cause distortion when they are supplied from relatively weak spots in the power grid.

The essential concept is to substitute the missing since wave in the current flowing through a nonlinear load. It is the concept. In order to track the load current or voltage and make it sinusoidal, an electronic control constantly checks the line voltage and/or current. As, there are two fundamental strategies: one utilizes a capacitor to store current that will be injected into the system at the proper moment, and the other employs an inductor to store current. As a result, even if the nonlinear load requires a certain amount of load current distortion, the current seen by the system is considerably more sinusoidal. Usually, active filters may be set to compensate for both harmonics and power factor[6], [7].

The instructions go into great depth about filter design techniques. The use of examples is the most effective method of explaining the design processes. For use at a 480-V bus in an industrial facility, a single-tuned notch filter will be created. The load where the filter will be put has a relatively low displacement power factor of 0.75 lagging and is around 1200 kVA. This load generates a maximum fifth harmonic of 25% and a total harmonic current that is around 30% of the fundamental current. A 1500 kVA transformer with a 6.0 percent impedance supplies the building. When there is no load, the utility side of the transformer's fifth-harmonic background voltage distortion is 1.0 percent of the fundamental. The next stages provide the harmonic design processes.

The filter's tuned frequency should be chosen. The harmonic properties of the relevant loads are used to choose the tuned frequency. A single-tuned filter's inherent characteristics dictate that filtering should begin at the load's lowest harmonic frequency. That will be the fifth harmonic in this situation. To account for tolerances in the filter's component parts and variances in the system's impedance, the filter will be slightly adjusted to the problematic harmonic frequency. This lessens the load on the filter's components by preventing the filter from acting as a direct short circuit for the objectionable harmonic current. Additionally, it reduces the likelihood of harmful harmonic resonance in the event that the system's characteristics alter and the tuning frequency shifts. Calculate the resonance frequency and the size of the capacitor bank. The filter size is typically determined by the load reactive power needed for power factor adjustment. The capacitor size is provided when an existing power factor correction capacitor is changed to a harmonic filter. The capacitor is then tuned to the appropriate frequency by choosing the reactor size. To accommodate the voltage increase across the reactor, the voltage rating of the capacitor bank may need to be greater than the system voltage, depending on the tuned frequency. So, replacing the capacitor may be necessary in any case.

Analyses of transformer derating and neutral loads

A data center's load is mostly made up of networking hardware and hundreds of single-phase servers. In low-voltage circuits, the phase currents exhibit harmonic properties. The neutral conductor may be overloaded because these loads are highly concentrated in the third harmonic. Calculating the neutral conductor loading in amps and as a percentage of the maximum phase current is the difficulty. Additionally, assuming an eddy-current loss factor of 8% under rated load PEC-R, the amount by which the transformer providing this load must be derated needs to be determined.

1. Neutral conductors that are distinct for each phase
2. Size of a double neutral conductor
3. Zigzag transformer near the loads to minimize the third-harmonic currents' return route and unload the overloaded neutral
4. In the transformer's neutral circuit, there is a series filter set to the third harmonic.

Induction Furnaces' Harmonic Interference

Residential clients in a large region reported that their clocks were ticking more quickly at about the same time each weekday. This was the main sign of the issue. Other timekeeping devices also acted strangely. The clocks that had the issue measure time by looking for voltage waveform zero crossings. A half cycle of the fundamental frequency of the power system is the amount of time between two consecutive zero crossings. These clocks are particularly precise because the frequency inaccuracy of the power supply is very small over very long times.

Fast-clock phenomena happen when the voltage waveform exhibits high-frequency distortion, causing more zero crossings than anticipated in a half cycle. The basic frequency signal is overlaid with a saw-tooth or sinusoid to represent the high-frequency signal. a typical voltage waveform that was measured on the client's property. There will undoubtedly be cases when multiple zero crossings occur inside a half cycle. The 29th and 35th harmonics are where the high-frequency distortion occurs. An induction furnace at a steel-grinding mill generated these frequencies, according to further investigation. Many kilometers distant home consumers were impacted by the distortion. According to the facility's one-line schematic, the same 46-kV distribution system fed both the grinding mill and residential consumers.The two induction furnaces' working frequency vary from 800 to 1000 Hz depending on the quantity and kind of material being melted. These furnaces' harmonic properties were characterized. Due to the fact that they are not integer multiples of the fundamental frequency, these currents are interharmonic currents. The first pair is more noticeable in the voltage since it is the strongest interharmonic component. The first pair of the resultant interharmonic current fluctuates between 1540 and 2060 Hz since the furnace's operating frequency ranges between 800 and 1000 Hz. Passive shunt filters cannot be used due to the variable harmonic distortion. The 46/12.47 kV transformer's high-voltage side held the PCC for this plant. On top of the fundamental frequency waveform, the voltage waveform at the PCC in Figure 6.30 clearly demonstrates high-frequency distortion.

A frequency scan of the system was done from the PCC's perspective in order to determine why the distortion was present across the whole 46-kV system. Impedance characteristic as a consequence is in 6.31. According to the results of the scan, the prominent resonance frequency was about around the 34th harmonic. The distortion will increase if the frequency components produced by a nonlinear load coincide with the natural frequency of the system. This is precisely what took place in this issue. The induction furnaces generated interharmonic frequencies between the 25th and 34th harmonics, with the system natural frequency at the higher end of this range. Therefore, finding voltage distortion over a large region was not unexpected. Single-tuned shunt filter solutions would not be effective since the high-frequency distortion changed over time and was amplified by the system frequency response. There were two potential filtering approaches:

1. Adjusting the frequency response at the 46-kV bus such that the natural frequency was offset from the harmonic frequencies of the induction furnace
2. The installation of a broadband filter at the facility's main bus to block the entry of disrupted currents to the 46-kV system.

A 46-kV capacitor bank must be carefully chosen for the first strategy. Any resonance that corresponds to a harmonic created by the nonlinear loads shouldn't be present in the new frequency response. According to simulations, a capacitor bank of around 3 Mvar would be needed to reduce the inherent frequency of the current system from the 35th harmonic to the 8th harmonic. Since there are no known nonlinear loads that produce harmonic currents of this order, the eighth harmonic was chosen. This was a workable approach, but adding a 3-Mvar capacitor bank would often be overcompensating. Additionally, there is a higher chance of difficulties with the fifth and seventh harmonics if the goal tuning lowers the eighth harmonic owing to line interruptions that would weaken the system.

For the second method, a device is needed to keep high-frequency interharmonics out of the 46-kV system. Multiple levels of single-tuned shunt filter banks would not function effectively, as indicated in the first technique, since the interharmonics are variable. The issue might be resolved by active filters, but they are pricey. A low-pass broadband filter similar to the one described in Sec. 6.5 would be a more environmentally friendly approach. Additionally, the short-circuit impedance may be more precisely controlled at the filter position. 6.32 provides an illustration of the answer. With this method, it is simple to attenuate frequencies above the 30th harmonic. Finding a capacitor size that won't cause a resonance with other furnace-produced harmonic frequencies, notably the 5th, 7th, 11th, and 13th, is the challenge. Once again, the eighth harmonic was picked as the tuning frequency to aim towards. The fourth harmonic could be the next-best frequency, but the increased voltage that would come from a bigger capacitor bank would necessitate the addition of a voltage regulator to buck the voltage down. This would greatly increase the cost of the solution.

A common 1200-kvar bank rated at 13.2 kV was found to be an acceptable option via simulation. The tune is shifted slightly higher when a higher-rated capacitor is used, which results in less seventh harmonic magnification. 1 A of current is flowing in the PCC's direction. The high-frequency interharmonic currents are significantly attenuated and are not allowed to enter the transformer into the 46-kV system above the 30th harmonic[8].

CONCLUSION

In summary,Electrical power systems use harmonic distortion-controlling devices to lessen the effects of harmonic distortion brought on by non-linear loads. Devices may be chosen from a variety of categories, including passive filters, active filters, and harmonic suppression transformers, depending on a number of variables. Harmonic distortion must be properly controlled in order for electrical power systems to operate safely and reliably and to adhere to all applicable standards and laws. Harmonic distortion must be properly controlled in order for electrical power systems to operate safely and reliably and to adhere to all applicable standards and laws. It may result in higher energy efficiency, less losses, and better equipment performance.

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CHAPTER 16

A BRIEF DISCUSSION ON STANDARDS ON HARMONICS

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ABSTRACT:

Standards on harmonics refer to the guidelines and regulations that are set by various organizations to ensure the safe and efficient operation of electrical power systems. Harmonic distortion is a common problem in electrical systems, caused by non-linear loads that draw current in a non-sinusoidal manner. These distortions can lead to issues such as equipment damage, overheating, and interference with communication and control systems. Several organizations have developed standards on harmonics, including the Institute of Electrical and Electronics Engineers (IEEE), and the National Electrical Manufacturers Association (NEMA). These standards provide guidelines on the acceptable levels of harmonic distortion, the measurement and analysis of harmonics, and the design and selection of equipment to mitigate the effects of harmonics.

KEYWORDS:

Distortion, Energy, Harmonics, Power Quality, Power Factor.

INTRODUCTION

To develop standards defining guidelines, suggested practices, and harmonic limitations, several organizations at the national and international levels collaborate with engineers, equipment makers, and research institutions. The main goal of the standards is to provide all parties concerned a place to collaborate and guarantee that the system equipment is used in harmony with end-use equipment. The system produces a voltage that is distorted and has harmonics between the 30th and 35th, and the end-use equipment is a clock with voltage zero-crossing detecting technology. This incompatibility results in improper functioning of the end-use device[1], [2]. On the basis of IEEE Standard 519-1992, the harmonic voltage and current restrictions are defined. It should be emphasized that the philosophy underlying this standard aims to both limit the overall harmonic distortion in the utility's supplied voltage as well as the harmonic injection from individual customers so that they do not produce unacceptably high voltage distortion under typical system characteristics.

For the worst-case scenario of typical operating circumstances lasting more than one hour, the voltage and current distortion limitations should be utilized as the system design values. The restrictions may be 50% surpassed during shorter times, such as start-ups. With this standard, the utility and end users share responsibility for reducing harmonics. While the utility will be primarily responsible for reducing voltage distortion in the supply system, end users will be responsible for minimizing harmonic current injections. At the PCC, the harmonic current and voltage restrictions are used. This is where more passengers board the bus or where potential future connections with new passengers may occur. The standard aims to assign a harmonic limit quota fairly to each client. According to the standard, current injection limitations are assigned based on the magnitude of the load in relation to the power system's size, which is determined by it's short-circuit capacity. The maximum short-circuit current at the PCC divided by the maximum demand load current at the PCC is known as the short-circuit ratio.

To prevent excessive amounts of voltage distortion, individual customers' harmonic injections are restricted. Thus, the current restrictions are created to ensure that the maximum voltage is not exceeded by all harmonic injections from a single client. Limits on harmonic current for different system voltages. Smaller loads with lower short-circuit ratio values are permitted to have a greater proportion of harmonic currents than bigger loads. Since greater loads take up more of the system load capacity, they must adhere to stricter constraints. The current limits account for the variety of harmonic currents, some of which have additive properties while others have a tendency to cancel out. A voltage more than 230 kV is regarded as extra high voltage, while a voltage less than 1 kV is regarded as low voltage. The harmonic current restrictions at the PCC are established to limit individual voltage distortion and voltage THD to the levels in age.

The standard makes the case that volt-age distortion should be used to determine emission limitations for specific equipment connected to MV and HV systems. This is done to prevent excessive voltage distortion levels from being caused by harmonic current injections from harmonic-producing machinery. Harmonic voltage compatibility and planning levels are provided by the standard for the LV and MV systems. The term "compatibility level" refers to a condition in which the equipment is compatible with its surroundings. In order for a piece of equipment to be compatible with its surroundings the majority of the time, the compatibility level is often defined experimentally. Compatibility levels are often based on the 95 percent likelihood level, meaning that the compatibility can be attained 95 percent of the time. In both LV and MV systems, compatibility levels for harmonic voltages are shown in 6.12 as a percentage of the fundamental voltage. For the purpose of determining whether equipment connected to MV and HV systems is admissible, the IEC 61000-3-6 offers assessment criteria. Equipment acceptability is assessed in three stages:

1. **Stage 1:** Simple assessment of disturbance emission.
2. **Stage 2:** Limits on emissions in relation to real network properties.
3. **Stage 3:** Acceptance of increased emission levels under special and unstable conditions.

As long as the equipment is deemed to be modest in comparison to the system's short-circuit capacity, stage 1 equipment may be connected to MV or HV systems without the need for harmonic studies. Manufacturers are in charge of regulating harmonic emissions from tiny gadgets. If the equipment satisfies the requirements for stage 1, the harmonic characteristics of the equipment and the available system absorption capacity should be thoroughly assessed. After examination, the proper system absorption capacity will be assigned to each piece of equipment based on its size. Therefore, the system voltage distortion should be within planned levels if the system absorption capacity has been completely allotted to all equipment and that equipment injects its harmonic currents up to its limitations. Equipment that does not fulfill stage 2 standards may still be connected to the system provided the utility and end user are willing to make special arrangements to make the connection possible.

The South African standard for addressing the quality of the power supply is NRS 048, and it has been in effect since July 1, 1997. According to this guideline, electricity suppliers must assess and inform the National Electricity Regulator on the quality of their delivery.

There are five sections in the NRS 048. It is perhaps the most comprehensive standard that addresses every area of supplier quality. The minimal requirements for quality of supply, measurement and reporting of QOS, application and implementation recommendations for QOS, and instruments for recording and monitoring voltage quality are all covered in this document. The quality requirements for the electrical products that South African utilities provide to end consumers are outlined in Part 2 of NRS 048. Limits for voltage harmonics and interharmonics, voltage flicker, voltage imbalance, voltage dips, voltage regulation, and frequency are among the minimum requirements. IEC 61000-2-2 harmonic voltage restrictions are adopted by NRS 048-02 as its compatibility requirements for LV and MV systems. The nominal voltage for LV systems in South African systems is less than 1 kV, but the nominal voltage for MV systems spans from 1 to 44 kV. Limits for harmonic voltages for HV systems have not yet been specified by NRS 048. As its suggested planning limits for HV systems, it instead uses the IEC 61000-3-6 planning levels for harmonic voltages for HV and EHV systems.

A European standard called EN 50160 addresses the needs of European utilities in terms of supply quality. The standard specifies the precise levels of voltage requirements that utilities must meet as well as the criteria for determining compliance. The European Committee for Electrotechnical Standardization adopted EN 50160 in 1994. Under typical operating circumstances, EN 50160 defines voltage characteristics at the customer's supply terminals or in public LV and MV energy distribution networks. In other words, EN 50160 does not establish any criteria for power quality inside the supply system or within client facilities; instead, it focuses only on voltage characteristics at the PCC.

The EN 50160 harmonic voltage restrictions are expressed as a percentage of the fundamental voltage. The restrictions apply to systems supplied at both LV and MV levels, or nominally from 230 V to 35 kV. The medium voltage ranges from 1 to 35 kV. The harmonic voltage restrictions in higher-order harmonics are not given since they are impractically tiny to be used as a useful benchmark.The only difference between EN 50160 limits and the IEC 61000-3-6 compatibility levels for harmonic voltages for its related LV and MV systems is that EN 50160 lacks higher-order harmonic limits[3]–[5].

DISCUSSION

Long-Duration Voltage Variations

The service voltage delivered to an end customer is typically kept within 5% of the nominal by utilities. ANSI Standard C84.1 authorizes the usage voltage to be between +6 and -13 percent of the nominal voltage under emergency situations and for brief durations. In order for certain sensitive loads to function properly, there are stricter voltage limitations, and equipment naturally runs more effectively when it is close to nominal voltage. Discusses the underlying issues with voltage regulation and the many device categories that may be used to solve the issue.

Most voltage control issues come from the power system's excessive impedance, which prevents the load from being supplied appropriately. The power system being insufficient for the load is another way to put it. As a result, when there is a significant load, the voltage decreases too low. In contrast, when the source voltage is increased to overcome the resistance, when the load decreases too low, an overvoltage situation may occur. Corrective actions typically entail adjusting for either the impedance Z or the voltage drop IR + jIX brought on by the impedance[6], [7].

Here are several popular alternatives for enhancing power system voltage regulation, listed roughly in the order of importance that a utility could use:

1. Shunt capacitors may be added to lower the current I and move it closer to the voltage's phase.
2. Voltage regulators should be added to increase the apparent V1.
3. To lower the impedance Z, enlarge the conductor lines.
4. To lower impedance Z, upgrade the substation or service transformers to greater sizes.
5. Add a dynamic reactive power compensation mechanism, which works similarly to capacitors for dynamic loads.
6. To counteract the decrease in inductive impedance, add series capacitors. IX. Voltage regulation equipment

Utility and industrial power systems use a range of voltage regulating devices. These are broken down into three main categories:

1. Transformers that change their tap.
2. Devices for isolation with independent voltage regulators.
3. Instruments for impedance correction, such as capacitors.

There are tap-changing transformers that are mechanical and electrical. Although two- and three-winding transformers may also be fitted with tap changers, autotransformer designs are often used to create tap-changing transformers. The mechanical devices are for loads that vary more slowly, but the electronic ones may react to voltage changes quite fast. UPS systems, ferroresonant transformers, and motor-generator sets are examples of isolation devices. By converting energy in some way, these devices basically insulate the load from the power supply. As a result, regardless of what is happening at the power source, the load side of the device may be individually controlled and maintain constant voltage. The disadvantages of employing such devices include their high cost, increased losses, and potential for harmonic distortion issues with the power supply system.

Shunt capacitors lower the current flowing across the lines, maintaining the voltage. A voltage increase may also be generated by overcompensating inductive circuits. The capacitors may be swapped together with the load, often in tiny increments to follow the load more closely, to maintain a more consistent voltage. The capacitors are often fixed if the goal is just to keep the voltage at a higher amount to prevent an undervoltage condition. Although they are relatively uncommon in utility distribution systems, series capacitors are helpful for various impulsive loads, like tire testers and rock crushers. Because of the additional technical care needed for the series capacitor installation to work correctly, many prospective consumers will steer clear of them. However, under certain system settings, particularly when dealing with huge, quickly changing loads that are causing excessive flicker, they are quite effective.

The majority of the inductance in the system before the load is compensated for by the series capacitors. This will result in a significant decrease in impedance if the system is strongly inductive. Series capacitors won't work well in a system with a high percentage of resistance but little to no induction. This is often the case in industrial plant power systems when there are extensive cables extending from the transformer to the load. It is necessary to increase the size of the cables and transformers in order to significantly reduce the impedance.Applying devices that are usually referred to as static var compensators is another method for dealing with flicker-causing loads. These may respond in a few cycles to maintain a voltage that is practically constant by swiftly regulating the supply of reactive power. Such devices are often employed on arc furnaces, stone crushers, and other loads that change randomly in places where the system is unreliable and the consequent voltage fluctuations are having an impact on surrounding consumers.

Step-voltage regulators for utilities

The conventional utility tap-changing regulator can control the incoming line voltage in 32 stages of 5/8 percent from —10 to +10 percent. Although there are various variants, this is the most common. While line regulators deployed outside on feeders are normally single-phase in North America, distribution substation transformers often incorporate three-phase load tap changers. Line regulators are often placed in banks of three when they are put on a three-phase feeder. On branches with light three-phase load, there are also many installations of open-delta regulator banks. It is less expensive and only needs two regulators than a complete three-phase bank. a utility step-voltage regulator schematic. Although the idea of a tap-changing autotransformer is straightforward, the utility voltage regulator is an instrument that must be somewhat complex in order to provide a long-lasting and very dependable tap-changing mechanism.

Substation LTCs and voltage regulators for utility lines move slowly. When the voltage leaves the band, there is a delay of at least 15 s and sometimes 30 or 45 s. Therefore, it is not very useful in situations where voltages might fluctuate by a few cycles or seconds. Their primary use is to increase voltage on lengthy feeds when the load changes gradually over a period of minutes or hours. On a 120-V base, the voltage band generally falls between 1.5 and 3.0 V. By employing the line drop compensator, the control may be configured to maintain voltage at a location downstream from the feeder. As a consequence, the average voltage response is more uniform, and overvoltages on clients close to the regulator are reduced.

Iron-Based Transformers

Ferroresonant transformers may be utilized by end users to provide extremely effective voltage control in addition to shielding equipment from voltage sags. Input/output parameters of a 120-VA ferroresonant transformer with a 15-VA load are shown in 7.3. The output voltage remains steady while the input voltage is decreased to 30 V. The output voltage starts to collapse when the input voltage is further decreased. Additionally, the current consumed by the ferroresonant transformer significantly rises from 0.4 to 2 A when the input voltage is decreased. Ferroresonant transformers are often lossy and ineffective as a result.

Tap-switching electronic regulators

Additionally, voltage may be regulated using electronic tap-switching regulators. They employ SCRs or triacs to fast alter taps, and thereby voltage, and are more effective than ferroresonant transformers. For medium-power applications, tap-switching regulators are favored because of their half-cycle reaction time and quick response.

Synthesizers with Magnets

Magnetic synthesizers may be utilized for steady-state voltage regulation even though they are designed for short-duration voltage sags. For instance, one manufacturer claims that for input voltages of 40%, the output voltage will be within 5% at full load.

Autotransformer

Voltage regulation may be done using on-line UPS systems that are designed to guard against sags and short interruptions, so long as the source voltage is kept high enough to keep the batteries charged. This is a typical remedy for modest, crucial electrical or computer control loads in an industrial setting where the voltage fluctuates due to heavy, fluctuating loads.

Generator sets for motors

Voltage control also makes use of motor generator sets. They insulate the load from electrical transients by entirely removing it from the electrical power supply. The generator control provides voltage regulation. The main problem with motor-generator systems is how slowly they react to significant changes in load. Motor-generator sets may take several seconds to restore the voltage to the desired level, making them too sluggish to regulate the voltage of certain loads, particularly those with fast variations. By storing energy in a flywheel, motor-generator sets may also be utilized to give "ride through" from input voltage changes, particularly voltage sags. Utility systems or commercial systems may both use static var compensators. By reacting extremely fast to produce or consume reactive power, they aid in voltage regulation. Cycle each cycle, this interacts with the system impedance to either increase or decrease the voltage.

Set of motor-generators

Static var compensators typically come in one of two primary varieties. Probably the most used reactor control method is thyristor-controlled. It uses a fixed capacitor bank to supply leading reactive power and a thyristor-controlled inductance to cancel all or part of the capacitance. To remove the harmonic distortion that the thyristors create, the capacitors are usually set up as filters. The thyristor-switched capacitor works by swiftly switching a number of capacitor stages to as nearly match the load needs as feasible. Although this regulation is rougher than a TCR, it is often appropriate. There are often no harmonics in the currents since the capacitors are gated completely on. There are no switching transients since the switching point is regulated.

Application of Utility Voltage Regulators

A picture of a typical 32-step three-phase voltage regulator bank used by American utilities. Single-phase regulators are typically pole-mounted, either one to a single pole or three on a platform between two poles, even though this image depicts a structural installation. In wye-grounded, leading delta, lagging delta, or open delta connections are among the options. Each phase is often regulated independently, and the controls are an essential part of the device. Some regulator controllers include features that enable ganged operation of all three phases such that every regulator is connected to the same tap. It should be understood that ganged operation does not always imply improved voltage phase balancing. Utility distribution lines are often built in an imbalanced manner, and there is little effort to transpose them. A major imbalance in the phase currents is also caused by a large number of single-phase loads. So, compared to ganged operation, three individually controlled regulators may very well provide superior phase voltage balancing. Volumes may be written on how regulators are used, but we will limit our discussion here to a few areas that are very pertinent to power quality: Utilizing a line drop compensator helps level voltage profiles and reduce load when applying regulators in series.

Compensator for line drops

When the load exceeds the distribution feeder's capacity under peak load situations, regulators are particularly effective at reducing low-voltage conditions. The R and X settings are often set to zero, and the voltage regulation set point is set close to the maximum permitted, since it takes time to determine the ideal values for line drop compensation. As a consequence, the load is only at peak for a tiny portion of the hours each year, causing the feeder voltage to be close to maximum for the most of the time.

This is sufficient in most ways, with the exception that transformers run closer to their saturation curve, creating more harmonic currents and adding to the feeder's harmonic distortion, which may be problematic at low loads.Customers may experience more frequent replacement of incandescent lamps. Increased power demand brought on by the higher voltage might sometimes be unwelcome and lead to worse energy efficiency.

In order to give the required voltage boost during peak load while maintaining the voltage near to nominal at lower loads, the line drop compensator levels out the voltage profile. We've made the assumption that there is no LTC in the substation and that the sole regulator of interest is a feeder regulator there in order to make the topic more straightforward. The voltage setting is 5% high, or 126 V on 120-V systems, and no adjustment is employed. The voltage may really go higher than this since the control has a certain amount of bandwidth. The feeder's line drop compensator is set at a distance from the voltage setting of 120 V. In order to maintain the right voltage at the feeder's end, the voltage at the regulator must increase to 105 percent during peak load. The feeder voltage profile, however, is more closely aligned with 100% voltage at low load.

The methods for choosing line drop compensator settings are various. The settings may be calculated using computer programs provided by the manufacturers using the current transformer ratings and potential transformer ratios. Before the correct setting can be calculated, they must be properly recognized since they change with regulator size. Naturally, this also calls for the user to simulate the feeders on a computer program, for which the data may not be easily accessible. Simple formulae and methods based on common sense are also provided in manufacturer's guidebooks for choosing settings. A few utilities have created typical preset settings that they have discovered to be efficient. Many people experiment to determine the R and X settings by sending a line technician to the feeder's low-voltage point while another person changes the R and X settings. In order to find a voltage setting and line drop setting that successfully match this criterion, this should ideally be done at the peak load. Despite the possibility that switched capacitor banks downstream from the regulator might trick the control when they flip to a different state, it will almost certainly properly handle the reduced load situations. To ensure the setting is appropriate, the voltage profile should be observed for a few days at one or two important spots.

It goes without saying that this operation takes time, and it is often inconvenient to dispatch a staff to verify a regulator setting just before the peak load. The personnel are often preoccupied with more critical tasks at this time, such replacing overloaded transformers to restore service to clients. If the regulator is adjusted correctly, there is definitely an advantage to the power quality, thus some effort should be done. Thankfully, producers are increasingly offering devices with telecommunications capabilities, allowing settings to be changed more easily from a control center.Additionally, a variety of manufacturers provide complex controls with load-following algorithm choices. Consult the user's handbook and experiment with various algorithms to produce a smoother regulation in the event that power quality complaints are made about the voltage moving out of band or too frequent tap changes[8].

CONCLUSION

In summary,in order to assure the secure and effective functioning of electrical power systems, many organizations have established standards on harmonics. These standards provide criteria for what harmonic distortion is considered to be acceptable, how harmonics should be measured and analyzed, and how to build and choose equipment to minimize their impacts.

The safe and dependable functioning of electrical power systems depends on proper adherence to harmonics regulations. IEEE 519, which sets rules for the restrictions on harmonic voltage and current distortion in electrical power systems, is the most widely used standard on harmonics. Along with guidelines for the design and equipment selection of equipment to lessen the impacts of harmonics, the standard also offers techniques for measuring and evaluating harmonic distortion. The safe and dependable functioning of electrical power systems depends on proper adherence to harmonics regulations. Improvements in equipment performance, decreased losses, and higher energy efficiency may result from compliance with these requirements.

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CHAPTER 17

A BRIEF DISCUSSION ON REGULATORS IN SERIES

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ABSTRACT:

Regulators in series refer to a type of voltage regulation circuit where two or more voltage regulators are connected in series to provide a stable output voltage. Voltage regulators are electronic circuits that regulate the voltage output of a power supply to a constant level, despite changes in input voltage or load. The use of regulators in series provides several advantages over a single regulator circuit. One advantage is that it allows for better regulation of the output voltage, especially when the input voltage varies widely or when the load changes significantly. The use of multiple regulators also provides redundancy, improving the reliability and robustness of the system.

KEYWORDS:

Automatic Voltage Regulator (AVR), Capacitive Reactance, Capacitor Bank, Capacitor Switching, Harmonic, Power Factor.

INTRODUCTION

It is normal to see two or more regulator banks in sequence on very long lines supplying distant loads in sparsely inhabited regions. Service to irrigation and mining loads, where lines reach for miles with just the odd load, are two no-applications. To prevent power quality issues, some applications need particular considerations[1]–[3]. Setting the initial time delay appropriately is a crucial factor in series regulator coordination. The regulator closest to the sub-station has a time delay that is generally 15 or 30 seconds. Regulators situated farther down the chain have a 15 s greater time delay. By reducing tap switching on the downline regulators, the voltage changes are kept to a minimum and contact life is increased.

The biggest power quality issue in this scenario could be load rejection. Since the regulator boosting is cumulative, a fault-related rapid loss of load would create significantly high voltages. Overvoltages of 20% or more are possible. The voltage will be kept down by transformer saturation and the remaining load, but it will still be far higher than the permitted range. Regulators use a "rapid runback" control method that skips the usual time delay and runs the regulators back down as rapidly as possible in order to reduce damage to loads. Per tap change, this normally takes 2 to 4 seconds.

Capacitors for Regulating Voltage

Capacitors may be set up in a series or shunt arrangement to regulate voltage on the power supply. Each kind of application will be covered individually. A capacitor linked in series with the feeder produces a voltage increase at the end of the feeder that changes in direct proportion to the load current, unlike a shunt capacitor. At zero load and maximum load, voltage increase is zero. As a result, switching series capacitors in response to variations in load is not necessary. Furthermore, a series capacitor that provides similar regulation will need much lower kV and kvar values than a shunt capacitor. Series capacitors, however, have a number of drawbacks. First off, they do not considerably cut system losses or offer reactive compensation for feeder loads. Series capacitors can only release extra system capacity if the feeder voltage drop is very great. Shunt capacitors, on the other hand, work effectively when high feeder current also limits system capacitance[4]–[6].

Second, series capacitors are incapable of withstanding fault current. In order to avoid a catastrophic overvoltage, the capacitor must be bypassed via an automated switch. To prevent electricity from flowing until the switch shuts, an arrester must also be placed across the capacitor. In a series capacitor application, various additional issues need to be assessed. These include ferroresonance with transformers and resonance and/or hunting with synchronous and induction motors. The usage of series capacitors in distribution systems is severely restricted as a result of these concerns. They have shown to be useful in situations when feeder reactance has to be minimized, such as when reducing flicker.

Use of End-User Capacitors

1. Reduced electric utility costs is one reason why a user could want to utilize power factor correction capacitors.
2. Reduce I2R losses, and subsequently the heating in the lines and transformers
3. Increase the voltage at the load to boost output and/or operational efficiency.
4. Reduce the current in the lines and transformers to service more load without adding new circuits.
5. Although there are technical advantages connected to power quality, the main economic driver is the elimination of utility power factor fines.

When capacitors are added, power quality issues may arise. Harmonics issues are the most prevalent. Power factor correction capacitors may interact with the system to amplify existing harmonics even if they are not harmonic generators. As another switching transient side effect, utility capacitor switching transients are magnified.

DISCUSSION

Location for Power Factor Correction Capacitors

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Second, series capacitors are incapable of withstanding fault current. In order to avoid a catastrophic overvoltage, the capacitor must be bypassed via an automated switch. To prevent electricity from flowing until the switch shuts, an arrester must also be placed across the capacitor. In a series capacitor application, various additional issues need to be assessed. These include ferroresonance with transformers and resonance and/or hunting with synchronous and induction motors. The usage of series capacitors in distribution systems is severely restricted as a result of these concerns. They have shown to be useful in situations when feeder reactance has to be minimized, such as when reducing flicker.

Use of End-User Capacitors

1. Reduced electric utility costs is one reason why a user could want to utilize power factor correction capacitors.
2. Reduce I2R losses, and subsequently the heating in the lines and transformers
3. Increase the voltage at the load to boost output and/or operational efficiency.
4. Reduce the current in the lines and transformers to service more load without adding new circuits.
5. Although there are technical advantages connected to power quality, the main economic driver is the elimination of utility power factor fines.

When capacitors are added, power quality issues may arise. Harmonics issues are the most prevalent. Power factor correction capacitors may interact with the system to amplify existing harmonics even if they are not harmonic generators. As another switching transient side effect, utility capacitor switching transients are magnified.

Including Power Quality in Distribution Planning

The conventional method of designing distribution systems calls for the most cost-effective system modifications, scheduled to accommodate anticipated increases in peak demand. Reliability is the primary motivator. Power quality is not specifically taken into consideration while making planning choices unless the utility has signed PQ contracts with significant penalties. However, PQ factors may support changing the investment strategy to provide higher service quality in addition to enough capacity and dependability.18–20 It is more probable that the investment strategy selected would be advantageous to both the utility and the customers if the expenses for missed output, cleaning, and equipment damage were included in to some extent. The indices previously discussed provide a way to evaluate power quality and ought to be helpful in assessing planning choices when the service quality is highly valued. It is difficult to calculate them using predicted models as opposed to historical data.

Planned action

The general utility investment planning criterion may be contrasted with both conventional and competitive criteria. The optimal choice is what can supply the anticipated peak load at the utility's lowest possible cost since the traditional criteria presume that the customer's cost of unserved load is quite high. This is often referred to as least-cost planning. Planning mistakes tend to be on the cautious side since utility consumers have already absorbed the risk that the actual peak demand will vary from the prediction. To keep up with the increase in demand, the utility makes investments in more capacity than is really required at any particular moment.

In a cutthroat business climate, the utility must bear a greater portion of the risk associated with unprofitable expenditures, while consumers and the utility share the risk associated with an unserved load. This results in the planning choice by the dashed curve taking customer damage costs into consideration. Customers may incur less costs due to outages as the system's capacity grows. The U-shaped total-cost curve would potentially be minimized by the best planning choice. The ideal system capacity point would move to the right if customer expenses were greater. While the utility may find it challenging to precisely assess the costs associated with consumer damage in order to justify adding less capacity, the new choice may be more cost-effective overall. Even if it is clear that consumer costs are reduced, it may be difficult to explain this. This section's primary focus is on more expensive investments that could be justifiable given the costs to end users with delicate loads. System capacity, which is indirectly related to dependability, is the primary factor influencing the planning choice. Impacts on power quality are a significant, though secondary, aspect. Only investments that enhance power quality across the board and have an impact on many customers are taken into consideration in order to combine capacity and PQ costs in the same planning process. Consideration of point solutions or even specialized feeders is more suitable when there are localized PQ issues or simply one high-value client.

A framework for planning that may assist planning that takes PQ and other factors into account. The so-called "do nothing case" is the baseline scenario, which is the current system with no planned investments. Then, to represent the risky business climate for utilities, system performance is simulated throughout the planning horizon, often 5 to 10 years. Utility additional costs may be zero in the basic scenario or they may include expenditures for fault repair and vegetation management if things are being researched later. The cost of customer harm is gathered throughout the study system and the system PQ performance is determined annually. The damage cost is a sum of the customer expenses for each index and the system performance indices for each load bus. These charges may only apply to high-value client loads for whom accurate cost estimations can be made in order to streamline the investigation. The overall utility-plus-customer cost's net present value is assessed at the conclusion of the planning horizon simulation. This then becomes the basic case, or the cost of doing nothing. Any appealing planning alternative must have a lower net present value of total cost than the baseline.

The planner plans new investments, modifies the settings on safety equipment, alters the method of controlling vegetation, etc. to think about design options for better power quality. The underlying system is altered by certain modifications, while others have an impact on the fault rates, restoration times, and planned system upgrade expenditures. With these modifications, the system is simulated once again across the planning horizon, and a new present value of the overall cost is determined. It should be noted that when running this simulation, the customer load growth and cost statistics shouldn't be modified. However, they could be adjusted while evaluating the risk of various planning scenarios. By including the proper simulators, this approach may also be used to assess distribution automation, demand-side management, and generation of distribution. It is designed to reduce the whole cost's predicted value. Although it is now the most used method, it has to be modified to properly take risk into account.

The choice to plan is based on projections that are unclear but to which probability may be attached. The real planning situation and the best course of action will be revealed after some time has passed. It is unlikely that the best option will be picked, and it's also unlikely that planning choice faults will be fully fixed. There will be a difference between the real cost and the ideal cost as calculated via induction. Ordinarily, cost minimization entails reducing the linear norm of actual deviations from the ideal outcome. The utmost regret that may happen would be minimized by an extreme risk-based strategy, which would reduce the infinity norm of actual departures from the ideal solution. A middle ground strategy would reduce the square of deviations from the ideal using the well-known euclidean norm. For the various planning predictions, both the anticipated value and the risk-based techniques call for probability estimations; however, the quantity reduced differs. When multiple trials can be run to hide unpleasant outcomes, expected value minimization performs well. However, a risk-based minimization is perhaps more suitable for significant investments in a cutthroat corporate climate.

Tools for system simulation

For long-term capacity planning, the data needs and analytical complexity for simulation software are basic yet unpredictable, whereas they are more intricate and difficult for design and operational studies. Even for planning studies, the needs for power quality data and analysis tend to be more specific.

Capacity Preparation: Traditional capacity planning studies may be effectively supported by a positive-sequence load flow program using balanced load models. A timetable of investments in additional capacity to accommodate anticipated load increase would be the output of these studies. Transformers, feeders, and substations are often the significant investments. The timeline may need completely new construction or significant renovations to already existing facilities. Recently, distributed generation has been suggested as a substitute for feeder, transformer, and substation expenditures. Although a new generator model could be necessary, the current software would already be sufficient in other ways.

Analysis of faults: It will be important to create an explicit phase-by-phase system model in order to account for rms variable implications throughout the planning process. When using complete multiphase models, the rms voltage variation magnitudes estimated from simulations will be more accurate. Accurate phase impedances are significantly more crucial for steady-state voltage imbalance, harmonic distortion, and transient overvoltages. The loads must be represented per phase for all variances.

To determine rms fluctuations, the customer service transformers must also be modeled with specific winding connections. It's possible that the utility will now need this info. While most European systems utilize the same MV and LV connection throughout, some systems—particularly those in North America use a variety of connectors. For high-value customers, the customer transformer data may already be accessible for use in utility-customer device coordination studies. By service transformer type and phase connection, smaller customers may be combined.

Transients and harmonics. In PQ simulation, harmonics and transients add another layer of complexity. The interaction between capaci-tors and harmonics is one area where fascinating design challenges exist. To boost system capacity, utilities often install capacitors. Others demand that end users adjust the power factor of their loads in order to lessen system demand. Both scenarios carry the risk of serious harmonic resonance issues. Naturally, replicating them may take a lot of time. When it will be feasible to regularly and clearly incorporate these occurrences in the planning cycle depends on the availability of sufficient tools and data. Despite the availability of technologies for checking planned plans for harmonic issues, the majority of utilities will opt to solve these problems after they manifest[10], [11].

CONCLUSION

In summary,multiple voltage regulators are linked in series to provide a consistent output voltage in a voltage regulation circuit known as a regulator in series. Regulators used in series provide greater output voltage control, redundancy, and dependability. Regulators in series are designed and chosen based on the needs of the individual application, such as the input voltage range, output voltage specifications, and current load. Regulators in series are often employed in a wide range of applications, including voltage regulators for automotive usage, battery charging circuits, and power supply for electronic devices. The input voltage range, necessary output voltage, and required current load are only a few examples of the variables that affect the design and selection of regulators in series.

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CHAPTER 18

A BRIEF DISCUSSION ON FAULT INCIDENCE RATES

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ABSTRACT:

Fault incidence rates refer to the frequency at which faults occur in electrical power systems. A fault is an abnormal condition in a power system that results in the interruption of the normal flow of electrical current. Faults can lead to power outages, equipment damage, and safety hazards for personnel. The incidence rate of faults depends on various factors, such as the design and condition of the power system, the types of equipment used, and environmental factors. In general, faults are more likely to occur in systems that are poorly designed, maintained, or operated. Environmental factors such as lightning strikes, high winds, and floods can also increase the incidence rate of faults.

KEYWORDS:

Circuit Breaker, Distribution System, Fault, Protective Relay, Short Circuit.

INTRODUCTION

The incidence rate for various failure types is one of the crucial inputs to rms voltage variation modeling. The easiest method is to calculate nominal fault resistance based on system design features, average fault rate per unit length of line, average percent- age of permanent faults, and average fault resistance. In the United States, it is typical to expect about 0.06 faults per kilometer each year, with around 20% of the faults being permanent, occur. The normal fault resistance ranges from 1 to 5, while certain utilities may utilize up to 20[1], [2]. It's crucial to distinguish between vegetation- and lightning-caused problems in planning assessments. This may be accomplished by the study of outage data, modeling of lightning behavior, or use of the findings from ongoing research on faults caused by vegetation. With distinct fault types, it is now feasible to model the impact on the system's PQ performance of investing in stronger lightning protection, such as line arresters, greater vegetation management, and better fault-locating equipment. Some of the crucial PQ improvement techniques cannot be assessed for planning reasons without distinct fault types. Since some of the countermeasures that are effective for failures on distribution feeders do not alleviate problems on the sub transmission or transmission system, the model should also contain a distinct category for these faults.

Response of an Overcurrent Device

The reaction of the overcurrent protection device system is a crucial aspect of the rms voltage fluctuation simulation. It is predicted that each feeder section would have defects on a yearly basis. The defects may be split into groups based on the number of phases involved, the proportion of transient faults, the fault resistance, etc. This may lead to various event sequences and rms variation patterns. Utility fault-clearing equipment's behavior may be quite complicated.

For a certain fault location and kind, there is one method for simulating the fault. The operation time of the overcurrent device is established using a priority queue. While the fault is being applied, a thorough multiphase short-circuit algorithm determines the load voltages and protective device currents. The computed currents and voltages are used by each protective device in the system to forecast its upcoming state change and add that time to the device events' priority queue. The most important event is carried out after every safeguard has been examined. This gadget switches from an open to a closed state, altering the circuit architecture. The internal states of all the other devices are updated using the predicted currents and voltages at the precise moment when the state changes. The fault currents and voltages are recalculated for the modified circuit topology after clearing the priority queue of device events. When none of the devices push any events into the priority queue, the failure simulation is complete. When the fault has been deenergized by a device opening, it acts as a "device" and may delay the clearing time for transient faults.

According to the specification given, interruptions and rms variations are determined using the predicted load voltages and event durations. All load costs are estimated when the fault simulation is complete, and the following fault type and location are taken into account. The handling of the protection devices is briefly explained in the paragraphs that follow. All devices are expected to function properly, with the exception of sympathetic tripping and relay overtravel, which may avoid mea- measures especially done to enhance power quality[3]–[5].

DISCUSSION

Circuit Breaker with Relay

If the currents of a circuit breaker, as modified by the associated current transformer ratio, are greater than the associated relay pickup setting, the circuit breaker will schedule an opening event. The event time is the relay instantaneous pickup time plus the breaker clearing time if the relay has an instantaneous setting and the current exceeds that level? Otherwise, the relay's time-current characteristic will determine the event time. This will be a constant relay setting plus breaker clearing time if the relay is a definite-time type. This will be a current-dependent time plus the breaker clearing time if the relay is of the inverted kind. For relays and reclosers, we use approximate time-current curves. An internal relay travel state variable is updated if the fault current is stopped before the breaker opens. As a result of relay inertia, this can cause a sympathetic trip. An event for a complete reset is thus posted into the priority queue if no empathetic journey is anticipated.

There may be one or two reclosure settings on the circuit breaker. The breaker will plan a shutting operation for the appropriate time if it has already opened. The breaker model must handle an internal state variable of time computed toward the reclose procedure in case there are additional events from other devices. The interval between opening and shutting is fixed. The fault-clearing action is followed by the breaker once it recloses. Before the breaker locks out and stops pushing events, there may be two reclosings at various time settings. Even though a permanent problem has a corresponding repair time, it will not add any events to the priority queue. Any customers who are still without power after the fault simulation will face a continuous outage lasting for the same amount of time as the repair process. Anytime a temporary fault's voltage is zero, a cleaning event is scheduled. Any estimated clearing time is reset to zero whenever the fault is reenergized before clearing. The fault simulation must continue to take into consideration successive device reclosures when the fault switch state changes from closed to open as a result of clearing.

Fuse: When the I2T product achieves the minimum melting I2t or when the fault current and time applied penetrate the minimum melting curve, a fuse will open. For studies of fuse saving, we utilize minimum melt rather than total clearing time to be cautious; this is inappropriate for studies of device coordination. Current-limiting fuses are modeled using I2t, whereas expulsion fuses are represented with a spline fit to the manufacturer's time-current curve. In both scenarios, an internal preheating state variable is changed in case the fault is reapplied if the fault is stopped before the fuse melts. We do not, however, explicitly monitor potential fuse damage throughout the simulation[6]–[8].

Fuse melting times are moved up the priority list if the fuse currents can break through the time-current curve or mini- mum melting I2t. No event is pushed if the fuse currents are too low to melt the fuse. Downstream consumers will suffer a sustained disruption equivalent to the fuse repair duration after the fuse opens.

Recloser. The circuit breaker with relay concept that was previously explained and the recloser model are extremely similar. The recloser may make up to four trips throughout the fault sequence, and two alternative time-current curves can be employed, which are the key distinctions.

Sectionalizer. When the current rent has dropped to zero a certain number of times, a sectionalizer will open. This number may range from 1 to 3. Under load or fault current, the device won't open.

Cost of Customer Harm

Expenses associated with customer harm are established by survey results, PQ contract values, or real mitigating expenses. Estimates for kilowatthours not used vary from $2 to more than $50 per kWh. An average feeder with some industrial and commercial load typically costs $4 to $6/kWh. If the incident has caused a similar quantity of unserved energy, weighting factors may be employed to approximate these costs to include short disruptions and rms changes. An alternative is to adopt a model like the one in Sec. 8.5, which is essentially based on event count. For a broad variety of consumer segments, average expenditures per event are often mentioned in the range of $3000 to $10,000.

Customer damage prices will influence the planning choices given the high cost values. These expenses, meanwhile, are quite hazy. Although surveys have generally been reliable, the expenses of enhancing dependability or electricity quality are seldom "verified" by customer payments. In spite of the polls, there is no proof that residential consumers would pay more for enhanced power quality. For instance, aggregating the impact on a large number of home customers may imply a high damage cost. Although this is a soft cost, there can be a loss of goodwill. Planning should concentrate on high-value clients whose damage costs are easier to verify.

Other PQ disruptions' costs are less well outlined. For instance, while it probably leads to early failures, the economic impact of long-term steady-state voltage imbalance on motors is unknown. The expenses for harmonic distortion and transients that don't trigger the load are also not clearly understood. The prices may be broken down by the quantity of consumers, the amount of energy used, or the peak demand. If the cost is determined by peak demand, a load duration curve should be used to weight the cost. The load variation should be incorporated in the electrical simulations for steady-state voltage, harmonic distortion, and transients, but not for continuous interruptions and rms changes. The EPRI Power Quality for Distribution Planning report19 includes a number of examples and algorithm descriptions that demonstrate how the planning approach may be used to decide on different investments for power quality improvement. We've just scratched the surface here, but maybe readers can find some inspiration.

Transmission and Distribution and Power Quality

There is a lot of overlap between distributed generation and power quality, therefore many people working in one have moved into the other. Therefore, including a on this subject is quite suitable. As suggested by the name, DG employs smaller generators than the usual central station plant. They are dispersed more closely to the loads throughout the power system. Numerous different generating sizes might be referred to as smaller-sized. The treatment of distributed generation (DG) will be limited to generator sizes under 10 MW since the main and secondary distribution systems are the focus of this book's major and secondary concerns. At trans- mission voltages, when the system is built to support several generators, generators greater than this are often coupled. The typical distribution system uses cables to transport electric energy from a single power source to several loads. Multiple sources result in a number of power quality problems. Will DG worsen the service end consumers have grown to anticipate, or will it enhance the power quality? Both sides of this debate have valid points to make, and this article looks at a few of them.

DG's resurgence

For more than 70 years, producing electricity in massive, centralized power plants and distributing it to consumers through transformers, transmission lines, and distribution lines has been the standard practice for the developed world's electric power business. In DG literature, this is often referred to as the "wires" system. This book essentially explains what may go wrong when electricity is delivered via wires. The first electrical power networks made use of DG and were built on remote islands using very tiny generators. Economies of scale allowed the current centralized structure to replace that approach. Additionally, there was a need to place electrical producing facilities near the source of fuel and water, and to sequester them away from population areas for environmental concerns.

In order to promote energy independence, the Public Utilities Regulatory Act of 1978 was passed in the United States in 1978. To encourage the development of renewable and energy-efficient, low-emission technology, tax credits were offered and electricity was bought at avoided-cost prices. This resulted in a surge in the building of gas-fired cogeneration facilities as well as wind, solar, and geothermal generation. With the development of better DG technologies and the liberalization of the power sector, which allowed more power producers to compete in the market, interest in DG once again reached a height in the middle of the 1990s. Additionally, there is now a need for local generation and storage to cover the gap produced by the emergence of important high-technology loads that need considerably better dependability than can be provided by wire delivery alone.

Some futurists predict a return to the original power system paradigm in a high-tech form. New technologies would make it possible for linked power grids to be tiny and the generation to be scattered as far as the load. Renewable resources or clean-burning, high-efficiency technology would power the generator. The method of distributing energy will change from using wires to using pipes filled with fuel, most likely hydrogen in the end. If the industry can go from its current position to this future at all, it is unclear how. Recent initiatives to deregulate the electric power industry have focused on allowing innovative technologies as well as improved electricity costs. The transition of the electricity sector to DG sources, however, is far from certain. Compared to generation methods, cables are relatively resilient, notwithstanding the challenges associated with wire-based delivery that are addressed in this book. Once installed, they need very little care and operate quietly for decades[9].

Perspectives on DG Benefits

Understanding that there are several viewpoints on every pertinent subject is one essential to comprehending the DG problem. To demonstrate, we go through the advantages of DG from three distinct angles.

End-user viewpoint: The majority of the value in DG today is located here. End customers that value electricity highly may often gain significantly from having backup generation to increase dependability. Some people will gain significantly from high-efficiency applications like combined heat and power, where the overall energy cost is decreased. In places where there may be potential power shortages, end users may also be eligible for compensation for making their generating capacity available to the power system. With the help of its current network of lines and substations, the distribution utility is interested in selling electricity to end consumers. Transmission and distribution capacity may be relieved using DG. This application typically has a short lifespan until the load increases enough to warrant the construction of additional T&D facilities. DG protects against unpredictable load increase as a result. It may also act as a buffer against sudden price increases on the electricity market. Those that approach DG from this angle are primarily focused on entering the local power market to offer electricity or ancillary services. In the context of DG, the majority of units are too small to participate in individual power market bids. Commercial aggregators will put up for auction the combined capacity of several units. The DG may either service the load off-grid or directly connect to the grid. The latter, although avoiding numerous interconnection-related issues, does not enable the full potential of the DG to be used.

The drawbacks of DG: The disadvantages of DG are seen from several angles as well. The rest of this article is mostly dedicated to the worry about power quality concerns that utilities have. Costs and maintenance should be the key concerns for end customers. Really, do end users want to run generators? Will power really be more affordable and dependable? Will DG continue to benefit from favorable electricity markets? There are a lot of unaddressed issues. But it is probable that for the foreseeable future, the quantity of DG linked to the electric grid will keep growing.

Various viewpoints on connection

The question of how to link DG to the electric grid is likewise a contentious one. In attempts to create industry standards for connectivity, this is the main cause of much contention. the perspective of end users and DG owners who wish to connect in order to reap one or more of the aforementioned advantages. This kind of illustration may be seen in several publications that promote the usage of DG. The DG is modest in comparison to the grid, which is the underlying message about electricity quality. This group often holds the belief that the grid is an enormous entity that is too big to be impacted by their comparatively little generator. Because of this, many people find it difficult to comprehend why utilities are reluctant to link and just see their regulations as barriers intended to keep out competitors. The fact that the grid is seen as unreliable and producing "dirty" electricity, despite its massive size, is another component of the end-user perspective that is not shown in this illustration. The literature for DG advocates often portrays DG as increasing system dependability and supplying higher-quality electricity.

It summarizes the viewpoint on interconnected DG of ordinary utility distribution engineers, the majority of whom take a fairly cautious approach to planning and operations. Customer-owned DG generates filthy electricity and has a size that is enlarged to look much greater than it really is. Its design is also a tiny bit off-center, implying that it was not made and maintained with the same care as utility equipment.Each of these viewpoints has some components of reality. The goal of this book is to describe the topics as honestly as possible while highlighting solutions to power quality-related difficulties, without taking sides in the argument.

Technologies DG

The power elements of DG and merely a brief overview of the pertinent technological problem will be provided. For further information, readers are directed to References 1 and 2. Additionally, there are a ton of materials about DG on the Internet. A word of warning: As with anything on the Internet, it is wise to approach any content you find online with a fair dose of skepticism. Particular technology proponents and marketers have a knack of making things look highly alluring while failing to warn the reader of significant drawbacks.

Rotating-engine Generator

The reciprocating engine-generator set is the DG technology that is used the most often. a standard unit. Generally speaking, this technique is the least cost DG technology, often by a factor of 2. Gas or diesel reciprocating engines are established technologies that are easily accessible. Currently, mobile gensets that can be transported to the locations where they are required are preferred by utilities. Supporting the transmission and distribution system during crises is a typical use. The substation-based units are linked to the grid by means of transformers, which normally increase the voltage from the 480 V generated by the generators. The manufacture of these units has increased recently as a result of increased demand to alleviate severe grid constraints that have developed in certain regions. As a result, the price of the units has decreased, which has widened the price difference between this technology and the next-cheapest alternative, which is often some kind of combustion turbine.

End consumers like using diesel gensets for backup power. High NOx and SOx emissions are one of this technology's drawbacks. This drastically restricts the amount of time the units, especially diesels, may work, maybe to as few as 150 hours per year. Thus, peaking generating and emergency backup will be the key uses. Less emissions are produced by natural gas-fired engines, which may often run for many thousand hours each year. Because they run at least throughout the workday, they are widely used in combined heat and power cogeneration applications in educational institutions, governmental agencies, and commercial buildings. The device is equipped with a synchronous alternator, which is the most typical design for standby and utility grid support applications. Reciprocating engines with induction generators, however, are equally prevalent. This is especially true for cogeneration systems under 300 kW since induction machines that are unlikely to sustain islands may often fulfill interconnection requirements more easily. With efficiencies in the range of 35 to 40%, reciprocating engine generator sets exhibit consistent performance characteristics under a variety of environmental situations. Compared to combustion turbines, which experience a significant reduction in power efficiency when the temperature outside increases, they are less susceptible to the environment. However, compared to a reciprocating engine, the waste heat from a combustion turbine is substantially hotter. As a result, when a combined heat and power application calls for process steam, turbines are often the preferred option.

Turbines that Burn Fuel

The typical size range of combustion turbines utilized in cogeneration applications linked to the distribution system is 1 to 10 MW. The turbines are usually geared down to the synchronous alternator's needed speed, which is between 8000 and 12,000 rpm. In either simple-cycle or combined-cycle configurations, units of 10 MW or more in size are often found linked to the transmission grid. Although other liquid fuels may also be utilized, natural gas is the most typical fuel. The microturbine, a new kind of combustion turbine, is what has sparked part of the resurgence in interest in DG. A microturbine is being used with the heat exchanger on the left in a combined heat and power application. The clean and compact installations of this technology are one of its main benefits. This enables deployment close to places where people live and work, albeit in certain settings the high-pitched turbine noise may cause some problems.

A microturbine's one-piece turbine with a permanent-magnet rotor is the sole moving component. The assembly normally rotates between 10,000 and 100,000 revolutions per minute (rpm). The output of the alternator is instantly rectified to direct current and supplied through an inverter that connects to the ac electrical power system. The inverter's reaction to system disturbances is therefore the aspect of the micro-turbine that interests engineers interested in power quality. The most typical applications for microturbines, which range in size from 30 to 75 kW, are modest commercial loads. To get better ratings, they might be mirrored in packs. Larger models, also referred to as mini-turbines, are now becoming available and range in power from 300 to 400 kW. The efficiency of microturbine energy production is sometimes said to be as high as 30%, however 25% is a more plausible figure. It is often not cost-competitive for only producing power because to its poor efficiency. However, net energy efficiency surpassing 60% may be attained when combined with an adequate thermal load. The combined heat and power applications of this technology are best suited for small- to medium-sized commercial and industrial buildings. Microturbines are sometimes utilized only for the production of energy in specialized applications. Microturbines offer practical and eco-friendly standby and peaking generators due to their small size and minimal emissions. They can take a broad range of fuel types and qualities, are employed in certain base-load applications, and provide a practical way to extract energy from bio-mass gas, flare gas, or natural gas that is not cost-effective to deliver to pipelines[10], [11].

CONCLUSION

In summary,when discussing the frequency of defects in electrical power systems, fault incidence rates are used. The design and state of the electrical system, the kinds of equipment being utilized, and environmental conditions are only a few of the variables that affect the frequency of problems. Fault incidence rates are used by engineers to provide safeguards and assess a power system's dependability. Power systems' performance and dependability may be increased by performing routine maintenance and using new technology. Power systems are constructed with redundancy and protective mechanisms to lessen the effect of failures in order to lower the incidence rates of faults. Defects may also be avoided with routine equipment maintenance and inspection. To find and stop problems before they happen, advanced technologies like condition monitoring and predictive maintenance may be deployed.

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CHAPTER 19

AN OVERVIEW ON FUEL CELLS

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ABSTRACT:

Fuel cells are electrochemical devices that convert the chemical energy of a fuel directly into electrical energy. Unlike conventional batteries, fuel cells can produce electricity continuously as long as a fuel source is available. Fuel cells have the potential to provide a clean and efficient source of power for a wide range of applications, including transportation, stationary power generation, and portable electronics. The basic components of a fuel cell include an anode, a cathode, and an electrolyte. Fuel, such as hydrogen or methanol, is supplied to the anode, and oxygen or air is supplied to the cathode. The fuel undergoes a chemical reaction at the anode, releasing electrons that travel through an external circuit to produce electricity. The electrons then combine with oxygen at the cathode, forming water as a byproduct.

KEYWORDS:

Distributed Generation, Interconnection Standards, Islanding, Microgrid, Power Quality, Stability.

INTRODUCTION

The fuel cell is a fascinating DG technology as well. Additionally, this technology has a tiny environmental impact, operates quietly, and produces almost no toxic pollutants. In order to attain one of the highest potential energy-conversion efficiencies, combined heat and power applications may make use of fuel cells, which are efficient electricity producers. The fuel cell is considered to be the key energy-conversion technology among those who see a hydrogen-based energy economy in the future. A fuel cell is essentially a battery that uses hydrogen to power an electrochemical process. It generates dc electricity, and connecting to the ac power supply necessitates the use of an inverter. Currently, cost is fuel cells' main disadvantage. About ten times as costly as reciprocating gensets are fuel cell technologies. This will confine the use of fuel cells for the generation of energy to specialized applications until a price breakthrough. This innovation is anticipated to happen when the car industry switches to fuel cells[1]–[3].

A windmill

Rapid growth in wind production capacity has made it cost-competitive with conventional forms of energy in certain areas. A typical application involves assembling many wind turbines with individual capacities ranging from 700 to 1200 kW into a "wind farm" with a combined maximum capacity of 200 to 500 MW. 9.6 provides one instance. Instead of the distribution system, such huge farms are linked to the transmission system. For uses like ski resorts, smaller farms of 6 to 8 MW have been suggested; these farms would be directly linked to distribution feeders. Voltage control is the main problem with power quality in wind power. Wind power plants are often found in sparsely populated places where the electrical infrastructure is inadequate in comparison to the power they can provide. Voltage fluctuations that come from this are challenging to control. As a result, serving loads from the same feeder that also feeds a wind farm is sometimes not practicable.

The electrical system interface for wind turbines uses three primary groups of generating technologies:

1. Traditional squirrel-cage induction devices or wound-rotor induction devices. To address the demand for reactive power, switching capacitors are commonly added to these.
2. Power converters are used in doubly fed wound-rotor induction machines to regulate the rotor current, which provides reactive power control.
3. Frequency generation without electricity that needs an inverter interface.

Solar Power Systems

The construction of rooftop photovoltaic solar systems has been prompted by recent power shortages in several states and the passing of net metering laws. 9.7 depicts a sizable system on a Californian business structure. A home unit should be between 2 and 6 kW in size. The cost of power after installation is relatively cheap, and the energy source is basically free while it is accessible. Even with buy-down incentives from government programs, the upfront cost is relatively high. Currently, installed prices vary from $5000 to $20,000/kW. Despite its high price, photovoltaic solar technology is preferred by many environmentalists, and it is anticipated that installed capacity will increase in the future. Inverters are used to connect photovoltaic solar systems to the utility grid and create dc electricity when the sun is shining on them. Some systems lack the capacity to function independently; the inverters only function in utility-interactive mode and need the presence of the grid[4]–[6].

DISCUSSION

Interface to the Utility System

The influence of DG on the distribution system's power quality is the main issue here. While the energy conversion technology may have some influence on power quality, the kind of electrical system interface is usually the source of problems.

Synchronized Devices

There are various issues when synchronous machines are used in grid parallel DG applications, despite the fact that they are an outdated technology, are widespread on power systems, and are widely recognized. They are the most common kind of electric equipment utilized in applications involving backup generating. The machine has the capacity to follow any load within its design limits with adequate field and governor control. Because of its natural inertia, it can withstand fluctuations in step-load. Even though this is ideal for backup power, utility distribution experts are quite concerned about it since this technology may readily support accidental islands that can emerge when the utility feeder breaker opens. Additionally, it has the ability to feed faults and may obstruct utility overcurrent protection.

Interconnected synchronous generators on distribution systems are typically run using a constant power factor or constant variable exciter control, unless the machines are big in relation to the system capacity. For starters, a tiny DG lacks the ability to control the voltage while connected. In most cases, doing so would cause the exciter to swing between the two extremes. Second, this prevents the utility voltage regulation system and the voltage controllers of several tiny equipment from conflicting with one another. The third reason for doing this is to lessen the likelihood that an accidental island would be maintained. To avoid being discovered, the island would need to be a nearly perfect match of the load at the moment of separation.

The utility system voltage may be controlled by a synchronous machine that is enormous compared to the PCC system's capacity. In certain fragile systems, this may be a benefit in terms of power quality. The utility system protection and voltage control equipment should be coordinated with this sort of system and properly analyzed. Without adding complex controls, it would be feasible to allow just one generator on each substation bus to run in this way. Voltage regulation will probably be taken over by the generation, which may cause voltage regulators to tap in the wrong places. However, utility voltage regulators have the potential to cause the generator exciter to operate at unfavorable set points. Many utilities will want a direct transfer trip between the utility breaker and the generating interconnection breaker in order to assure the identification of utility-side failures when the connected generator is being run under automated voltage regulation.

The impedance of synchronous generators is one feature that is often disregarded. Generators scaled for average backup power needs have large impedances in comparison to the utility electrical power supply. Harmonics often detect a sub transient reactance of about 15% of the machine's rated capacity. Around 25% of the fault contribution may be governed by the transient reactance. The synchronous reactance is often more than 100%. As opposed to this, the power system's impedance as viewed from the main load bus is often just 5 to 6 percent of the service transformer's rating, which is typically higher than the machine rating. End customers who anticipate a reasonably painless transition from an integrated operation to an isolated backup operation are often let down. The harmonic voltage distortion develops to unbearable levels when the generator is trying to provide adjust-speed-drive loads, to give one concrete example of unforeseen effects[7]–[9].

1. Fuse sizes depending on the contribution of the power system are insufficient to trip breakers or blow fuses.
2. Fluorescent lights go out when elevator motors are turned on due to power drops.
3. To provide adequate power quality in isolated operation, generators must be scaled far greater than the load.

The imperfection of a synchronous machine's voltage waveform is another issue that is often disregarded. There are significant third-harmonic currents in the voltage in certain configurations. This flaw may also exist in utility central station generation, but the unit step-up transformer's delta winding prevents the harmonic from moving. Because many possible end-user DG sites' service transformer connections are not set up to accomplish this, a lot of third-harmonic currents will flow into the generator and perhaps into the utility system. More information is provided about this.

The end consequence is that, in order to reduce the third-harmonic component, synchronous generators for grid parallel DG applications should typically be constructed with a 2/3 winding pitch. If not, great care must be used while connecting the interface transformer, or other devices such a neutral reactor and shorting switch must be fitted.

Synchronous Devices

In many respects, connecting induction devices to the utility grid is straightforward. Induction motors are operated a little bit faster than synchronous speed to create induction generators. The likelihood of accidental islanding is significantly decreased since they need an additional source of stimulation. No specialized synchronization hardware is required. Induction generators can even be started across the line if the electrical power system's capacity allows for it. Before the machine is linked in weaker systems, the primary mover is started and brought to almost synchronous speed. After closure, there will be an inrush transient, although this will be minimal compared to beginning from a stop across the line. Operating an induction generator and an induction motor of the same size have roughly the same requirements. The main problem is that a basic induction generator needs reactive power from the linked electrical source to excite the machine. This may be advantageous on rare occasions when there are high-voltage issues, but in most induction generator applications, low-voltage issues will prevail. In order to provide the reactive power locally, power factor correction capacitors are often included as a repair. While it generally works well, there may be additional power quality issues as a result.

One of the issues is that harmonics generated in the same facility will coincide with resonances created by the capacitor bank. Self-excitation is a different problem. An induction generator may keep producing for a while after being abruptly disconnected on a capacitor bank. Since this voltage is unregulated, it is likely to soon stray outside of the expected range and be noticed. However, this circumstance often leads to a Ferro resonant state with harmful voltages. Instantaneous overvoltage relaying is often needed for induction generators that may get isolated on capacitor banks and loads that are less than three times rated power.

The idea that induction generators don't contribute to utility-side problems is one common misconception about them. Examples from textbooks often illustrate how an induction machine that dies after 1.5 cycles contributes current to a problem. However, there aren't many failures like this on a utility distribution system. This is true for three-phase faults close to the machine terminals that collapse the terminal phase voltages. The voltage on the affected phase does not fall to zero in the majority of SLG breakdowns. In fact, delta-wye transformer-served generators could not even notice a very little voltage change. Unbalanced failures result in a variety of intricate machine dynamics, and in order to calculate them properly, a thorough examination of electromagnetic transients is required. A general rule of thumb is to presume that an induction machine will continue to feed into a problem as if it were a synchronous machine if the voltage powering it is greater than 60%. This voltage level is enough to keep the machine's excitation levels high.

Digital Power Inverters

To connect to the electrical power grid, all DG technologies that produce either dc or non-power frequency ac must employ an electronic power inverter. Early line-commutated, thyristor-based inverters soon gained a reputation for being bad for the power system. In reality, plans to build thousands of rooftop photovoltaic solar arrays with line-commutated inverters served as the impetus for the creation of a large portion of the harmonics analysis technology. These inverters generated harmonic currents in a manner that was comparable to that of loads driven by conventional thyristor-based converters. One concern was that this kind of DG would generate a substantial amount of power at the harmonic frequencies, in addition to adding to the distortion on the feeders. Wires are only heated by such power.

The inverter technology has evolved to switched, pulse-width modulated technologies in order to improve control and prevent harmonics issues. A more user-friendly interface to the electrical power system is the outcome of this. the fundamental parts of an interactive utility inverter that complies with IEEE Standard 929-2000. On the left side of the figure, direct current is delivered either directly from a conversion technology or by rectifying the output of an ac generator. Many fuel cells, microturbines, photovoltaic solar systems, and certain wind turbines use variations of this kind of inverter.

An insulated gate bipolar transistor switch is used to switch the dc voltage rapidly in order to produce a sinusoidal voltage or current with a high frequency. Typically, the switching frequency is 50 to 100 times higher than the power frequency. These high-frequency components are often inconsequential due to the filter on the output's attenuation. However, these high frequencies might sometimes be audible due to resonance circumstances in the power supply. Typically, the biggest low-order harmonic is less than 3 percent, and the other harmonics are often insignificant. Based on the standards of IEEE Standard 519-1992, the overall harmonic distortion limit is set at 5%. Under certain circumstances, certain inverters will sometimes surpass these limitations. Manufacturers could cut corners with filtering or the switch control algorithm might include a bug. However, compared to inverters based on previous technology, the harmonic problem with current inverters is unquestionably much less of a worry. Commonly used inverters primarily aim to produce a sine-wave current that mirrors the voltage waveform when connected to the utility. They would generate electricity at a unity power factor as a result. Although alternative techniques may be programmed into the switching control, the unity power factor approach is the most straightforward and widely used. Additionally, it enables active power to be delivered using the switch's full current-carrying capacity. The control goal would shift to creating a sinusoidal voltage waveform at power frequency if the inverter had stand-alone capabilities, and the current would then follow the load.

One benefit of such an inverter for DG applications is that it may be immediately shut off when a problem is found. If there are synchronous machines with significant inertia maintaining the voltage on the system, there may be some delay in realizing that anything is amiss. The switching simply stops when a problem that requires disconnecting is found. Changes may occur in milliseconds because to the inertia that inverters often display. Rotating machinery could take a few cycles to react. As long as the current surge restrictions in the semiconductor switches are not exceeded, it would be feasible to reclose out of phase on inverters without causing harm. Reconnection and resynchronization thus provide less of a challenge than in the case of synchronous devices. The maximum current capacity of the IGBT switches is often what restricts an inverter's ability to feed utility-side faults. Analysts often anticipate that the current will be restricted to two times the inverter's rated output. Naturally, the inverter will most likely presume a problem and stop working for a certain period of time once the current hits these numbers. Utility interactive operations may benefit from this, while applications that need a certain level of fault current to trigger relays may find it to be a drawback.

In accordance with IEEE Standard 929-2000, utility interactive inverters additionally feature a destabilizing signal that persistently tries to adjust the frequency of the control. The goal is to guarantee that inaccurate islands are quickly found. Despite being tied to the utility; the electrical power system's strength outweighs this tendency toward instability. The frequency will immediately vary if the inverter system is unexpectedly placed on load, enabling the control and external relays to notice it.

Power Quality Issues

The main power quality issues affected by DG arepersistent interruptions. The usual dependability area is this. Many generators are built to provide backup power to the load in the event of a power outage. However, in certain circumstances, DG could lead to more disruptions.

1. **Voltage control**: When it comes to how much DG can be supported on a distribution feeder without requiring adjustments, this is often the most limiting element.
2. **Harmonics**: Both spinning machinery and inverters have harmonics issues, albeit the issue with inverters is less significant with contemporary technology.
3. **Low voltage**: This is a unique situation since DG could or might not be helpful. These topics are covered one by one.

Persistent interruptions

A large portion of the existing DG was deployed as backup generation. Diesel gensets are the most often utilized technology for backup generating. Simply shifting the load to the backup system will realize the majority of this sort of DG's capabilities. Paralleling with the power system will allow for the extraction of more power, nevertheless. Due to its huge capacity, the utility system will allow for more DG plants to run with improved power quality. Not every backup DG, meanwhile, can be paralleled without incurring significant costs. Not all DG technologies have the potential to significantly increase dependability. The DG must be able to handle the load when the utility system is unable to do so in order to achieve improvement.

In order to survive rotating blackouts, a homeowner can, for instance, build a rooftop photovoltaic solar system. Unfortunately, the less expensive systems lack the necessary inverter and store capacity to function independently. As a result, dependability has not increased. By using DG to cover emergencies when a portion of the distribution system is down, utilities may increase dependability. In this instance, the DG only serves a portion of the load—just enough to make up for the capacity that is not in use. This may enable deferring significant construction costs for a few years. The drawback is that overuse of this strategy might eventually result in lower dependability. If the load increase exceeds the system's base capacity, load shedding will be necessary during peak load periods or the system won't be able to maintain accept voltage after a failure.

Voltage control

At first glance, it could seem that DG might enhance a feeder's voltage regulation. Compared to switched capacitor banks and typical tap-changing transformers, generator controls are substantially quicker and more streamlined. This is possible with sufficiently huge DG with proper engineering. Voltage control, however, is not without its issues. Voltage control problems are often the most restricting for being able to handle the DG without alterations to the utility system in circumstances when the DG is placed relatively distance from the substation for the amount of DG.

It is important to acknowledge that certain technologies are inappropriate for controlling voltage. Simple induction machines and the majority of utility interactive inverters that don't generate reactive power fall into this category. Second, because doing so would interfere with utility voltage regulation equipment and increase the likelihood of sustaining an island, most utilities do not want the DG to try to regulate the voltage. Different DG would conflict with one another.

Last but not least, a tiny DG simply lacks the power to control the voltage and will instead be controlled by the daily voltage fluctuations on the utility system. To link with a fixed power factor or fixed reactive power regulation, small DG is nearly always necessary.

In order for large DG more than 30% of the feeder capacity that is configured to regulate the voltage to function successfully with the utility voltage-regulating equipment, specific communications and control are often needed. One frequent occurrence is that, as the load cycles up and down, the DG will take over the voltage-regulating responsibilities and push the substation load tap changer into a considerable bucking position. When the DG abruptly disconnects, like it might due to a failure, this causes a difficulty. When this happens, the voltage is insufficient to maintain the load, and it takes a while for it to recover. Establishing a control system that locks the LTC at a certain tap while the generator is running and connected is one option.

If there were a sufficient penetration of smaller, distributed DG providing a constant power factor, large voltage shifts would also be achievable. Shockingly attaching or unplugging such generation may cause a significant voltage shift, which will last until the utility voltage-regulating system notices it. The adjustment should not be more than 5% since this might take a few minutes. Fault clearing on the utility system is one circumstance that might result in this. When a problem occurs, all of the generators would disconnect, wait five minutes, and then rejoin. Customers would first experience low voltage for around a minute before experiencing high voltages five minutes later. Faster tap-changing voltage regulators and the need that the load be removed anytime the DG is forced off are two solutions to this problem. When the DG is running at a power factor that is close to unity, there is less voltage excursion. However, there could be certain circumstances when having the DG create reactive power would be helpful in everyday operation.

Harmonics

Many people still connect DG with unpleasant encounters with harmonics from electronic power converters. This would be a significant issue if thyristor-based, line-commutated inverters were still the standard. Fortunately, switching inverters like the one previously mentioned have been included into devices that need inverters. The majority of the harmonics issues with these technologies have been resolved as a result. When a switching inverter is deployed in a system that resonates at frequencies created by the switching operation, one uncommon issue might develop.

High-frequency hash often appears on the voltage waveform as the symptom. The most common power quality issue, if there is one, is that clocks powered by this voltage may sometimes run too quickly. Adding a capacitor to the bus large enough to shut off the high-frequency components while preventing new resonances usually resolves this issue. In grid parallel operation, harmonics from spinning machines are not necessarily insignificant. Zero-sequence triplen harmonics in the voltage are short-circuited by the utility power system, which may lead to very large currents.

Only synchronous machines with a 2/3 pitch may be paralleled without specific guidelines to control neutral current for grounded wye-wye or delta-wye service transformers. Nearly any kind of three-phase alternator may be paralleled without this harmonic issue for service transformer connections with a delta-connected winding on the DG side.

Voltage Drops

Voltage sags are the most typical power quality issue, however DG's ability to assist with sags depends greatly on the kind of generation technology and the interconnection location. a situation when DG is linked on the service transformer's load side. A voltage sag may be countered by DG during the sag. The voltage magnitudes and phase correlations may be supported by large spinning machines. It is conceivable to operate an inverter to offset voltage excursions, despite this capability not being common. The impedance of the service transformer, which offers some isolation from the source of the sag on the utility system, aids the DG's impact on sags at its own load bus. However, because of this impedance, the DG is unable to provide any relief to other loads on the same feeder. DGs with capacities more than 1 MW often need to have their own service transformer. The main distribution system serves as the point of common coupling with any load. As a result, it is unlikely that connecting DG in this way will have any effect on other loads fed by the feeder's voltage sag characteristics[10]–[12].

CONCLUSION

In summary,the chemical energy of a fuel is converted directly into electrical energy via fuel cells, which are electrochemical devices. In comparison to conventional power sources, they provide a number of benefits, including great efficiency and minimal emissions. Although there are many uses for fuel cells being explored, there are a number of obstacles preventing their general implementation. These issues and enhancing the effectiveness and dependability of fuel cells are the subject of ongoing research and development. Despite its promise, there are a number of obstacles preventing broad implementation of fuel cells. These difficulties include exorbitant prices, a dearth of fuel supplies, and a need for infrastructure to support fuel distribution and storage. Nevertheless, attempts are being made to overcome these issues and boost the effectiveness and dependability of fuel cells via continuing research and development.

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CHAPTER 20

A BRIEF DISCUSSION ON UTILITY DISTRIBUTION SYSTEMS

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ABSTRACT:

A utility distribution system is a network of power lines, transformers, and other equipment that distributes electricity from power plants to consumers. The distribution system is responsible for delivering electricity to homes, businesses, and other facilities, and plays a critical role in ensuring the reliability and safety of the electrical grid. The distribution system typically operates at lower voltages than the transmission system, which is responsible for transmitting electricity over long distances at high voltages. The distribution system is designed to accommodate the varying levels of demand for electricity throughout the day and to ensure that power is available to consumers at all times. The distribution system is divided into several levels, including primary distribution, secondary distribution, and service drops. Primary distribution refers to the high-voltage power lines that carry electricity from substations to distribution transformers. Secondary distribution refers to the low-voltage power lines that carry electricity from distribution transformers to homes and businesses. Service drops refer to the cables that connect the power lines to individual buildings.

KEYWORDS:

Capacitor Bank, Distribution Automation, Ferroresonance,Fault, Feeder, Substation.

INTRODUCTION

Conflicts often arise when deploying generators along utility distribution lines since the system's architecture only allows for one source of electricity. Without making any alterations, a certain level of generation may be tolerated. Conflicts will eventually become too severe, and adjustments will need to be made. Several of the operational conflicts that might lead to issues with power quality are explained in this section.

Requirements for resolving utility faults

The essential elements of a radial feeder's overcurrent prevention system. The lateral fuse is the lowest-level component, and the other devices are made to conform to the fuse's characteristics. The single substation bus will typically have two to four feeds. This design is mostly centered on ecological issues. This is the most affordable protection strategy that can provide enough reliability for electricity distribution. One essential feature is that only one device has to be active in order to clean and isolate a short circuit, and local intelligence can successfully complete the operation. Contrarily, defects on the transmission system, which can easily manage generation, often need the operation of at least two breakers, and in certain instances, local intelligence is inadequate[1]–[3].

The majority of the issues for interconnecting DG with the utility distribution system are, in essence, caused by this architecture. The amount of infrastructure already in place prevents any consideration of a completely new distribution system design that would better fit DG, therefore the DG must adjust to how the utility system functions. All DG devices must independently identify the issue and separate to enable the utility protection system to finish the clearing and isolation procedure when just one utility device is functioning to clear a fault. The information that can be detected at the generator does not always make this easy to perform. Some of the challenges are discussed in the following paragraphs. For further information on the fault-clearing procedure for radial distribution systems.

Reclosing

Utility breakers are often closed again after a fault, especially in North America. Temporary faults are frequent on the overhead distribution lines, which make up the majority of the network. The line insulation is restored when the current has been cut off and the arc has been dispersed. By shutting, it is possible to quickly restore power to the majority of clients.

Regarding DG, reclosing poses two unique issues:

To ensure that the reclose is effective, DG must disconnect before the end of the reclose period to give the arc time to dissipate. Reclosing on DG may harm the generator or prime mover, especially in systems that utilise rotating machine technology. The time gap between the utility breaker's first two operations before closing. To be able to disconnect before the reclose period, the DG relaying must be able to recognize the existence of the fault and the opening of the utility fault interrupter. This identification and disconnection procedure ought to be simple in most cases. However, some defects might be hard to find in specific transformer connections, which could postpone disconnecting. The widespread usage of rapid reclosing by utilities is a more complicated aspect. To improve power quality for vulnerable consumers, this is utilized during the initial reclose interval. The issue with the flashing clock may be mostly avoided, and many other kinds of loads can travel during this short period of inactivity. The instantaneous reclose interval is generally 0.5 s, however it may happen as quickly as 0.2 s. For certain DG breakers, this is within the range of relaying and opening timings. Therefore, it is quite probable that instantaneous reclose is incompatible with DG. The likelihood that some DG will still be connected during the reclose or that the fault did not have enough time to clear, leading in a failed reclose, rises significantly.

When there is DG on the feeder, a reclose interval of at least 1.0 s is recommended for safety. When DG is installed, many utilities set the initial reclose interval to 2.0 or 5.0 seconds. This reduces the possibility that the DG won't disconnect in time. It is often essential to use direct transfer trip in order to trip both the utility breaker and the DG breaker at the same time in order to preserve the instantaneous reclose. When it comes to smaller DG installations, this might be a very pricey option. To better accept large volumes of DG, certain distribution systems may thus need to sacrifice one component of power quality.

DISCUSSION

Interference with relaying

Here, we'll look at three of the most typical scenarios in which DG might affect the over-current protection relaying on distribution feeders:

1. Decrease in reach
2. Tripping of feeder breakers sympathetically
3. Failure of fuse-saving

The zone of protection for each over-current relay device is determined by its minimum pickup value. Some people refer to this as the relay's "reach" in general. The relay's range may be shortened by DG infeed if it senses less current. When the total DG capacitance reaches a certain level, the infeed into faults may de-sensitize the relays, leaving vulnerable far-flung portions of the feeder. Near the feeder's end, a low-current defect is more likely to go unnoticed until it causes enough damage to turn into a significant problem. The effects on power quality include voltage sags being extended for certain consumers and more continuous outages in the future due to fault damage[4]–[6].

Peaking generation situated close to the feeder's end may have additional difficulties as a result of this issue. When a high-impedance fault occurs, the overcurrent relaying on this generation would typically be very sensitive. There is a chance that the DG infeed will hide a lot of problems that would otherwise be noticeable.

Solutions comprise:

To expand the zone, lower the minimum pickup current of the relay. For ground relays that are already set to a highly sensitive level, this may not be viable. To add another protective zone that goes well beyond the feeder's end, add a line recloser. Since high-impedance problems are probably ground faults, choose a transformer connection that reduces the DG contribution to ground faults. A situation known as "sympathetic tripping" occurs when a breaker trips "in sympathy" with another breaker who saw fault current. Backfeed into a ground fault is the most frequent circuit condition on utility distribution feeders. The DG is the source of the backfeed current for the scenario in 9.13. The vast majority of utility feeder breakers lack directional sensing. As a result, the ground relay incorrectly trips the breaker by misinterpreting the DG contribution as a defect. If the service transformer for the DG has a grounded wye-delta connection, the situation is even worse.

In order to solve this issue, directional overcurrent relaying is mostly used. This might turn out to be a costly change if the proper potential transformers are not already in place. It may be feasible to accomplish coordination with the proper time-delay characteristic or by boosting the instantaneous trip pickup beyond the amount of DG infeed since the DG contribution in breaker B is likely to be much smaller than the fault current through breaker A. The sympathetic tripping effect on power quality results in unnecessary interruptions for many consumers. Additionally, the DG is made to go offline, which might provide issues for the DG owner. The remedies themselves could have effects as well. There will be greater arcing damage to lines and through-fault duty on transformers as a result of delaying the ground trip. Eventually, this can result in more failures.

Utility overcurrent prevention plans often incorporate fuse saving, especially in more remote areas. The recloser R should work in the circumstance shown in 9.14 before the lateral fuse has a chance to explode. If the problem is just momentary, the arc will go out and service will be resumed after the next reclose, which typically happens in 1 or 2 seconds. As a result, the dependability of the customers serviced on the fused lateral is increased without incurring the expense of dispatching a line worker to replace the fuse. In the best case scenario, a "horse race" involves fuse-saving action. It is difficult for the mechanical recloser to identify the issue and react quickly enough to stop the fuse element from being damaged. The current in the fuse is increased by DG infeed, tightening the race. The fuse can no longer be saved if the DG capacity reaches a point where it can feed the fault.

The amount of synchronous machine DG that may be supported without system modifications is limited by this circumstance. Around the same level of generation that has issues with voltage control, fuse-saving coordination fails. Increasing the size of the lateral fuses is one solution. It would be necessary to replace each fused cutout in the zone, which may be rather costly. Choose to just stop using fuse saving, especially if the DG is only connected sometimes. DG must have connections to transformers that do not feed single-line-to-ground problems. This has conflicting effects on electricity quality. Customers often see the brief blink as bad service, even though the utility generally regards fuse saving as an increase in power quality. As a result, several utilities have already stopped using fuse saving.

Difficulties with voltage regulation

Voltage regulation difficulties are more likely to happen and lead to interconnection concerns, despite the fact that there is a great deal of worry about a variety of difficult-to-analyze dynamics and transients issues. One issue with voltage control might develop when the total DG capacitance on a feeder rises to a substantial level. Because all DG must be disconnected when a malfunction occurs, this issue results. Before the issue developed, the voltage profile along the feeder is shown in Figure A. Maintaining the voltage magnitude between the two limitations is the goal of the voltage regulation technique. In this instance, the DG aids in maintaining the voltage over the minimum and is really big enough to provide a little voltage increase at the feeder's end. The DG disconnects when the issue occurs and might be disconnected for up to five minutes. The situation is caused by the breaker quickly closing again. The feeder and the voltage regulation devices can no longer handle the load at their current settings.

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As a result, the voltage at the feeder's end sags the least and will continue to do so until voltage control devices can respond. This may take the best part of a minute or more, which raises the possibility that extremely low voltages will cause harm to the load equipment. The voltage regulation devices must not already be at the maximum tap position for this to work. This is one of the risks of depending on DG to satisfy capacity, utility planners will often point out. The system's actual load increase is concealed, and the basic capacity of the cables is inadequate to transmit the required amount of electricity. Regarding the amount of DG that may be handled on a feeder, this problem may be one of the most restrictive ones. It is especially problematic for long lines on which the DG is situated far from the substation. Because it delays the development of large wire infrastructure to service the distant location, this use of DG may be appealing. However, it can need changing long-standing operational procedures and reducing the system's dependability.

It also offers a test that an analyst may use to assess if a proposed DG application would probably call for modifications to the utility system. Calculating the voltage change at peak load in the event of a sudden DG disconnect would be the test. Unless there is quick-acting voltage control equipment that can account for a bigger shift, this adjustment should be no more than roughly 5%. A bigger modification will need at the very least some specialized research and maybe improvements to the feeder's voltage regulation control[7], [8].

The quantity of generation that this test can handle will obviously vary depending on where you are on the feeder. Finding out how much DG capacity can be supported at different feeder lengths is an important investigation. For instance, if one were to set a 5 percent change criteria for the limit, the generation limit versus distance curve would resemble that in and may still experience downtime, negating the positive dependability advantages of DG. Adding extra voltage regulators with the flexibility to start changing taps right away rather than waiting the customary 30 to 45 seconds. Other consumers will experience less inconvenience as a result. Give DG more time to reconnect than the typical 5-minute disconnect period. Direct contact between the DG and utility system control would make this safer to accomplish. Step-voltage regulators are used to highlight another another problem with voltage control. Utility voltage regulators often have a reverse-power capability that enables the usage of the regulators when a feeder receives power from its secondary source. According to the logic, the regulator control reverses directions and governs the original source terminal when the net power flowing through the regulator is going in the other way. This allows the regulator to function as intended. If not, the control will try to control the other source side, which is impossible. Typically, the tap position would shift to one extreme or the other and remain there.

Consider, for instance, that a feeder has received the addition of numerous cogeneration sites and that there is extra generation during periods of low demand. Now that reverse power has been detected, the regulator tries to control the utility source. The regulator will fail since the DG is not nearly as powerful as the utility source. The tap will be run to an extreme position, often in the worst direction conceivable, similar to the situation when the controls fail to change direction on the alternative feed. Regulator suppliers have developed cogeneration features on the controls that can identify this circumstance in order to stop it. Maintaining the regulator's forward gaze is the intended outcome. While the reverse-power situation is present, the parameters for the line-drop compensator R and X may also be modified.

Technologies for generation whose output vary quickly might be challenging to manage on a distribution feeder. Because a substation is seldom located close to the desired location, wind turbine generating is the most challenging. On a feeder that may already have multiple switching capacitors and a voltage regulator, the generating is often located several miles from the closest sub-station. One illustration based on a potential wind farm in a ski area. The geometry of the line, which is a standard untransposed horizontal crossarm geometry, causes unique problems. One outer phase's voltage tends to increase while the other tends to decrease when the generator's output changes. There is a balance problem in addition to a magnitude issue.

The outcomes after modeling the system voltages for around 40 minutes under the same management. It's interesting to note that the bank of single-phase voltage regulators maintains a relatively even balance between the three-phase voltages. There were a few tap modifications throughout this time, but the quantity of capacitor switching operations is the bigger issue. The regulator taps changes dramatically increase after altering the capacitor control setting to prevent excessive operations, which is typical of this kind of generation. Typically, regulator tap changes occur around twelve times per day, while capacitors swap one or twice per day. Capacitors and regulators will thus virtually probably fail before their time if subjected to this type of task.

One option is to widen the controls' bandwidth to reduce the number of activities. More voltage fluctuation will arise from this, but it could be bearable. Although the magnitude variation in this instance was more than 2 percent, it is not changing quickly enough to be a potential source of complaints about voltage fluctuations. The major option when the volatility is too severe is to construct a separate feeder for the wind generating. Additionally, some wind generators use doubly fed wound-rotor induction devices, which have a short response time for controlling reactive power. This may assist to reduce voltage fluctuations with correct regulation.

Harmonics

Inverters and a few synchronous machines are the sources of DG harmonics. The procedures to get rid of the bigger, low-order harmonics were outlined in the prior discussion on inverters. Compared to prior line-commutated, thyristor-based inverters, the harmonic current content produced by PWM switching inverters is far lower. Generators are restricted to the most stringent limits in the s on the permitted quantity of harmonic current injection per IEEE Standard 519-1992. Although power converters used in loads are not always better than generator inverters, the IEEE standard's creators allotted the whole system's capacity to loads, leaving relatively little for generators. Thankfully, the transition to PWM switching technology has made it rather simple for inverters to satisfy the requirement. The switching frequencies of contemporary inverters can cause resonances in the main distribution system, which is a new distortion issue. On the voltage waveform, this produces nonharmonic frequency signals, often at the 35th harmonic and above. Clocks and other circuits that rely on a clean voltage zero crossing are affected by this. An industrial park with a few thousand feet of cable and its own substation is an example of a circumstance where this may happen. Increased capacitance in the form of power factor correction capacitors is a rapid cure, but caution should be used to prevent the occurrence of any extra detrimental resonances.

As was indicated in the section on the characteristics of synchronous machines, zero-sequence triplen harmonics might cause harmonics issues. 9.20 depicts an instance where this happens often. A common delta-wye transformer supplies power at 480 V to the building where the generator is installed. The operator is usually taken aback to see a sizable quantity of current cycling in the neutral when the generator is paralleled to the utility system via this transformer. In the above case, the current is totally third-harmonic and is 26% of the machine's rated current. The machine's performance and efficiency may suffer as a consequence, and certain circuit components may fail. Because the triplen harmonics are caught by the delta winding in this instance, the issue is limited to the generator side of the transformer and does not impact the main distribution system. With a grounded wye-wye transformer, the same phenomenon may occur, with the exception that the harmonic currents do get to the main distribution system.

The manufacturers of standby generating equipment are aware of this issue. Most will suggest a machine with a 2/3 winding pitch that can parallel without trouble if this information is known in advance. A reactor may be put in the neutral to restrict the current flow in the event that it becomes essential to parallel a system that does create substantial triplen harmonics. When the generator is utilized as backup power, a shorting switch is closed to preserve stable grounding. The majority of the time, islanding DG protection relays will carry out their task without the need for outside knowledge of the system to which they are linked. The possibility that DG relaying may fail to recognize that the utility breaker has opened and continue to activate a section of the feeder is probably the utility protection engineer's biggest concern. As a result, identifying islands or making islands uns so they can be identified has received a lot of interest. The dependability issue is that other customers might be exposed to such subpar voltage that harm would result. The utility is concerned that it will be held accountable for the harm. The risk of a generator unintentionally igniting the line and injuring customers and utility workers is another issue.

The DG itself is a further issue. Reclosing is frequent, thus it's crucial that the DG find the island quickly and disconnect. Prime movers, shafts, and other machine parts may sustain damage if they are still connected when the utility breaker recloses because of the shock from the out-of-phase reclosing. This draws attention to one area where utility practices may conflict: To give DG enough time to identify the island and disconnect, utilities that use instantaneous reclose may need to increase their reclose intervals. Relaying is one approach to solving the problem. Finding anomalies in voltage and frequency that are outside of normal expectations when connected is crucial. Making constraints for the DG's operating mode while connected that considerably lower the likelihood that the generation will meet the demand when an accidental island arises is another method of preventing islands: If they are serving as current sources and have a destabilizing signal that is continually attempting to push the frequency reference out of band, parallel-operating inverters are less likely to produce an island. To achieve islanding, the inverter would need a voltage from a different source. Of fact, any synchronous machine DG that is still on the island might serve as this source.

A mode of operation for linked DG should avoid attempting to adjust voltage. This often refers to a constant reactive power mode or power factor. This will have a power factor of one for many inverter-based devices, generating just watts. Unless the generator is physically linked to a control center to receive dispatching and transfer trip signals, automatic voltage management should be avoided while DG is coupled to the distribution system. The match between load and generation would need to be nearly flawless in order to avoid detection by the protective relaying if voltage regulation wasn't possible. While most of the time, these precautions will be effective, there will be instances when islanding detection by local intelligence at the DG site is too unpredictable. Large generation that is allowed to run with automated voltage regulation is one instance. In these situations, a direct transfer journey is often necessary.

Ferroresonance

This section discusses an intriguing conundrum that results from attempting to incorporate DG into a system that was not intended for it. A unique kind of resonance called a ferroresonance uses the nonlinear property of an iron-core device as its inductive component. The most frequent cause of ferroresonance is an accidently series-connected transformer's magnetizing reactance and cable capacitance or power factor capacitance. One intriguing instance is DG supplied via cable-fed transformers. For the bigger DG systems, having a separate transformer is standard procedure. Additionally, it is almost always necessary for DG to be disconnected at the first indication of difficulty on the utility system. A common ferroresonant situation may result from this confluence of conditions. The point where underground cable lines are tapped off the overhead feeder line is often when they are fused. The riser pole or dip pole are two other names for this. The relaying on the DG will detect an imbalanced state and trip the generator breaker if anything were to cause one or two fuses to blow. With one or two open phases and no load, the transformer is left isolated on the cable as a result. Because the cable capacitance in an open phase or phases now appears in series with the transformer's magnetizing impedance, any situation is favorable for ferroresonance.

The riser-pole fuse has a number of potential causes for blowing or opening. They often blow for cable failures, however there are other situations in which they could do so. Snakes or squirrels might scale the pole and come into touch with the line. Frequent inrush currents or lightning surge currents may wear out fuse components as well. Due to corrosion or faulty installation, fused cutouts may open. Finally, a line crew may operate them for maintenance reasons. The unique design of the device and a number of other variables determine whether a blown fuse causes harm. Various ferroresonance modes are conceivable based on the transformer's connection, size, and cable length. Ungrounded transformer connections are the most prone to failure. one phase open in the delta configuration. Without arresters, the possible overvoltages for this circumstance may easily approach a value of 3 to 4 pu.

The voltages calculated for a transformer with a delta connection of 300 kVA that is supplied via cable with a 30 nF capacitance. This simulates a situation when the transformer has no load and there are no arresters. Unless they had thermally failed from extended exposure to this waveform, arresting officers would clamp the voltage to a lesser amount. The transformer slamming in and out of saturation is the cause of the high voltages and the erratic waveform. The core emits very loud sounds that have been compared to the sound of a big bucket of bolts being shaken or a chorus of hammers pounding anvils due to the magnetic forces associated with this transformation. This may result in failures of both the transformers' arresters and the transformers themselves. The transformers are exposed because the arresters thermally fail. The transformers might then fail due to dielectric breakdown or heat impacts. During this kind of ferroresonance, low-voltage arresters and transient voltage surge suppressors often fail.

It was formerly thought that grounded-wye connections weren't susceptible to ferroresonance. This hypothesis, however, was shown to be untrue in a seminal article. The bulk of pad-mounted transformers used in commercial installations are of the three-legged or five-legged core design, despite the fact that grounded-wye transformers made up of three single-phase transformers or a three-phase shell core design are resistant to this sort of ferroresonance. Due to the magnetic core's phase coupling, both are vulnerable to ferroresonance. Although not immune, the overvoltages are often between 120 and 200 percent lower than with ungrounded connections. In certain cases, the voltages are insufficient to prevent the transformer from failing. The transformer is generating a lot of noise when the utility line team arrives in response to a service report, but it is still working and has no visible damage. In some instances, when the high fluxes in the core have heated the tank, there can be a burnt area on the paint on the tank's top. Before re-engaging, primary arresters should be examined, and the secondary system should be checked for malfunctioning components.

This circumstance isn't always exclusive to DG installations. When there is a problem with the utility system, many contemporary commercial buildings are provided with cable-fed service transformers that are cut off from the mains. The goal would be to transition to backup generation or UPS systems. Unfortunately, it results in little to no load on the transformer, leaving it isolated. Generally speaking, there shouldn't be any single-phase reclosers or line fuses between the generator and the utility substation. This is done to avoid the generator becoming single-phased, which might lead to ferroresonance as well as heat damage to spinning machinery. Particularly for DG with cable-fed service transformers, this regulation is applicable.

Solid blades or three-phase switchgear, such as a recloser or sectionalizer, may be used to replace the riser-pole fuses. The feeder section's dependability will be somewhat decreased if the fuses are swapped out for solid blades. The whole feeder or a portion of the feeder will be out of commission if there is a failure with the cable system. This might very well be the cheapest choice if the connection is short and dig-ins are uncommon. The three-phase switchgear option is chosen if protection is necessary. The kind of ferroresonance is highly dependent on the load. The resonance may be reduced if the system is set up such that the secondary bus is always connected to a resistive load. The burden must be considerable, even if it is not always heavy. In the given situation, a 2 percent load was enough. However, in some circumstances, a load more than 10% may be needed[9]–[11].

CONCLUSION

In summary,electricity from power plants is distributed to users by a network of power lines, transformers, and other devices known as a utility distribution system. The distribution system is in charge of making sure the electrical grid is reliable and safe, and it is built with a number of safety mechanisms to shield customers and stop electrical mishaps. Utility distribution systems are continually altering to adapt to customers' changing requirements and to improve the electrical grid's dependability and efficiency. Utility distribution systems are continually altering to adapt to customers' changing requirements and to improve the electrical grid's dependability and efficiency. To enhance monitoring, control, and reaction times, distribution systems are incorporating new technology such sophisticated sensors and automation systems.

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CHAPTER 21

A BRIEF DISCUSSION ON SHUNT CAPACITOR INTERACTION

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ABSTRACT:

Shunt capacitors are widely used in power systems to improve the power factor and increase the efficiency of the electrical grid. However, the interaction between shunt capacitors and the power system can lead to several issues, including overvoltage, resonance, and instability. When shunt capacitors are connected to the power system, they can cause overvoltage in the system. This occurs because the capacitors absorb reactive power, which reduces the voltage drop across transmission lines and other system components. If the shunt capacitors are too large or too close to the load, they can cause the voltage to exceed the safe operating range and damage equipment.

KEYWORDS:

Capacitor Switching, Harmonic, Resonance, Suppression, Transients.

INTRODUCTION

Switched capacitors are used by utilities to sustain the voltage during times of excessive load. Most of the time, these banks are managed by local intelligence, switching at regular intervals or when the load reaches a certain level as measured by voltage, current, or kvar. Reactive power may also be produced by certain DG types, which can lead to control hunting and other issues. On the feeder, there may be a number of capacitor banks. Unless specific communications and control have been introduced to coordinate dispatch, the capacitors flip independently of the generator management. When a normal capacitor bank is activated, the voltage typically rises by 2 to 3 percent[1], [2]. In general, generators running in parallel maintain a constant power and power factor. The exciter field, which will have certain minimum and maximum voltage or field excitation limitations as specified on the diagram, controls the machine's reactive power. Up until it hits one of these limitations, the generator control makes an effort to keep the reactive power output constant.

There may be circumstances when the generators' and capacitors' combined reactive power output is excessive, leading to high voltages. This is especially probable when capacitors are switched by a timer or the amount of current flowing through them. At this stage, the generator may be tripped by at least three different events: The generator control tries to reverse the field to reduce the overvoltage it detects at its terminals. However, the utility system overwhelms the generator, and the field falls to a level that is declared unsafe for the machine to operate at. Reactive power enters the machine when the generator hits its voltage limit. The generator protection sees this as a fault when it reaches a specific threshold. When there is an overvoltage, a DG that doesn't create reactive power just trips.

Connectors for Transformers

The effect that DG will have on the power quality may be greatly influenced by the service transformer that is utilized for connecting. This section discusses the benefits and drawbacks of typical three-phase transformer configurations.For three-phase loads, this is the connection that is used the most often in North America. It is preferred because it has fewer operational limits when switched for maintenance and is less susceptible to ferroresonance on cable-fed loads. In terms of DG connectivity, it is likewise typically well-behaved, however there are a few problems.

Benefits include:

1. Voltages on the utility side are not phase-shifted. This increases the certainty with which DG protection relays can detect utility issues.
2. Ferroresonance is less of a problem, but it is still a possibility.
3. Negative aspects include:
4. Permits all faults to be sent to the utility system using DG.
5. Does not prevent the flow of zero-sequence harmonic currents that might be generated by certain generator types.

It could be challenging to parallel certain generators with this transformer connection due to these two issues. Depending on the winding pitch of the machine, a third-harmonic voltage distortion may be present if the DG is a synchronous machine. The utility system offers a relatively low impedance channel for the third harmonics if a synchronous generator does not have a 2/3 winding pitch, and the ensuing neutral currents may injure generating equipment or just contribute unwanted harmonic currents to the utility system.

DISCUSSION

Delta-wye connection

In North America, this is the second-most typical three-phase load connection; in Europe, it is the most typical. If the connection's vulnerability to ferroresonance in cable-fed systems weren't present, it would likely be chosen for supplying loads in almost all situations[3]–[5].

Benefits include:

1. Ground problems on the utility side get less input.
2. The utility system does not get third harmonics from the DG.
3. There is some isolation from power drops brought on by utility-side SLG failures.
4. Negative aspects include:
5. Some SLG defects from the secondary side are challenging to detect using just voltage relaying.
6. In systems that are supplied by cable, it is prone to ferroresonance.
7. The secondary-side neutral may experience excessive current as a result of third harmonics in the DG.
8. Utility arresters may be exposed to overvoltages if islanded on an SLG failure.
9. Residual overvoltages may occur if arresters are deployed on an SLG fault and there is minimal load.
10. All transformers with an ungrounded main connection share the final two components.

You should be aware that although this connection stops third harmonics from the generator from entering the utility system, it does not stop them from flowing from the DG side. Similar to the grounded wye-wye connection, it is often not advised to link non-2/3 pitch synchronous alternators directly without adding an impedance to the neutral to restrict the passage of third-harmonic current.The phase shift may help the load by lessening the effect of voltage sags brought on by SLG failures, but it can also make certain SLG problems on the utility system harder to detect. The likelihood of islanding rises as a result of the delay in fault detection until the utility breaker engages. As a result, it is typical to include additional relaying capabilities to help with early utility-side failure detection. The detection may be more accurate using a negative-sequence relay. While the secondary voltage magnitudes may not vary much due to a defect, they will be unbalanced and detectable negative-sequence voltages and currents.

The addition of relaying, such as a type 59G relay ground overvoltage that can detect the existence of the SLG fault, on the main side of the transformer is an alternative strategy. This overvoltage relay, which senses zero-sequence voltage, is mounted in the corner of a damaged delta potential transformer. These connections are still typical for commercial and industrial loads even if they are not in the majority. Both exhibit comparable conduct when it comes to providing DG. Both might be used in legacy systems if a client wants to parallel DG, but neither would be the ideal connection for most new DG installations. Because the inverter's dc side is grounded, certain inverter-based systems call for an ungrounded connection on the DG side. Instead of using the main service transformer, this is often achieved by using a separate isolation transformer. Nevertheless, any of these connections would work. A four-wire connection with one of the delta legs center-tapped and grounded to handle single-phase 120-V loads is occasionally used for the delta secondary. Smaller commercial buildings with three-phase HVAC equipment and the usual office load often have this situation. If so, no component of a three-phase DG that is parallel to the grid may be grounded.

Benefits include:

1. It is feasible to install transformers at a lower cost for smaller three-phase services with certain single-phase loads.
2. On the utility side, the load is separated from ground faults.
3. Except when resonance occurs, DG wouldn't normally feed utility-side ground faults.
4. Systems based on inverters that need ungrounded connectivity may get it.
5. Negative aspects include:
6. Utility-side SLG issues are difficult to find.
7. If landed on an SLG fault, utility arresters are exposed to large steady-state overvoltages. The same is true for connections made via a delta-wye.
8. In systems that are cable-fed, these connections are very vulnerable to ferroresonance.

Switching is subject to higher limitations for utility maintenance. Due to the many issues that might arise while performing single-phase switching, three-phase switchgear can be necessary on the main. The cost of the hookup will go up because of this. These connections have issues with the quick identification of SLG utility outages via voltage relaying. This will cause at least a temporary island and postpone fault detection until after the utility breaker has opened. As a consequence, all ungrounded primary connections may experience overvoltages and a resonant state. The detection may be strengthened by adding negative-sequence relaying to voltage relaying on the DG side. A ground overvoltage relay is often added to the main side to detect the persistence of a ground fault. Due to the opposing application concerns, this relationship is intriguing. This winding connection, in the opinion of many utility experts, is the most effective one for connecting generation to the utility system. Almost all central station generation is done via this link. There are several benefits, including:

1. Utility-side faults are simple to identify in part due to the fact that the transformer actively contributes to ground faults.
2. The delta winding prevents any electricity from flowing when the generator produces triple harmonic voltages. As a result, with this connection, almost any generator may be paralleled.
3. Due to years of utility generating expertise, protection mechanisms are well known.

Despite these advantages, it may come as a surprise to hear that this connection is not allowed on distribution systems without extensive research and particular considerations that might need expensive system upgrades. In reality, because of the inconvenience to other customers, it may not be able to accommodate the connection on certain distribution networks. The connection is often referred to as a "ground source" since it contributes to ground faults and typically interferes with the coordination of ground fault relaying on the feeder. There is a chance that the same substation bus's feeders may also experience disruptions. The most typical four-wire, multigrounded neutral distribution system in the United States is shown in 9.27 as the condition leads to an SLG failure. The arrows that are thicker represent the typical contribution anticipated from the primary utility source. On the distribution side, there is just one phase implicated, and the failure from the transmission side looks to be a line-to-line issue. The pathways used by the current from the grounded wye-delta connector transformer are shown by the thinner arrows. The currents return to the substation and increase to the fault's current by flowing through it again. The size and impedance of the transformer would affect the contribution. the output of the generator. This contribution is contingent on the DG's capacity to provide a short circuit. The contribution that the transformer alone will make in certain circumstances will be greater. When this trait is present in the distribution system, a variety of negative side effects are possible:

1. Greater persistent outages and decreased dependability will ultimately result from higher fault current, which causes greater damage at the fault site.
2. The connection is likely to result in the feeder breaker tripping sympathetically for problems on adjacent feeders. In order to keep additional feeders linked to the same substation bus with ground current, the transformer provides it. There would be disruptions for a large number of clients who would typically just notice a sag.
3. In order to preserve coordination, ground trip pickup levels must be raised and greater delay must be employed, which leads to less sensitive fault protection.

If fuse saving is tried, it will be considerably more challenging to succeed since the fault is likely to be bigger than from the DG itself. When a ground fault occurs, the transformer itself is vulnerable to short-circuit failure. This is especially true for transformer banks that are smaller and have impedances around 4%. Typically, a specific transformer has to be ordered. Due to the feeder load's infrequent balancing, the transformer is also vulnerable to heat failure. Thus, zero-sequence load currents will be absorbed by the transformer. Almost usually, the distribution system can be designed to function using grounded wye-delta connections. This increases the certainty and simplicity of the DG connection protection. However, this can need pricey adjustments, which might end up being an insurmountable barrier for small- and medium-sized

DG. Additionally, the utility must be prepared to tolerate unique transformers and operating practices that differ from those used by the rest of the system. Some utilities are hesitant to take this action. One risk is that persons changing the transformer may not be aware that it needs a certain minimum impedance to avoid failure if the transformer fails at some point in the future. It may fail catastrophically if a conventional transformer is used to replace it. When line personnel from other companies must be called in during catastrophes, this becomes a special problem. Therefore, it makes sense that many utility companies oppose the usage of unique choices.

DG on Low-Voltage Distributed Systems

The most typical distribution architecture, DG coupled to radial primary or secondary distribution circuits, is the main topic of study. However, many utilities in big cities distribute their services via low-voltage networks. The secondary network and the spot network are the two main kinds of these low-voltage network systems. A grid of low-voltage mains at 120/208 V, three-phase serves several locations, often several city blocks, from secondary networks. Spot networks typically serve a single location, which might be a whole huge building or perhaps just a section of one. Spot networks' secondary voltage is often 277/480 V, three-phase, however they may also be utilized with 120/208 V. Street networks and spot networks are supplied by integrated transformer/breaker/protection combinations known as network units from two or more primary distribution lines. These network components are often found in underground or transformer vaults inside buildings or on public streets.

Basic principles of Network Functioning

We will focus on the spot network to help you understand how network functioning varies from radial service. By paralleling the low-voltage secondaries of the network transformers on the spot network bus, the spot network is normally fed concurrently from all of the main feeders. The network units are each outfitted with a low-voltage circuit breaker called the network protector and a directional-power relay called the network relay or master relay so that the spot network may keep running even if a principal feeder develops a fault.

When a main feeder malfunctions, the network relay detects reverse power flow and unlocks the network protector, separating the network bus from the malfunctioning feeder and enabling uninterrupted network operation. This function gives rise to the term "network protector," and it also explains why it is so difficult to link DGs to networks. the process through which a network protector isolates a main feeder with a defect. The network relay detects voltage at the transformer side of the open network protector later, after the faulty primary feeder has been fixed and put back into operation. The network relay instructs the protector switch to reclose if the voltage is sufficient that power will transfer from the network unit to the bus when the protector is closed. The timing of the reclose might cause problems with connections.

The network relay has a pickup level on the order of 0.1 percent of the network transformer's rated power, making it an extremely sensitive reverse-power relay. These options range from 1 to 2 kW. The reverse-power relay's goal is to be able to detect reverse power flow using just its own network transformer's core losses as feeder loads. This high sensitivity is required because the network protector must function for all faults, including ground faults, on the main feeder. Since network transformers often employ a delta-connected primary, after the source sub-station feeder circuit breaker has opened, no ground fault current will flow from the network toward the main feeder. It's possible that the main feeder has no additional loads, or that the only additional loads are network devices that have already detached from the defective feeder. As a result, the network relay must be able to detect reverse power using nothing but the losses of its own transformer[6]–[8].

No DG may be linked to the network with the intention of exporting power to the utility system due to the sensitive reverse-power function. It also implies that even brief power reversals caused by atypical circumstances must be taken into account in the interconnection architecture. The conventional network relay has no purposeful time delay and is electromechanical. Because the usual working period at normal voltage levels is about 0.05 s, even momentary power reversals brought on by the DG are cause for worry. In modern network units, microprocessor-based network relays have taken the role of electromechanical ones, and these relays may be retrofitted into many different kinds of old network units. Although they have greater flexibility and additional capabilities, microprocessor types function fundamentally in a way that is comparable to electromechanicals.

An air circuit breaker known as a network protector was created especially to handle fault current situations seen in low-voltage network systems. It only responds to commands from the network relay. The network protector does not open for low-voltage secondary system failures and lacks overcurrent protection. Circuit breakers or fuses at the facility being serviced clear low-voltage problems. The fact that practically of network protectors in use are not meant to separate two electrical systems that are in operation makes this design feature the most important one. A DG must never be permitted to island on a network bus as a result.

The Problems with Network Connections

It is abundantly evident from the discussion in this section that implementing DG in facilities serviced by a spot network presents a number of unique application challenges that do not exist under the typical radial service configuration. Due to the reverse-power technique of protection utilized on the network units, it is not possible to export power from a spot network or even to serve the full facility load from a DG. If DG, even briefly, surpasses the on-site demand, power flows from the network into the principal feeders, the network relays activate their network protectors, and the network is cut off from its source of utility supply. The size or operational hours of a DG may be heavily constrained by minimum site loads, such as weekend or late-night loads. A DG must take into account the potential of a sudden loss of a substantial load, which might result in reverse power flow across the network units even if it is designed to the site's lowest load. Additionally, they are not needed to interrupt fault currents with X/R ratios that are larger than those that are often present in low-voltage network systems. The severity of this issue was made evident by a major network protector failure on a network in New Mexico during a DG installation test.

Network protectors may open as a result of the fault current delivery from synchronous DG to external faults, possibly isolating the network. 9.30 is an illustration of how this may occur. As stated before, without thorough investigations, it is impossible to predict how induction generators may affect unbalanced and high-impedance faults at such sites. Induction generators should be viewed as if they had synchronous generating capabilities for choosing the best connectivity solution to this distant fault problem if such studies don't exist. The network relay may constantly try to reclose the network protector, resulting to the protector's destruction and the potential for catastrophic network unit failure, if the network protectors open, cutting the network and the DG off from the utility supply. The network relays are not as readily adjusted as a normal relay control system since they are a component of an integrated assembly in a submersible enclosure, which is often located in street vaults. It is possible that a protector might cycle under light-load conditions if the bus tie breaker is left open or if a second substation is utilized to power the network. This problem will become worse if DG is added to the network bus. Without the help of advanced load flow calculations, it is especially difficult to predict when and where the cycle issue may arise on street networks.

Techniques for DG integration on networks

Even with such a long list of issues, there are still ways that DG might be supported on spot networks by using new technologies. The benefits of inverter-based DG include the fact that fault current is very constrained to between 100 and 200 percent of the usual inverter load current and that an inverter can react to signals controlling its power output level very quickly. This example employs a tie-line load management method that measures the total incoming power to the facility and adjusts the DG power output to guarantee that power flow is always inward since the most important requirement for DG on networks is that the local generation must never exceed the local load. Size the DG with a buffer in case a significant load is suddenly lost such that it is smaller than the lowest load that might possibly exist on the network. When the inbound power flow drops below a safe level, add up the network's incoming power and trip the DG.

By keeping the DG below the on-site load, all three of these strategies aim to prevent opening the network protectors. It should be noted that similar approaches may be used to determine the minimal load at which cycling won't occur if that is a concern. There may not be much time available to evaluate power flow and make a control choice due to the network relays' quick responses. By setting up the network relays to have a time delay at low reverse-power levels, such as reverse flow below the rated capacity of the network transformer, this issue may be made easier. The network relays continue to instantly function despite the large amounts of reverse power flow seen during multiphase breakdowns on the major feeds.

To cope with regenerative loads like elevators, time delay on low reverse power has been employed for many years. Relays for modern microprocessor-based networks often come equipped with this feature. The microprocessor has the benefit that this delay may be as little as 6 cycles. Such a little time delay may be acceptable from the perspective of power quality if the instantaneous trip threshold can be maintained at or the rating of the transformer. To provide electromechanical network relays the capacity, a separate overcurrent and time-delay relay is required. Due to the fact that their primary function was to wait for the elevator to descend, these supplemental relays used to have minimum time delays of 1 second or more. However, not all utilities support this time-delayed, low-current method. According to others, any delay in activating the network protectors lowers the high level of service that the network system is supposed to provide.

The network protectors are never meant to be opened by exported power thanks to the load-generation control and DG tripping mechanisms outlined above. As long as the plans are implemented correctly, the network protectors are never subjected to out-of-phase voltage conditions that could be too high for the switches to handle. However, it is advisable to provide a backup due to the potentially disastrous effects of creating a network protector failure. The network protectors won't be exposed to out-of-phase voltages for more than a few cycles thanks to an interlocking system that instantly trips the DG when a certain amount of them have opened.

A trade-off must be made between the DG's bothersome tripping and the security of the protectors when determining how many protectors must open before the DG is tripped. The DG installer is still required to provide stuck-breaker backup protection for the DG's switching device; take note of this. Replacing the present network protectors with new ones that can interrupt fault currents from sources with greater X/R ratios and sustain out-of-phase voltages across the open switch is an even more secure method of preventing overstressing the network protectors. One significant American maker of network protector units recently released such large-capacity protectors in ratings ranging from 800 to 2250 A and aims to release them in ratings as high as 6000 A. These protectors are designed to be retrofitted in a variety of current network unit types.

Network protectors without a network bus interface are a potential source of DG connectivity issues. If a DG is hooked on a feeder that also serves a network unit, it may have the same effects on one or more of the network units as if it were isolated on the network bus if the feeder breaker trips and the DG is not quickly separated. The DG output does not have to equal the feeder load for this kind of occurrence to happen. It simply has to be briefly bigger than the load on the network bus in the surplus generation situation. In this scenario, the feeder with the attached DG continues to provide power to the network bus, keeping that protector closed.

The protectors attached to those feeders open as a consequence of the surplus power flowing back through the network to the other feeders. When these protections are opened, two independent systems will be kept apart. The protector connected to the feeder with the generator may trip in the event that there is less generation than load. Once again, in such a situation, a guardian would stand between two separate systems. Therefore, unless the DG breaker is linked with the feeder breaker using a direct transfer trip method, such DG applications should be avoided[9]–[11].

CONCLUSION

In summary,Shunt capacitors have the potential to boost the electrical grid's efficiency and power factor, but their interactions with the power system have the potential to cause overvoltage, resonance, and instability. Advanced management and monitoring systems, together with careful shunt capacitor system design and installation, may assist avoid these problems and guarantee the safe and dependable functioning of the electrical grid. Shunt capacitor systems must be properly designed and installed in order to minimize these problems. Shunt capacitors should be sized and placed appropriately to assist avoid overvoltage and resonance. They should also be properly coordinated with other system elements to help avoid instability. Furthermore, sophisticated control and monitoring systems may assist in identifying and resolving problems before they harm or disrupt the electrical grid.

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CHAPTER 22

A BRIEF DISCUSSION ON SITING DISTRIBUTED GENERATOR

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ABSTRACT:

Siting distributed generation involves the process of selecting the most suitable location for installing small-scale power generation systems such as solar panels, wind turbines, or generators. The goal is to maximize the benefits of distributed generation, which include reducing energy costs, improving grid resilience, and promoting renewable energy sources. The siting process involves several considerations, including the availability of renewable energy resources, the proximity to electrical loads, the availability of interconnection infrastructure, and the environmental impact of the generation system. For example, solar panels require access to sunlight, wind turbines require consistent wind speeds, and generators require access to fuel sources. Additionally, the location should be close to the electrical loads to reduce transmission losses and improve system efficiency.

KEYWORDS:

Backup Power, Distributed Generation, Energy Storage, Grid Connection, Load Shedding, Micro Grid.

INTRODUCTION

The contribution of DG to the electricity delivery system is highly influenced by place and time. It must be there when required and accessible when needed. This is a topic that is sometimes overlooked or misinterpreted in debates about DG. The assumption made by many DG articles is that if 1 MW of DG is supplied to the system, 1 MW of extra demand can be supported. That isn't always the case[1]–[3]. Engineers in charge of utility distribution usually feel more secure when DG is put on facilities they look after and manage. A substation with enough room and communication to control centers is the logical option for a site. If the transmission system or substation transformer requires capacity alleviation, this is the right place to put them. There are numerous peaking units in substations, and it is also suitable for dealing with basic power supply concerns. The DG must be installed far enough from the substation on the feeder to support distribution feeders, however. Additionally, such generating will ease transmission and power supply capacity restrictions. Compared to the same amount of DG put in the substation, it is really more efficient. Sadly, because this generation is often owned by the consumer, distribution planners are hesitant to depend on it for capacity.

The use of DG to alleviate feeder capacity restrictions. The feeder load has increased to the point that it surpasses the feeder's capacity. This restriction could be enforced by switchgear or current ratings on lines. Bus voltage limitations may also impose it. DG is despatched close to the daily peak to assist service the demand and is present on the feeder at a point where it may genuinely ease the bottleneck. The figure's clear message is that the load that would have to be reduced otherwise may now be supplied. As a result, the dependability has increased.The use of this application to postpone the development of the infrastructure for wire-based power transmission is become increasingly widespread. For a time of high load, the power might be rented. However, it is more typical to provide consumers in suitable locations with capacity credits so they may utilize their backup generation for the utility system. Depending on regulatory requirements, utilities may lease land to link generation if there are no nearby customers using DG or they may provide incentives to customers who add backup generation.

No one, by any means, agrees that this is a long-term fix for the dependability issue. Utility planners will most often admit the obvious but may not agree that the circumstance indicates an increase in dependability. Only the customer with the DG notices an increase in dependability if the feeder is down. The ser- vice reliability indicators have not changed much. It is impossible to count on customer creation to begin when necessary. Thus, it is impossible to anticipate an increase in dependability. This method of using customer-owned generating hides the real load increase. The possibility that the distribution system won't be able to handle the load in the long run increases when investment in cable infrastructure lags behind demand. It should be mentioned as well that when the distribution system is improved and there is no longer a limitation, the advantage of capacity alleviation is lost. As a result, the capacity credits made available for this application often have a short period of between six months and a year.

Where the DG should be situated on the distribution feeder, if one had to make a decision? The ideal DG siting issue is comparable to the ideal shunt capacitor bank siting problem. The main variation is that the item being added creates watts in addition to vars, but many of the same techniques may be utilized. The same general principles also apply. The ideal location for loss reduction and capacity alleviation, for instance, is around two-thirds of the way down the main feeder assuming the load is evenly distributed along the feeder. Computer programs are needed to analyze the issue when there are more generators to take into account.

Generally speaking, the utility has no control over where feeder-connected DG is located. The issue is figuring out if the provided site offers any capacity-related benefit to the power distribution system for customer-owned generating. Algorithms for optimal siting may be used to compare the relative worth of potential locations. The extra load that may be serviced in relation to the size of the DG is one way to assess the utility of DG in a given site. Transmission networks are very intricate systems that may sometimes be restricted by a tiny region that has an impact on a broad geographic area. Several times that amount of load may be provided by the system with a relatively little amount of load decrease in the limited region. Distribution feeders might also have this impact. There is often not a severe enough constraint that DG application will permit the servicing of additional load many times more than the size of the generator due to the simple, radial construction of most feeders. But there can also be a multiplicative impact.

The limitation is assumed to be on the feeder rather than the substation in this scenario. No extra load could be serviced on the feeder even if 1 MW of generation were installed in the sub-station since no feeder relief was obtained. However, the total feeder load may often increase by as much as 1.4 MW if there is a suitable site on the feeder. This is a common upper limit for this radial distribution feeders DG benefit measure. The use of DG to prepare for emergencies is a further use that is growing in popularity. In the past, utilities have constructed enough wire-based distribution capacity to handle the peak demand in the event of a significant failure. This is done at the distribution feeder level by connecting enough feeders to other feeders to allow for easy switching of the load to a different feeder in the event of a breakdown. Additionally, the substation must have enough capacity to handle both the regular load and the extra load that will be shifted over in the event of a breakdown. When the system is operating normally and there are no breakdowns, this leads to a significant overcapacity.

Providing support for feeders when it's essential to transfer them to a different source while repairs are completed is one potentially beneficial economic use of DG. Using the DG on the feeder for this objective. This will be far less expensive than adding a new feeder or updating an existing substation to account for this eventuality. In this instance, the DG is situated close to the connection point of two feeds. Although there are often advantages to running the DG during peak load, it is not always employed for feeder support under normal circumstances. The open tie switch is closed to pick up load from the other side when a failure takes place on either side of the tie. To assist in supporting the backup feeder, the DG is activated and linked. The utility has greater flexibility and reconfiguration choices by placing the DG in this location. Diesel gensets are now the most used DG technology for this application. When a specific circumstance renders the system vulnerable, the gensets may be installed on trailers and only rented during the peak demand season. A pad-mounted transformer and a recloser with a DG protection relay may be used to connect one or more units. This results in a small and secure hookup package utilizing tools that utility workers are used to using[4]–[6].

DISCUSSION

Interconnection Standards

This section examines the requirements for connecting DG to distribution networks. We provide two instances to show the variety of interconnection protection requirements.

Work on Industry Norms

In the US, there have been two significant DG connectivity standardization initiatives. To satisfy the needs of inverters used in solar systems linked to utility systems, IEEE Standard 929-20005 was created. All technologies needing an inverter interface have typically been subject to the standard. The anti-islanding strategy is one of the primary challenges this standard addresses. The main concept is to put a destabilizing signal into the switching control such that, if left to run alone, the control would rapidly wander in frequency while still believing it is linked. Agreement was obtained on a standard direction to drive the frequency amid concerns that manufacturers might individually choose techniques that would cancel each other out[7], [8]. As of the time of this writing, it has not been accepted.

The goal is to create a nationwide standard that will govern how all DG types are connected to both radial and network distribution systems. This initiative, which seems to be convergent, has been joined by vendors, utilities, and end users. The method chosen here is generally consistent with the topics covered in this article, and this proposed standard tackles many of the problems mentioned.

Voltage Control: Unless an exception is made and a specific agreement is struck with the utility, DG must not seek to adjust voltage while interconnected. As was previously said, this often implies that the DG will run at a constant power factor or constant reactive power output in accordance with the system's functioning. To attain a certain power output level, inverters in utility-interactive mode would normally function by creating a current that is in phase with the voltage.

Anti-islanding: The DG must have relays that can recognize when it is acting as an island and cut off the power supply. When disconnected from the utility source, inverters should naturally drift in frequency in accordance with IEEE Standard 929-2000. In applications of susceptible DG, relaying should be used to identify potential resonance circumstances.

Fault finding: DG must have relays that can identify utility system problems and cut power after a delay of generally 0.16 to 2.0 seconds, depending on how far from the norm the fault is. For the initial reclose period, DG should disconnect far enough in advance to give temporary faults time to clear. However, the tripping shouldn't happen too quickly to avoid bothersome DG tripping. The 0.16-second delay is there to prevent problems on the nearby feeder or the transmission system from needlessly trip- ping the DG. For this application, settings for voltage and frequency relays are suggested. The cutoff voltages are nominal recommendations, and certain applications may need modifications. Decreased voltage trip levels are a frequent adjustment used to prevent parallel feeder faults from unnecessarily trip- ping the feeders. For instance, problems on parallel feeders can result in voltages of less than 50%, necessitating a setting reduction on the 10-cycle trip to about 40%. You may modify the frequency trip parameters to meet local requirements. When a significant generating plant or a tie-line is lost, some utilities may prefer that bigger DG stay linked to a much lower frequency to aid with system stability concerns.

Travel via Direct Transfer: Direct transfer trips should be used so that the DG interconnect breaker trips simultaneously with the utility breaker in cases where it is difficult to identify islands and utility-side faults or when it is not feasible to coordinate with utility fault-clearing equipment. When DG is allowed to function with automated voltage management, a transfer trip is often advised since the likelihood of an accidental island is substantially higher. Transfer trips are typically only used on big DG systems since they are somewhat expensive. These conditions are met by two relaying systems that are shown.

A straightforward link

Small systems that are not anticipated to be able to sustain islands on their own are covered by the protection plan in. What what qualifies as a "small" DG system is a matter of debate. Others could limit this to less than 10 kW. Some utilities draw the line at 30 kW. Some may accept sizes up to 100 kW or more for this kind of interface protection. Even for large DG systems, the two relaying functions are anticipated to handle the majority of the work. Large systems have more relaying to provide them a bigger safety margin. Small DG systems would typically be wired at secondary voltage levels to the load bus. Although there may be separate metering, there wouldn't be a separate transformer. Circuit breakers with molded cases provide overcurrent protection. The primary DG interface protection features are:

1. Under/over voltage
2. A range of frequency

Depending on the required mode of operation, these relays may be used to trip either the generator breaker or the main service breaker. For most loads using modest cogeneration or peaking generators, tripping just the generator leaves the load connected, which is probably the intended behavior. However, if a disruption occurs while the DG system is in operation, the utility may insist on tripping the main breaker. If the DG system is to be utilized as backup power, the main service breaker would also be tripped so that the DG system may continue to provide the load off-line. It should be highlighted that certain restrictions could be necessary to ensure a smooth transfer. It's not always simple to complete.

Utility-side disturbance detection is mostly the task of the over/under voltage relay. No frequency variation should occur until the utility fault interrupter opens. The overcurrent relaying may also detect the problem if it is extremely near to the generator connections point and the voltage sag is severe. This will be based on the DG system's capacity to provide fault current. In the event of an internal malfunction, the DG system must be protected by overcurrent breakers. An island develops once the distribution feeder is cut off from the utility bulk power system. Then, the voltage and frequency relays cooperate to find the island. Normal expectations would be for the voltage to rapidly drop and for the undervoltage relay to notice it. If for some reason this does not occur, the frequency should immediately leave the extremely restricted band predicted so that the 81 O/U relay would notice it.

An intricate web of Connections

The second protection system shown here is the polar opposite of the straightforward plan that defines the essential elements of a real distribution-connected DG installation that makes use of a primary-side recloser. For a big synchronous generator, this is an interconnection protection system. The reader is directed to manufacturers of DG packages whose literature discusses the several different alternate methods that may also be used in great detail.

Generators in the 1- to 10-MW range would likely be associated with a big DG installation on the distribution system. Most generators bigger than this will have relaying comparable to utility central station generation and be linked at the transmission level. In this illustration, a primary-side utility breaker is present, and utilities normally employ a standard three-phase recloser for this kind of breaker. This switchgear package is easy for utilities to install and is likely the least expensive as well. The recloser already supports overcurrent relaying, and an additional DG relay package that uses a different potential transformer has been installed. This primary breaker is used to separate the generator from the utility or to verify that it does so. The system's relaying components and their roles are as follows.

Principal side

Standard under-/overvoltage relay: This is the primary method for locating faults and islands. There may be a separate relay for that function, or this may be used to prevent the breaker from shutting until there is electricity on the utility system.

Relay for negative voltage sequence: This is a backup method for identifying utility-side defects, which in certain circumstances may be more sensitive than voltage magnitudes. Additionally, even though there is another relay for that here, it aids in preventing unbalance-related generator damage.

Instantaneous overvoltage: This extra islanding detecting feature is used. When ferroresonance or other resonance phenomena are expected, this would be used. This would happen if utility-side capacitors and the generator response interacted. The time delay is substantially shorter than for the other relays because such overvoltages might rapidly cause damage, but it is not so short that it trips on utility capacitor-switching transients. On the potential transformer, this relay is mounted in the corner of a broken delta connection. The zero-sequence voltage is measured via a supplementary fault and islanding detection relay function. This would be used to identify situations when the generator is grounded due to an SLG failure. It is more important when the transformer's main connection is an ungrounded-wye or delta connection.

If there is no high-side breaker, these relaying operations may be relocated to the secondary side of the service transformer. The primary breaker on the secondary side would then be tripped by the relays. Since net export is anticipated, no reverse power function is used at this interface. Accountable for triggering the main breaker in the event that the generator system has a breakdown. may potentially trip if there are problems with the utility system the generator serves. To prevent accidental trippage, the time delay must be synchronized with the other relays.

The information in this chapter might easily give readers the notion that connecting a DG plant to the distribution system is rife with Gordian knot-like tangling power quality issues. However, given that the overall penetration is still rather low, there shouldn't be many issues with the majority of DG applications in the foreseeable future. Although there is a limit, a significant quantity of DG can be handled without impairing the performance of the distribution system. The grid's capacity is limited[9], [10]. Generally speaking, issues start to arise when the combined connected DG capacity exceeds 15% of the feeder capacity. This might decrease to as low as 5% of capacity on more rural feeders or up to 30% if the DG is concentrated close to the structure. Frequently, voltage control issues are the first to surface, followed by interference with utility fault-clearing, which includes islanding concerns. Almost any quantity of DG can be accommodated with a few adjustments. The simple, inexpensive distribution system design must be replaced with a more effective one as the number of DG rises. Although it will almost definitely cost more, engineers can still make it work. Who pays for it is another story?

According to others, communications and control will be crucial in a world with widely dispersed generation. Today, local intelligence that operates independently controls the majority of distribution networks. Fast, integrated communications networks would be very advantageous for systems with high DG penetration. If DG is to be a successful contributor to dependable, high-quality electric power, this is one technological development that must go along with its expansion[11], [12].

CONCLUSION

Overall, siting distributed generation requires a careful and thorough analysis of various factors, including resource availability, proximity to electrical loads, environmental impact, and regulatory requirements. By selecting the most suitable location, the benefits of distributed generation can be maximized, including reduced energy costs, improved grid resilience, and increased use of renewable energy sources.

Successful siting of distributed generation requires careful planning and coordination between various stakeholders, including developers, utilities, regulators, and local communities. Effective communication and engagement with local communities is particularly important, as they may have concerns about the potential environmental impact and visual aesthetics of the generation system.

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CHAPTER 23

A BRIEF DISCUSSION ONWIRING AND GROUNDING

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ABSTRACT:

Wiring and grounding are essential components of any electrical system, and play a critical role in ensuring the safety, reliability, and performance of the system. Wiring refers to the physical connections between electrical components, while grounding refers to the process of connecting electrical equipment and structures to the earth. Proper wiring is crucial for ensuring that electrical power is safely and reliably distributed throughout a system. This involves selecting appropriate wire sizes and types, using proper connectors and termination methods, and ensuring that wiring is installed and maintained in a neat and organized manner. Improper wiring can lead to power loss, equipment damage, and even electrical fires.

KEYWORDS:

Bonding, Electrical Safety, Ground, Fault, Lightning Protection.

INTRODUCTION

Wiring and grounding issues are the cause of many power quality variances in client facilities. It is often said at conferences on power quality and in publications that 80 percent of all power quality issues that customers notice are due to wiring and grounding issues at a facility. Although it may be exaggerated, many power quality issues may be fixed by simply tightening a loose connection or replacing a conductor that has become corroded. Therefore, when assessing power quality issues generally, a review of wiring and grounding techniques is a crucial initial step[1]–[3].

The basic requirements for wiring and grounding are provided by the National Electrical Code®* and other significant standards. To create a system that also minimizes the effects of power quality changes on connected equipment, it is sometimes required to go above and beyond the criteria of these standards. The basic concepts of wiring and grounding are presented in this book to provide the reader at least a rudimentary grasp of why things are done, even if the intention of the book is to focus on topics that are more susceptible to engineering analysis. An electrical circuit or piece of equipment that is linked to the earth or to another conducting body of comparatively great size that functions as the earth either intentionally or accidentally. It is used for transmitting ground current to and from the earth as well as for creating and maintaining the earth's potential, or a potential that is close to it, on conductors connected to it.

Unanchored System

A circuit, system, or equipment that does not intentionally connect to ground, unless it is done so by potential measuring, indicating, or other extremely high impedance devices.

Anchored System

A conductor arrangement in which at least one conductor or point is purposefully grounded, either directly or indirectly, using an impedance.Solidly linked directly with a suitable ground connection that hasn't had any deliberate resistance added to it. Grounding in place for all system circumstances, the ratio of zero sequence reactance to positive sequence reactance must be positive and less than 3, and the ratio of zero sequence reactance to positive sequence reactance must be positive and less than 1. This is known as being grounded via a suitably low impedance. Resistance was met. grounded by impedance, whose main constituent is resistance.Grounded inductance grounded by impedance, whose primary component is inductance.

Electrode for grounding

The grounding electrode must be as close to and ideally in the same location as the system's grounding conductor connection as is reasonably possible. The closest available successfully grounded structural metal part of the structure, the closest accessible effectively grounded metal water pipe, or other electrodes in the absence of the electrodes listed in and should serve as the grounding electrode. Grounded connected to the ground or to a conducting body that acts as the earth's substitute. A system or circuit conductor that has been purposefully grounded. A grounding conductor is a conductor that connects a grounding electrode or electrodes to a piece of machinery or the grounded circuit of a wiring system.

The grounding electrode conductor and/or the system grounded conductor at the service equipment or at the source of a separately derived system are connected to the noncurrent-carrying metal components of the equipment, raceways, and other enclosures via the grounding conductor, equipment. The conductor used to link the grounding electrode to the grounded conductor of the circuit and/or the equipment grounding conductor at the service equipment or at the source of a separately derived system. System of grounding electrodes Described in NEC Section 250-81 as consisting of a ground ring, a metal subterranean water pipe, and the building's metal frame. To create the grounding electrode system, these components must be linked together when they are accessible. If a metal underground water pipe is the sole option for a grounding electrode, one of the grounding electrodes listed in Section 250-81 or 250-83 must be added to it.

Bonding jumper, primary the connection at the service entry between the grounded circuit conductor and the equipment grounding conductor. Between the final overcurrent protector safeguarding the circuit and the outlets, branch circuit the circuit wires. The permanent connection of metallic components to create an electrically conductive tunnel is known as a conduit enclosure bond. This ensures electrical continuity and the ability to properly transmit any current that may be imposed. All circuit cables between the final branch circuit overcurrent device and the service equipment of the system's source that was independently generated. Outlet a location on the wire system where current is drawn to power use devices.

Overcurrent is any current that exceeds a conductor's capacity or the rated current of a piece of equipment. Overload, short circuit, or ground fault might be at blame. A panel of Buses, automatic overcurrent devices, and switches for controlling light, heat, or power circuits are all included in a single panel or a collection of panel units intended for assembly into a single panel. These panels are intended to be installed in cabinets or cutout boxes that are positioned in or against walls or partitions and are only accessible from the front. A premises wiring system that derives its power from a generator, a transformer, or converter windings and doesn't have a direct electrical connection, such as a securely linked grounded circuit conductor, to supply conductors coming from another system is known as a separately derived system.

Service equipment refers to the necessary tools, typically a circuit breaker switch, fuses, and their accessories, placed close to the point where supply conductors enter a building or other structure, or in another specifically designated area, and intended to serve as the primary control and means of supply cutoff. A grounding technique or connection to the soil in which the building's reinforcing steel, particularly at the base level, acts as a grounding electrode.

DISCUSSION

Reasons for Grounding

Safety is the main justification for grounding. Personnel safety and power quality are two crucial considerations when it comes to grounding standards. The main justification for requiring a safety equipment ground on all machinery is to ensure employee safety. This is intended to avoid the potential for excessive contact voltages in the case of an equipment malfunction. The voltage between any two conducting surfaces that may be touched by a person simultaneously is known as the touch voltage. One of these surfaces might be the earth[4]–[6].

Electric circuits shouldn't be close to "floating" panels or enclosures. Any electric charge that occurs on a panel, enclosure, or raceway must be drained to "ground" or to a reliable grounded item in the case of insulation failure or unintentional application of moisture. Grounding ensures the functionality of a protective device.

An important safety element is a ground fault return line to the location where the neutral conductor of the power source is grounded. Electrically continuous conduit and wire device enclosures may be used as this ground return channel in accordance with the NEC and certain municipal wiring regulations. Some rules demand that a bare or insulated conductor be added to the conduit along with the other power conductors.

A low-impedance route back to the power source neutral will be found in the event of insulation failure or another issue allowing a phase wire to make contact with an enclosure. The circuit breaker or fuse will quickly disconnect the faulty circuit as a consequence of the ensuing overcurrent. An effective grounding path must meet the following requirements: a. be permanent and continuous; be able to safely conduct any fault current that may be imposed on it; have sufficiently low impedance to limit the voltage to ground and to make it easier for the circuit's circuit protective devices to operate; and d. not use the earth as the only equipment ground conductor.

Noise reduction

Transients from all sources are included in noise control. Here, grounding and power quality are related. The minimal specifications for a grounding system are defined by grounding for safety reasons. The NEC and local codes' minimal standards must be met in addition to whatever that is done to the grounding system to enhance noise performance. Creating an equipotential ground system is the main goal of grounding for noise reduction. Potential discrepancies between several ground sites may cause insulation to become stressed, result in circulating ground currents in low-voltage cables, and interfere with sensitive equipment that may be grounded numerous times. When the equipment grounding wires are linked to the grounding point of a single power source, the ground voltage equalization of voltage discrepancies between components of an automated data processing grounding system is partially completed. It is challenging to maintain a consistent potential throughout the grounding system, especially for high-frequency noise, if the equipment grounding wires are lengthy. For enhancing the power quality, additional conductors, ground grids, low-inductance ground plates, etc. may be required. These must be utilized in addition to, not in instead of, the equipment ground conductors, which are necessary for safety.

Common Wiring and Grounding Issues

Typical wiring and grounding issues in electrical systems are the cause of several power quality issues. When doing site surveys, it is helpful to be aware of these common issues since many of them may be identified via simple observations. Other issues call for circuit impedance, current, or voltage measurements.

Lack of a safety ground

A defect in the equipment from the phase conductor to the enclosure causes line potential on the exposed surfaces of the equipment if the safety ground is absent. No breakers will trip, creating a dangerous situation.

Multiple connections from neutral to ground

The sole neutral-to-ground bond should be at the service entry, barring an independently derived system. All panel boards and junction boxes should keep the neutral and ground apart. Parallel routes for the load return current are created by lateral neutral-to-ground links, one of which forms the ground circuit. Protective devices may malfunction as a result of this. Additionally, the fault current will divide between the neutral and the ground during a fault state, which can impair the correct functioning of protective devices. The NEC is being directly broken here.

Ungrounded machinery

Sometimes isolated grounds are utilized because it is thought that they would provide a "clean" ground. An isolated ground must be used in accordance with the correct process. The use of unlawful insulating bushings in power source conduits and the substitution of a "isolated dedicated computer ground" for the required equipment grounding cable are risky, against code, and unlikely to be effective in reducing noise.

When all of the building's grounding electrodes are joined together, a facility grounding system should be connected using ground rods. At the service entry, many ground rods may be bused together to lower the total ground resistance. As previously mentioned, sensitive equipment might be employed on isolated sites. These shouldn't, however, include separate ground rods that would serve as the equipment's new ground reference. The fact that extra ground rods offer more channels for lightning stroke currents to travel is a very significant power quality issue. Any lightning stroke current that enters the facility via the service entry is grounded at the entrance by the ground rod, raising the facility's ground potential as a whole. If there are extra ground rods, some of the lightning stroke electricity will travel through the building wiring to reach them. This might lead to equipment transient voltage issues and potential overload issues for the contractors.

Floor Loops

In many commercial and industrial settings that use data processing and communication devices, ground loops are one of the most significant grounding issues. A ground loop develops when a communication wire connects two grounded devices that are grounded separately and provides a second ground connection. If there is a full route, then slightly differing potentials in the two power system grounds may result in cycling currents in this ground loop. The insulation levels in communication circuits are often relatively low, so even if there isn't a full channel, it's possible that it may flash over.

Similar to this, even little amounts of circulating current might result in significant noise issues. Using optical couplers in the communication lines, which eliminates the ground loop and provides sufficient insulation to tolerate transient overvoltages, is often the best solution to this issue. The grounded conductors in the signal line may need to be augmented by stronger conductors or greater shielding if this is not practicable. Due to the possibility of coupling with signal circuits, equipment on both ends of the cable should be safeguarded by arresters in addition to the better grounding. Fluorescent lighting with electronic ballasts and switch-mode power supply are often employed in business settings. The need for the neutral conductor rating for the supply circuits might be significantly impacted by the high third-harmonic content inherent in these load currents. The zero-sequence circuit in a balanced system exhibits third-harmonic currents. This implies that, unlike the 60-Hz current, the third-harmonic currents from three single-phase loads will contribute to the neutral. The neutral current in typical commercial buildings with a variety of switched-mode power supply loads is generally between 140 and 170 percent of the magnitude of the fundamental frequency phase current.

The following are some potential remedies for neutral conductor overloading:

When using a three-phase circuit to power single-phase nonlinear loads, run a separate neutral wire for each phase. The neutral conductor capacity should be about double that of the phase conductor capacity when a shared neutral must be utilized in a three-phase circuit with single-phase nonlinear loads. For nonlinear loads, delta-wye transformers may be employed to restrict the penetration of strong neutral currents. The nonlinear loads and these transformers should be situated as closely as feasible. Based on the anticipated neutral current magnitudes, the neutral conductors on the secondary of each individually generated system must be rated. There are now available filters that may be installed at each individual load to regulate the third-harmonic current. These will provide as an option in installations that already exist when upgrading the wiring may be a costly endeavor. In order to reduce the route of third-harmonic currents and improve their dispersion, zigzag transformers provide a low impedance for zero-sequence harmonic currents and, like filters, may be positioned at different points along the three-phase circuit.

An Earth Electrode

The electrical connection between the power system ground and earth is made possible by the ground rod. The resistance of this connection is the main factor to consider when assessing the suitability of the ground rod. A ground rod's resistance is made up of these three fundamental elements:

1. **Resistance of an electrode:** Due to the grounding wire's physical connection to the grounding rod, there is resistance.
2. **Resistance at the rod-earth contact:** Resistance brought on by the soil-to-rod interaction. This resistance is inversely proportional to the grounding rod's surface area.
3. **Ground opposition:** Due to the soil's resistivity near the grounding rod, there is resistance. Depending on the kind of soil and moisture level, the soil resistivity ranges widely.

Because it affects the transient voltage levels during switching events and lighting transients, the resistance of the ground-rod connection is crucial. A voltage across the resistance is produced by high-magnitude currents after lightning strikes, elevating the ground reference for the whole facility. At grounded equipment within the facility, the voltage differential between the ground reference and genuine earth ground will show, and this may lead to hazardous contact potentials.

Connections at the service entrance

At the service entry are the main parts of a system that is correctly grounded. At this point, the grounded conductor is linked to the supply power system's neutral point. Additionally, this is the only place in the system where a bonding jumper is used to link the grounded conductor to the ground conductor. The ground conductor is further linked to the building's ground electrode via the conductor for the ground electrode at the service entrance. The grounding electrode conductor should be exothermically welded at both ends for the most effective grounding. For the grounding electrode for buildings, there are many alternatives. The service entry is where all of the various grounding electrodes utilized in a building must be connected. The use of the following items as grounding electrodes is acceptable:

Water pipe that is Underground

Constructing Steel

Building steel may be used with a ground ring to provide the grounding electrode a better equipotential ground. A conductor no bigger than the ground ring conductor is used to link it to the primary grounding electrode. To keep all exposed conductors that could be touched at an equal potential throughout the system, a safety ground must be maintained. Additionally, this safety ground offers a ground fault return channel to the location where the neutral conductor of the power source is grounded. The conduit itself or the conduit and a different conductor within the conduit might serve as the safety ground. This safety ground starts at the service entrance and extends throughout the whole structure.

The panel board is the part of the system where a feeder from the service entry supplies the numerous branch circuits. The panel board links the grounded conductor of the branch circuit to the grounded conductor of the feeder circuit, as well as the ground conductor to the feeder ground conductor, conduit, and enclosure. It also provides breakers in series with the phase conductors. It's crucial to remember that the panel board shouldn't have a neutral-to-ground connection. The NEC forbids this neutral-to-ground connection because it would cause load return currents to flow between the panel board and the service entrance. There should be no load return current in the ground route in order to maintain an equipotential grounding system. Additionally, fault currents would diverge between the ground return channel and the neutral conductor. The fault current flowing in the earth route provides the basis for protection.

Provide the load with an isolated ground can occasionally enhance the noise performance of the supply to sensitive loads. Orange-colored, separate ground receptacles are used for this. If an isolated ground receptacle is utilized downstream of the panel board, the isolated ground conductor is solely linked to the ground conductor of the supply feeder and is not connected to the conduit or enclosure of the panel board. In this instance, the conduit serves as the safety ground and is attached to the enclosure. The safety ground may also be connected to a different conductor in addition to the conduit. The NEC, Article 274, and Exception 4 on Receptacles both specify this method. It isn't referred to as a grounding method[7]–[9].

For identification, the solitary ground container is painted orange. The ground conductor for this outlet is not connected to the enclosure or conduit for the outlet. Until grounded at the service entry or another independently derived ground, the isolated ground conductor may travel back via a number of panel boards without being linked to local ground. To prevent accidental connections between the isolated ground and the safety ground, isolated ground receptacles must be used with caution. Dedicated branch circuits, in general, provide the same goal as isolated ground receptacles without the need for intricate wiring. Some hospital equipment is grounded using a particular instance of isolated grounds. The NEC and the White Book both provide descriptions of these methods.

Separate Derivations of Systems

A system that is independently generated has a ground reference that is distinct from other systems. A delta-wye isolation transformer is a typical illustration of this. In order to provide a fresh ground reference that is separate from the rest of the system, the wye-connected secondary neutral is linked to the local building ground. In that the system neutral is linked to the grounded conductor, which is connected to the ground conductor using a bonding jumper, the point in the system where this new ground reference is established is like a service entry.

Sensitive loads are given a local ground reference using independently determined techniques. If an isolation transformer is utilized to power the independently derived system, the noise levels in the local ground reference may be significantly lowered when compared to the system ground. Neutral currents are restricted to the load side of the independently generated system, which provides an additional advantage. When there are a lot of single-phase nonlinear loads, this may assist lower neutral current magnitudes in the system as a whole.

Grounding methods for Reference Signals

The safety and correct functioning of protection devices are the main issues for the grounding criteria that were previously discussed. Additionally, grounding is utilized to provide equipment exchanging signals across communication or control circuits within a facility a signal reference point. The specifications for a safety ground and a signal reference ground are often significantly different. When constructing a grounding strategy, the safety ground needs must always come first.

The most crucial requirement for a signal reference ground is that it have low impedance across a broad frequency range. Using a ground conductor that is the right size is one approach to do this. Because it depends on connections staying intact and has a high impedance in comparison to the phase and neutral conductors, conduit is particularly bad for serving as a signal reference ground. High impedance is a concern with undersized ground conductors as well. The ground conductor should be at least the same size as the phase conductors and the neutral conductor in order to minimize power quality issues.

As frequency rises, the wavelength shortens to the point where comparatively small wire lengths may experience resonances. A decent rule of thumb is that the ground conductor loses its effectiveness at a frequency when its length exceeds one-twentieth of the signal wavelength. There is really a complex impedance vs frequency characteristic involved since the grounding system is more intricate than a straightforward conductor. A signal reference grid, sometimes known as a zero-reference grid, is one approach to provide sensitive equipment a signal reference ground that is effective across a broad range of frequencies. This method makes use of a rectangular copper wire mesh with spacing of around 2 feet. It is often used in rooms with huge data processing equipment. Due to the many courses that current might take, even if a portion of the conductor system is in resonance at a certain frequency, other parts of the grid will always be out of resonance. The enclosure of each piece of equipment must still be connected through the ground wire to a single common ground when employing a signal reference grid. To provide a high-frequency, low-impedance signal reference, the enclosures may also be linked to the nearest interconnection of the grid. The impact of the ground impedance against frequency characteristic of the signal reference grid as a whole.

How to ground sensitive equipment, in more detail

Any installation with equipment that might be susceptible to noise or disturbances brought about by coupling in the ground system should follow the recommended practices:

1. When feasible, power delicate equipment with isolated branch circuits. Branch circuits on their own provide effective isolation from noise and high-frequency transients.
2. For delicate equipment, conduit should never serve as the only source of grounding. Communications and electronics may be interfered with by currents running on the pipe.
3. The individual circuit conduit should be joined at both ends, and the green-wire grounds should be the same size as the current-carrying conductors.
4. When possible, use building steel as a ground reference. A building's steel often serves as a great, low-impedance ground reference. Additionally to the building steel, additional ground electrodes may be employed.
5. These procedures are often used in computer rooms, where the frequency response of the grounding system is even more crucial owing to the need of communication between various computer system components:
6. Use the elevated floor as a signal reference grid, or construct a signal reference grid below it. This does not take the place of the safety ground, but rather improves it in terms of noise reduction.
7. To create a regulated capacitive and magnetic coupling noise bypass between the reinforced steel of the building and the electrical ground wires, place a transient suppression plate at or close to the power entry point

CONCLUSION

In summary,any electrical system must have adequate wiring and grounding since they are crucial to the system's efficiency, dependability, and safety. When wiring is done properly, the right connections and termination techniques are used, the right wire sizes and kinds are chosen, and the wiring is placed and maintained in an orderly fashion. By using grounding electrodes, conductors, and other components, it is possible to ground electrical apparatus and buildings. Achieving good wiring and grounding in any electrical system requires adhering to relevant rules and standards, employing the right supplies and tools, and working with qualified experts. It's crucial to adhere to relevant laws and standards, utilize the right supplies and tools, and collaborate with qualified experts if you want to assure good wiring and grounding. To guarantee the continuous safe and dependable functioning of wiring and grounding systems, regular inspection and maintenance are also essential.

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CHAPTER 24

A BRIEF DISCUSSION ON POWER QUALITY MONITORING

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ABSTRACT:

Power quality monitoring is a process that involves measuring and analyzing various parameters of electrical power to ensure that it meets the necessary standards for safe and efficient operation of electrical equipment. This process is essential for identifying and resolving power quality issues that can cause equipment damage, production downtime, and financial losses. Power quality monitoring typically involves the use of specialized instruments such as power quality analyzers, which can measure a wide range of parameters including voltage, current, frequency, power factor, harmonics, and transients. These instruments can provide real-time data on power quality, allowing operators to quickly identify and diagnose issues as they occur.

KEYWORDS:

Current Transformers, Distortion, Electrical Measurements, Harmonic, Oscilloscopes.

INTRODUCTION

Gathering, evaluating, and turning raw measurement data into information is the process of power quality monitoring. Data collection is often done by measuring voltage and current continuously over a lengthy period of time. Traditional analysis and interpretation were carried out manually, but recent developments in the fields of signal processing and artificial intelligence have made it possible to design and implement intelligent systems to automatically analyze and interpret raw data into useful information with little to no human involvement[1].

Programs for power quality monitoring are often motivated by the need to enhance system-wide power quality performance. It is particularly crucial to comprehend the quality of the electricity being given since many industrial and commercial clients have equipment that is sensitive to power interruptions. These facilities include ones for computer networking and communications, ones for producing semi-conductors and electronics, ones for biotechnology and pharmaceuticals, and ones for financial data processing. As a result, several utility companies have put in place significant power quality monitoring systems during the last 10 years.

Considerations for Monitoring

One should clearly establish the monitoring goals before starting any power quality monitoring activity. The selection of monitoring tools, trigger thresholds, techniques for data collection and storage, and the demands for analysis and interpretation are often influenced by the monitoring goals. Here is a list of a few typical goals for power quality monitoring. Monitoring to assess the performance of the system. The most general criterion is this. This purpose could be significant to a power producer if it wants to understand system performance and then match that performance to customer demands. A proactive method of power quality monitoring is system characterization. Understanding a system's typical power quality performance allows a provider to see issues as soon as they arise and to supply its clients with knowledge that will enable them to match the features of their sensitive equipment with actual power quality characteristics.

Short-term monitoring is a common method used by power quality service departments or plant management to address issues at particular customer locations or with challenging loads. Although this technique of power quality monitoring is reactive, it typically pinpoints the root of equipment incompatibility, which is the first step in a remedy. As part of a better service for power quality monitoring. Many energy providers are presently thinking about adding new services to their customer offerings. Offering varied degrees of electricity quality to meet the demands of various consumers would be one of these services. This objective may be met by a provider and a customer working jointly by putting equipment on the customer's property or changing the power infrastructure. In either scenario, monitoring is crucial to determining the standards for the differentiated service and ensuring that the utility meets the agreed-upon standards for power quality. Monitoring as a component of preventative or just-in-time maintenance. Power quality data obtained over time may be examined to offer details on the performance of certain equipment. For instance, repeated capacitor-switching restrikes may indicate an approaching failure of the capacitor-switching mechanism, much as repeated arcing faults from an underground cable may indicate an impending cable failure. Equipment upkeep may be swiftly requested to avoid catastrophic failure, hence averting significant power quality disruptions that would eventually affect the performance of overall power quality. The monitoring program must be created with the right goals in mind and make the information accessible quickly and in a comfortable format. A permanently placed monitoring system that automatically gathers data on energy usage, steady-state power quality conditions, and disruptions will be the most thorough monitoring strategy[2].

DISCUSSION

Monitoring as part of a facility site survey

Site surveys are carried out to assess issues with the functioning of the equipment and the quality of the electricity in a facility. The study will look at issues with wiring and grounding, equipment connections, and the facility's overall voltage and current characteristics. An essential component of the total audit is power quality monitoring, which is done in conjunction with infrared scans and visual inspections. The first site assessment need to be planned to gather as much data as possible regarding the client facility. When the monitoring purpose is to address particular power quality issues, this information is very crucial. The details are outlined here.

1. The nature of the issues
2. Specifications of the problematic sensitive equipment
3. The times when issues occur.
4. Coincident difficulties or operations that happen at the same time that are known to happen.
5. Potential causes of the facility's fluctuating power quality.
6. Use of current power conditioning equipment.
7. Electrical system information

A site assessment should be carried out to confirm the one-line diagrams, electrical system data, wire and grounding integrity, load levels, and fundamental power quality characteristics once these fundamental data have been collected via conversations with the client. There are supplied data forms that may be utilized for this preliminary assessment of the power distribution system. They may be used to arrange the facility's power quality monitoring data.

Choosing what to Watch

Power system conditions fall under the broad category of power quality. Important disruptions may include long-term overvoltages brought on by a regulator tap switching issue, current chopping during circuit interruptions, or very high frequency impulses brought on by lightning strikes. The variety of situations that must be described poses problems for the performance specifications of the monitoring equipment as well as the requirements for data collecting. 2 provides information on several power quality variation categories, techniques for characterizing the differences, and common disturbance sources.

For the needs of monitoring, the techniques for describing ac power quality are crucial. For instance, high-frequency waveform sampling is necessary to characterize the majority of transients. A plot of the rms voltage against time may be used to identify voltage sags. A time frame is all that is needed to describe an outage. Steady-state sampling is necessary for the monitoring of harmonic distortion levels and typical voltage changes, and the data must be analyzed for trends over time. It may be expensive in terms of gear, communications costs, data administration, and report creation to conduct extensive monitoring of all the many sorts of power quality variations at several sites. As a result, the goals of the endeavor should be used to set the monitoring priority. A sufficiently thorough monitoring effort should be included in projects to benchmark system performance. Only steady-state monitoring of harmonic levels may be necessary for projects intended to assess conformity with IEEE Standard 519-1992 for harmonic distortion levels. Other initiatives aimed at solving certain industrial issues would just need to monitor rms changes, such voltage sags[3]–[5].

Selecting the Monitoring Sites

Of course, in order to fully comprehend the system's total power quality, we would want to keep an eye on circumstances almost everywhere. However, the cost of such monitoring can be unaffordable, and there are difficulties in data administration, processing, and interpretation. Fortunately, because measurements gathered from a number of strategically placed points may be utilized to derive features of the entire system, collecting measures from every conceivable position is often not required. Therefore, it is crucial that the monitoring sites be properly chosen depending on the monitoring goals. Here are some examples of how to choose a monitoring site. The actual feeder circuits were monitored since it was the main goal, to quantify power quality on principal distribution feeders. Two other locations were chosen at random, and one monitor was placed close to the substation. The entire project findings reflected power quality on distribution feeders generally by selecting the distant locations at random. However, assuming that the three chosen locations accurately represented the power quality on each of the individual feeds involved may not be feasible.

The monitoring locations should be at actual customer service entrance locations when a monitoring project involves characterizing specific power quality issues that are actually being experienced by customers on the distribution system because it includes the impact of step-down transformers supplying the customer. Data gathered at the service entry may also be used to describe harmonic distortion levels and client load current variations. The added benefit of monitoring at customer service entry sites is lower transducer expenses. Additionally, it offers clues as to where the disturbances originated, i.e., on the utility or customer side of the meter. Locating the monitors as near as feasible to the equipment impacted by power quality changes is another crucial component of the monitoring site when characterizing particular power quality issues. The monitor must display the same fluctuations as the sensitive equipment in order to function properly. If there is a large distance between the monitor and the afflicted equipment, high-frequency transients in particular may vary dramatically. Monitoring at the substation and certain customer service entry sites is a suitable compromise strategy. Because it serves as the PCC for the majority of rms voltage changes, the substation is important. All consumers on other feeders supplied from the same substation bus suffer the voltage sag observed at the substation during a feeder malfunction. The service entry sites for monitoring are determined by the sensitivity of the customer equipment and its placement on a feeder. For example, it is advantageous to be situated just downstream from each protective device on the feeder. The idea of a monitoring system based on customer and substation monitoring. It also shows how knowledge may be made available to everyone who is interested through the Internet.

Options for devices to permanently Monitor Power Quality

Permanent power quality monitoring systems, like the system, ought to make use of the vast range of hardware that could be able to capture data on power quality. The following are some of the equipment categories that may be used in an overall monitoring system:

Fault recorders in digital form: The majority of substations may already have them in situ. The gadgets are not specifically made by DFR manufacturers for power quality monitoring. The voltage and current waveforms that characterize the fault event are often recorded by a DFR, which normally triggers on fault occurrences. They are thus useful for defining rms disturbances during power system problems, such as voltage sags. For determining harmonic distortion levels, DFRs can provide periodic waveform capture.

Other IEDs and smart relays: There are many different kinds of substation equipment that might be an intelligent electronic gadget with monitoring capabilities. Manufacturers are including the capability to record disturbances and provide the information to an overall monitoring system controller in equipment like relays and reclosers that monitor the current anyhow. Both at the substation and on the feeder circuits are possible locations for these devices.

Voltage monitors: To keep track of steady-state voltage changes in distribution networks, power companies use a variety of voltage recorders. More and more complex models are appearing, fully able to describe transient voltage sags and even harmonic distortion levels. The maximum, lowest, and average voltages within a certain sampling window are often provided as a trend by the voltage recorder. The recorder can accurately assess the amount of a voltage sag using this kind of sampling. It won't, however, provide the length with a resolution of less than 2 s.

Power monitoring within the facility: Industrial facility monitoring systems now often contain some power quality features. These monitors may be used as a component of a utility monitoring program, especially those situated near the service entry. Typical capabilities include triggered waveshape captures for voltage sag circumstances, voltage profiles for steady-state rms changes, and waveshape captures for harmonic distortion levels. Transient monitoring capabilities are uncommon for these sensors.

Power quality monitors with a specific function. The monitoring tool created for the EPRI DPQ project was especially designed to track any fluctuations in power quality. This device can measure voltage and current on all three phases in addition to the neutral. A 14-bit analog-to-digital board can sample current and voltage at a rate of 128 points per cycle and 256 points per cycle, respectively. Due to the high sampling rate, it was possible to detect voltage harmonics up to the hundredth and current harmonics up to the fifty-first. Most power quality measuring devices have the ability to capture both triggered and sampled data. For rms and transient variations, respectively, triggers should be based on waveshape and rms thresholds. An essential feature of these instruments is the simultaneous voltage and current monitoring with triggering of all channels during a disturbance. Substations, feeder sites, and customer service entry locations have all shown to benefit from the use of power quality monitors. Revenue meters already monitor voltage and current, thus it is sense to provide options for more sophisticated monitoring that may capture data on power quality. Almost all revenue meter manufacturers are headed in this way, and data from these meters may subsequently be integrated into a system for monitoring power quality as a whole.

Interfere with Monitor Connections

It is advised to power the monitor's input from a circuit different than the circuit being monitored. If the monitor is supplied by the same circuit that is being monitored, certain manufacturers' input filters and/or surge suppressors on their power supply may change the data that is being disturbed. An essential factor to consider is the power disturbance monitor's grounding. The disturbance monitor will include a ground connection for the instrument's power supply as well as a ground connection for the signal that will be monitored. The instrument chassis will be wired up to both of these grounds. Both of these ground terminals need to be linked to earth ground for safety reasons. However, if many circuits are involved, this might result in ground loops.

Priority one is safety: Therefore, if there is a question regarding what to do, the two justifications should be related. It could be conceivable to power the instrument from the same line that is being monitored if ground loops are a severe issue that might cause transient currents to harm the instruments or invalidate the results. The instrument might also be connected to only one ground and set down on an insulating mat. If it's conceivable for the instrument to become more potentially dangerous when compared to other equipment and ground references that the operator could come into touch with, proper safety precautions must be taken, such as employing insulated gloves while operating the instrument.

Setting Monitor Thresholds

Disturbance monitors are intended to detect abnormal circumstances. The range of situations that may be regarded as normal must thus be defined. As a place to start, some disturbance monitors feature pre-selected thresholds. The ideal method for choosing thresholds is to match them to the requirements of the affected equipment. Due to a lack of standards or application rules, this could not always be practicable. An alternate strategy is to first set the thresholds quite low, gather data, and then choose acceptable thresholds for longer-duration monitoring. Some monitoring systems tout the benefit of requiring no installations or thresholds to be established.

Naturally, there must be thresholds since no monitor has sufficient storage to record every cycle of the voltages and currents it is watching. In these situations, the instruments' thresholds are largely set, and algorithms may be changed internally depending on the disturbances being recorded. This kind of system is user-friendly since it is easy to set up, but it is still a compromise because you are unable to alter the thresholds depending on the local conditions at a certain site.

Measurement quantities and time frames

Sometimes monitoring merely the voltage signals is enough to characterize system disturbances. For instance, the voltages define the transients and voltage sags that can impact client equipment and provide information about the caliber of power being supplied to a facility. The currents connected to these disturbances, however, include a wealth of data that may be used to determine the source and whether or not equipment was harmed. Furthermore, if harmonics are a problem, current measurements are necessary because they capture the harmonic injection from the customer into the power system.

To describe how nonlinear loads on the system produce harmonics, current measurements are employed. These harmonic generation properties may be determined by measuring the current at distinct loads. A collection of loads or the whole facility may be identified as a source of harmonics by current measurements on feeder circuits or at the service entrance. Groups of consumers or a whole feeder may be described using the distribution system's current readings. Voltage measurements aid in describing how the system reacts to harmonic currents that are created. When resonance circumstances exist, significant harmonic voltage distortion will be present at certain frequencies. Voltages and currents must be monitored concurrently in order to determine the features of a system's frequency response from measurements. The simultaneous sampling of all three phases is required to quantify harmonic power flows. The monitoring's duration is determined by its goals. For instance, while utility system breakdowns are probably uncommon, monitoring may be necessary for a considerable amount of time if the goal is to resolve issues brought on by voltage sags during distant outages. It may be able to describe the circumstances over a few days if the issue includes capacitor switching. To gain a sense of how the load fluctuates and how system variables may impact these levels, harmonic distortion issues and flicker difficulties should be described over a period of at least one week. The length of the monitoring is becoming less important as permanent power quality monitoring systems are increasingly being used, taking use of the vast range of devices that may give data as part of the system.

Identifying the cause of a problem

Correlating a disturbance's waveform with potential causes is the initial step in determining its origin. Identification is much easier after a categorization for the reason has been established. The basic principles listed below might be useful:

Only areas near to the disturbance's source will see high-frequency voltage changes. Due to circuit resistance, low-voltage wiring often rapidly dampens out high-frequency components, thus these frequency components only show up when the monitor is placed near to the source of the disturbance. A very sudden shift in voltage will result from power outages near to the monitoring site. Due to the stored energy in spinning machinery and capacitors, voltage will decay in the event of a power outage far from the monitoring station. The capacitors that are producing resonance issues will be near to where the greatest harmonic voltage distortion levels will occur. In these circumstances, the voltage harmonic spectrum will often be dominated by a single frequency.

Instruments for Measuring Power Quality in the Past

In the past, monitoring devices were large, hefty boxes that needed a screwdriver to operate. Strip-chart paper was used to record the data that were gathered. Developed by General Electric in the 1920s2, a lightning strike recorder is one of the oldest tools for power quality monitoring. To document a lightning strike event, along with its time and date of occurrence, the device leaves an impulse-like imprint on strip-chart paper. Because the data were more qualitative than quantitative, it was challenging to analyze them. The device's main parts were two electrodes that created an arc on the paper and a wind-up clockwork motor that moved the strip of paper from one spool to the next.

It wasn't until the 1960s that Martzloff created a surge counter that could record the voltage waveform of lightning strikes. The device was an analog oscilloscope with a high level of persistence and a logarithmic sweep rate. The fact that this device's collected data were quantitative as opposed to qualitative marked it as an advance over its predecessor. By the middle of the 1960s, the trigger mechanism and programmed frequency response restrictions of power quality devices were widely known.When Dranetz Engineering Laboratories debuted the Series 606 power line disturbance analyzer in the middle of the 1970s, many engineers believe the first generation of power quality monitors had officially begun. Many of the original units of this microprocessor-based monitor analyser from 1975 are still in use today. These monitors displayed text-based output on a paper tape. According to the event type and voltage magnitude, the printout represented a disturbance. Compared to contemporary monitors, these monitors had fewer features, but the triggering mechanism was already well established.

Midway through the 1980s, second-generation power quality devices made their appearance. For viewing and storing collected power quality events, including transients and steady-state events, this generation of power quality monitors often included a complete graphic display and digital memory. Some sensors might transfer data to a central location for further analysis from a remote monitoring point. The fundamental criteria of the triggering mechanism were essentially perfected by second-generation power quality sensors. Data must be continually captured and processed without any downtime since the occurrence of a power quality disruption is very unpredictable. What data, and how much data, should be stored to the digital memory is decided by sophisticated triggering engines. Waveshape variations, fixed and floating limits and sensitivities, and particular event characteristic characteristics are all examples of trigger mechanisms. These techniques increase the likelihood that the user's vital information will be recorded and saved. The third-generation power quality devices first appeared in the middle of the 1990s. The EPRI DPQ project served as some of the inspiration for the third-generation power monitor development. A full power quality monitoring system was more suited for this generation of monitors, and software solutions to gather and handle the data were also created. Since the project's completion, extensive fieldwork has made clear some of the challenges involved in running a large system of power quality monitors:

As the number of monitoring sites increases, managing the enormous amount of raw measurement data that must be gathered, examined, and preserved becomes a significant difficulty. The amount of data that is gathered at each monitoring site might put a burden on the communication systems used to transfer the data from monitor to analysis point. A summary or shortened version of some occurrences, such typical capacitor switching, would be increasingly useful as knowledge of system performance improves thanks to the feedback supplied by the monitoring data.

Instead than gathering and storing vast amounts of intricate raw data, any monitoring system's true worth is found in its capacity to produce information. The knowledge gathered from the EPRI DPQ project led to the realization that a power monitoring program's information system component is crucial for monitoring power quality performance. Therefore, the most current generation of power quality monitors was developed to satisfy the new information system need, i.e., to be able to quickly distribute the information and uncover knowledge or information from the acquired data as they are taken. This kind of gadget makes use of cutting-edge communication and expert system technology.

Instruments for Measuring Power Quality

It is evident that power quality issues affect a variety of frequencies. They range from very brief transient overvoltages to protracted outages. Other issues with power quality include intermittent issues like voltage flicker and steady-state issues like harmonic distortion. Chap gave definitions for the various categories. 2. Power quality is characterized by a broad range of factors, which makes it challenging to design standardized measuring techniques and tools.

Many Instrument Types

Various instruments may be utilized based on the phenomenon being studied, despite the fact that instruments have been devised to measure a broad range of disturbances. the following fundamental sorts of instruments may be used:

1. Test equipment for grounding and wiring
2. Millimeters
3. Oscilloscopes
4. Disruption analysts
5. Spectrum analyzers and harmonic analyzers
6. Harmonic and combination disturbance analyzers
7. Flashing meters
8. Energy metering

The uses and restrictions of these various devices. In addition to these sensors, which directly assess steady-state signals or disturbances on the power system, there are other devices that may be used to identify issues with power quality by monitoring the surrounding environment: Finding loose connections and overheated conductors may be done with the use of infrared meters. This kind of system checkup should be done annually to help avoid power quality issues brought on by arcing, faulty connections, and overloaded conductors. Field strengths around the damaged equipment may need to be measured in order to solve noise issues caused by electromagnetic radiation. For reasons related to inductive coupling, magnetic field strengths are measured using magnetic gauss meters. For worries about electrostatic coupling, electric field meters can detect the intensity of electric fields.

In order to monitor static electricity near sensitive equipment, static electricity meters are specialized instruments. Some kinds of electronic equipment may have power quality issues as a result of electrostatic discharge. No matter what kind of equipment is required for a certain test, there are a number of crucial considerations that should be made while choosing the instrument. The number of instruments needed decreases as more tasks may be accomplished by a single instrument. We cover the fundamental types of instruments for direct measurement of power signals while keeping in mind that there is considerable overlap between the various instrument categories.

Grounding and Wiring Testers

Many power quality issues that end users have observed are brought on by wiring and/or grounding issues in the facility. These issues may be located visually by inspecting the wiring, connectors, and panel boxes as well as using specialized test equipment for finding wire and grounding issues. The following features are crucial for a wiring and grounding test device:

1. Isolated ground shorts and neutral-ground bonding detection
2. Measurement of or indication for ground impedance and neutral impedance
3. Detection of open neutrals, open hot wires, or open grounds
4. Detection of neutral/ground or hot/neutral reversals

Phase rotation and phase-to-phase voltages should both be checked using three-phase wire testers. These test instruments may be relatively straightforward and provide a great first check for circuit integrity. Many issues may be found without the need for costly instruments or in-depth monitoring.

Multimeters

A facility's voltage and/or current levels may need to be quickly checked after initial inspections for wire integrity. This method may be used to identify circuit overload, issues with undervoltage and overvoltage, and unbalances across circuits. All that is needed for these measurements is a basic multimeter. Indicators used to look for them include:

1. Voltages from phase to ground
2. Voltages from phase to neutral
3. Voltages from neutral to ground
4. Voltages from phase to phase
5. Polarity currents
6. Unbiased currents

The multimeter's calculating technique should be taken into account while choosing and operating the device. The rms indicator for the measured signal is provided by all regularly used meters that have undergone calibration. The RMS value is nonetheless calculated in a variety of ways.

The meter reads the signal's peak and divides the result by to get the rms, supposing the signal is a sinusoid. A rectified signal's average value is found using the meter. This average value has a constant relationship to the rms value for a pure sinusoidal signal. The heating that will occur if a voltage is impressed across a resistive load is measured by a signal's rms value. Using a thermal detector to measure a heating value is one way to get the genuine rms value. Modern digital meters calculate the rms value digitally by squaring the signal sample-by-sample, average the result throughout the period, and calculating the square root of the outcome[6]–[8].

These various approaches all provide the same outcome for a pure sine-wave input, but they may produce very varied results for distorted signals. This is crucial since large distortion levels are often present in the facility, particularly for the phase and neutral currents. The rms value for each waveform is 1 pu. Under the accompanying waveforms, the corresponding measured values for each kind of meter are shown, normalized to the real rms value.

Electronic Cameras

For reasons of documentation, photographs are quite helpful. Those who are performing the measurements often get sidetracked while attempting to organize experiments and ensure that instruments are working correctly. Due to their haste, they forget to record some crucial information that would later prove to be crucial. When there are hundreds of measurement details to memorize, human memory is very unreliable. When collecting field measurements, a contemporary digital camera has become a necessity. Taking pictures to record the tests is an easy process. If the shot was unsuccessful, the photographer can identify right away and try again with a different exposure. During field measurements, typical objects to photograph include

1. Transformer and motor nameplates, etc.
2. Equipment arrangements
3. Probe and transducer connections
4. Instruments' key waveform shows
5. Arrester locations, switchgear configurations, and substations, etc.
6. Important electrical component dimensions, such as wire lengths

Similar to photography, video cameras are helpful when there is movement or unpredictable situations. They might be used, for instance, to assist pinpoint the sites of flashovers. Many industrial facilities will need special permission to take pictures and might have strict rules about how much of those pictures can be shared.

CONCLUSION

Monitoring power quality is essential for adhering to different regulatory norms and criteria. In order to prevent fines or service disruptions, for instance, several utilities have set power quality criteria that consumers must adhere to. In addition, numerous industry standards like IEEE and IEC provide recommendations for acceptable power quality levels for particular equipment and applications.

Overall, power quality monitoring is a crucial step in making sure electrical systems are operated safely and effectively. Operators can detect and fix problems with power quality before them result in severe damage or downtime by monitoring and evaluating several electrical power characteristics.

This procedure is crucial for adhering to legal obligations and industry standards, and it may enhance the general effectiveness and dependability of electrical systems.

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CHAPTER 25

SPECTRUM ANALYZERS AND HARMONIC ANALYZERS

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ABSTRACT:

Spectrum analyzers and harmonic analyzers are specialized instruments used in the field of electrical engineering to measure and analyze electrical signals, particularly those containing harmonic components. Spectrum analyzers are used to display the frequency content of a signal in a graphical format, showing the amplitudes of individual frequency components. These instruments can be used to measure and analyze the frequency content of various electrical signals, including radio and television signals, audio signals, and power signals. In the context of power signals, spectrum analyzers are used to analyze harmonic content, allowing engineers to identify and diagnose harmonic issues that can cause equipment damage or poor power quality.

KEYWORDS:

Distortion, Frequency Response, Harmonic, Harmonic, Noise, Oscilloscopes.

INTRODUCTION

When doing real-time testing, an oscilloscope is useful. Even without doing an in-depth harmonic analysis on the waveforms, just at the voltage and current waveforms may reveal a lot about what is occurring. The magnitudes of the voltages and currents may be obtained, as well as any significant variations in the signals and any noticeable distortion[1]–[3]. There are many different brands and kinds of oscilloscopes available. It is advantageous to have a digital oscilloscope with data storage so that the waveform may be preserved and examined. These oscilloscopes often also include the capacity to analyze waveforms. Additionally, digital oscilloscopes are often available via communications, allowing waveform data to be sent to a computer for further analysis using a software program. The most recent oscilloscope innovations are portable devices that can show waveforms and engage in some signal processing. These are quite versatile and can be used like a volt-ohm meter, but they provide significantly more information, making them very handy for power quality investigations. These are perfect for doing initial plant surveys.

Disruption Analysts

Instruments created expressly for power quality measurements fall under the categories of disturbance analyzers and disturbance monitors. They can generally measure a broad range of system disturbances, from undervoltages to extremely short-duration transient voltages. Set thresholds and leave the equipment unattended to record disruptions over time. The data is often stored on a paper tape, although several gadgets have disk recording adapters as well.

These gadgets fall mostly into two categories:

Conventional analyzers that provide a detailed summary of events, including the magnitudes of overvoltage and undervoltage, sags and surges, transients, and their duration.Analyzers based on graphics that record and publish the real waveform together with the descriptive data that would be produced by a traditional analyzer. From the summary data provided by traditional disturbance analyzers, it is often difficult to ascertain the features of a disturbance or a transient. For instance, a peak and a duration cannot adequately characterize an oscillating transient. Therefore, a graphics-based disturbance analyzer's waveform capture capability is practically required for a thorough investigation of a power quality issue. However, for first examinations at a problem area, a basic conventional disturbance monitor might be useful.

Harmonic analyzers and spectrum analyzers

The harmonic analysis capabilities of instruments in the disturbance analyzer category are quite constrained. Fast Fourier transform computations to identify the lower-order harmonics may be performed using add-on modules that are available for some of the more potent analyzers. However, any significant harmonic measurement needs will necessitate the use of a spectral analysis or harmonic analysis instrument. For meaningful harmonic measurements, key features include:

1. The capacity to detect voltage and current concurrently in order to determine how harmonic power flows.
2. The capacity to quantify each harmonic component's magnitude and phase angle.
3. A reliable measurement of harmonic components up to at least the 37th harmonic may be obtained with synchronization and a sampling rate that is quick enough.
4. The capacity to define harmonic distortion levels' statistical nature.

In general, there are three types of instruments to take into account for harmonic analysis:

Basic meters: At a site where there is an issue, it could sometimes be required to do a rapid harmonic levels check. For this, a straightforward, simple meter is excellent. These types of handheld equipment are now widely available. Each instrument has benefits and drawbacks related to how it functions and is constructed. These devices often use microprocessor-based circuitry to carry out the computations required to estimate the rms, the THD, and the telephone influence factor, as well as individual harmonics up to the 50th harmonic. Some of these gadgets have the ability to compute harmonic powers and transfer waveforms and data calculations to a computer.

Spectrum analyzers with a wide range of uses. This category of instruments is designed to analyze waveforms' spectra for a broad range of applications. They are common signal analysis tools. These instruments have the benefit of having highly powerful capabilities at a fair price since they are made for markets other than power system applications. The disadvantage is that careful usage is required to ensure correct harmonic analysis since they are not especially built for capturing power frequency waveforms. This category includes a broad range of instruments. Harmonic analyzers for power systems specifically. In addition to the general-purpose spectrum analyzers already mentioned, there are a few more tools and gadgets made specifically for power system harmonic analysis. These use sample rates created especially for identifying harmonic components in power signals and are based on the FFT. They often include connectivity capabilities for remote monitoring and may be left in the field.

Harmonic and combination disturbance analyzers

The most modern instruments also have full disturbance monitoring capabilities along with harmonic sampling and energy monitoring features. The data are collected remotely through phone lines and displayed visually in a central database. The information may then be subjected to statistical analysis. Additionally, the data may be used as input and output in other applications, including spreadsheets and other graphical output processors. This instrument, which is installed in a Sui enclosure for external placement on utility poles, is designed for both utility and end-user applications. It concurrently monitors three-phase voltages and currents, which is crucial for identifying issues with power quality. The device records the unprocessed data and stores it inside for later remote downloading. With the help of robust software that can provide a range of outputs, offline analysis is carried out. The top chart displays an example of a volt-age sag's usual outcome. Both the actual wave shape for the first 175 ms and the rms variation for the first 0.8 s. A typical wave fault capture from a capacitor-switching operation is shown in the center graph. The capacity to report harmonics of a distorted waveform is seen in the bottom chart. It is possible to retrieve both the harmonic spectrum and the real waveform.

For important utility accounts, this power quality monitoring system was created. It can record disturbances, page power quality engineers, and monitor three-phase voltages. When the engineer’s phone in, a voice message outlining the incident will play. More than 30 occurrences are stored in its memory. As a result, whereas power quality monitoring was formerly a function that was uncommon to find in instruments, it is now far more frequent in commercially accessible equipment[4], [5].

DISCUSSION

Flicker meters

Many alternative techniques have been developed throughout time to measure flicker. These techniques vary from utilizing very basic rms meters with flicker curves to complex flicker meters that assess the intensity of voltage flicker using precisely calibrated filters and statistical analysis. The many techniques for measuring flicker are covered in this section.

Techniques for measuring flicker

Strip charts for RMS. Historically, load duty cycle, rms meters, and a flicker curve have been used to quantify flicker. The system was considered to have flickered if abrupt rms voltage deviations occurred with required frequencies surpassing ones observed in flicker curves. a representative graph of rms voltage changes showing significant voltage variances up to 9.0 V rms. Comparing this to the flicker curve reveals that the feeder would be suffering flicker regardless of the load's duty cycle, since any abrupt total voltage change more than 7.0 V rms causes annoying flicker regardless of frequency. Such a technique has the benefit of being fairly basic in nature and having relatively simple requirements for the rms data. Such a method's obvious drawback would be its lack of precision and inability to determine the precise frequency content of the flicker[6], [7].

Quick Fourier transformation. In order to extract the different frequencies and magnitudes included in the data, a quick Fourier transform is applied to the demodulated signal after raw samples of the voltage waveforms are taken. Then, a flicker curve would be used to compare this data. Despite being comparable to utilizing rms strip charts, this technique quantifies the data more precisely since the size and frequency of the flicker are known. Quantifying flicker levels when the flicker-producing load comprises several flicker signals is a drawback of using this approach. Some instruments make up for this by just recording the dominant frequency and throwing away the remainder.

Flashing meters. The most thorough method of assessing flicker is to utilize flicker meters since it is difficult to define levels of flicker that are dependent on human perception. In its simplest form, a flicker meter is a tool that demodulates the flicker signal, weights it in accordance with recognized "flicker curves," and then analyzes the processed data statistically. These meters may often be broken down into three components. The input waveform is demodulated in the first part, which eliminates the carrier signal. The demodulator results in the production of higher-frequency phrases and a dc offset. The modulating signal is the sole thing that remains after the second segment uses filters to eliminate these undesirable words. Filters in the second segment likewise weight the modulating signal in accordance with the individual meter standards. Typically, a statistical analysis of the detected flicker makes up the last component.

Monitors for Smart Power Quality

All of the power quality measuring equipment previously mentioned is designed to gather data on power quality. Some devices have the ability to transmit data through a communications network to a centralized processing facility for evaluation and interpretation. One thing all instruments have in common, however, is that they lack the capacity to locally evaluate, interpret, and ascertain what is occurring in the power system. They only capture and send data for processing. The process of gathering data, transforming it into meaningful information, and then disseminating it to consumers is an emerging trend in power quality monitoring. These procedures all take place within the instrument. To address this new difficulty, a new breed of power quality monitor was created with integrated intelligent systems. This kind of power quality monitor is an intelligent power quality monitor, meaning that data is directly produced within the device and made accessible to users right away. Engineers can quickly take the required or suitable steps with the help of a smart power quality monitor. Engineers will thus operate pro-actively rather than in a reactive manner.

Transducer specifications

Transducers must often get accurate voltage and current signal levels in order to monitor the quality of the power flowing through power systems. Direct connections may often be used for voltage monitoring on secondary systems, although even in these cases, current transformers are needed for the current signal. Many power quality monitoring devices can handle current inputs of up to 5 A rms and input voltages up to 600 V rms. For these signal levels, voltage and current transducers must be chosen. When choosing transducers, two key issues need to be taken into account:

1. **Signal strength:**

Signal levels should make advantage of the instrument's entire range without clipping or distorting the intended signal.

2. **Reaction to frequency:**

In transient and harmonic distortion monitoring, where high-frequency signals are crucial, this is especially crucial.

3. **Signal strength:**

To use the instrument's maximum resolution without clipping the measured signal, much thought must go into the size of voltage transducers and CTs. Damage to the monitoring device or transducer may come from improper sizing.

Analog-to-digital converters are used in digital monitoring equipment. The analog signal that the instrument receives from the transducers is converted into a digital signal by these A/D boards so that it may be processed. Use as much of the A/D board's whole range as you can to get the most accurate depiction of the signal under observation. A typical A/D board has noise levels that are around 33% of the full-scale bit value. In order to ensure that the signal entering the instrument is always substantially above the A/D board's noise level, it should never be less than one-eighth of the full-scale value. The right transducers may be chosen to achieve this.

The size of VTs should be chosen to avoid having measured disturbances cause saturation. This typically calls for the knee point of the transducer saturation curve to be at least 200 percent of the nominal system voltage for transients. It is usually a good idea to account for overvoltage situations in your calculations. The steady-state voltage shouldn't be exactly at the monitoring instrument's full-scale value. The A/D board would cut the signal in the event of an overvoltage, rendering the measurement meaningless. It is advised to allow for a 200 percent overvoltage. This may be done by adjusting the instrument's input scale or scaling the VT appropriately. It is more challenging to choose the right transducer for currents. Any system's current will fluctuate more often and more dramatically than its voltage. The majority of manufacturers of power quality instruments include CTs with their machinery. These CTs are available in a variety of sizes to handle various load levels. The maximum continuous load current for the CTs is often specified. The measurement aim determines the appropriate CT current rating and turns ratio. The CT must be sized between 20 and 30 times the usual load current if fault or inrush currents are a problem. Low resolution of the load currents and an inability to precisely define load current harmonics will result from this. CTs should be chosen to properly measure load currents if harmonics and load characterisation are significant. This enables precise estimation of load current harmonics and measurement of load response to system voltage fluctuations. Plotting the ratio correction factor, or the ratio of the predicted output signal to the actual output signal, as a function of frequency may be used to see the features of the transducer's frequency response.

Transducers for voltage. The kind and load affect the standard metering class VT's frequency response. The burden should typically have a very high impedance. With the majority of monitoring technology on the market today, this is often not an issue. Digital multimeters, oscilloscopes, power quality monitoring devices, and other tools all have very high impedances to the transducer. A high impedance load often results in a response that is satisfactory to at least 5 kHz. Voltage transducers in certain substations are capacitively connected voltage transformers. For general power quality monitoring, avoid using them. The lower capacitor in the capacitive divider is in parallel with a low-voltage transformer. This arrangement produces a circuit tuned to 60 Hz, which will not accurately reflect any higher-frequency components.

Ability to sever a circuit to insert a transducer

Current monitoring is necessary

Transducers for substations. Usually, power quality monitoring may be done with the use of existing substation CTs and VTs. It is often desired to employ a transducer that might be fitted without putting the circuit out of operation for power quality monitoring on distribution primary circuits. Transducers that can be put on a live line have recently been created to monitor voltage and current. These gadgets combine a window-type CT and a resistive divider-type VT into a single unit. To shunt the line current via the CT in the insulator, a split-core choke is clamped around the phase conductor. The device may be mounted on the crossarm in lieu of the original insulator using this technique. The phase conductor does not need to be severed when utilizing the split-core choke, allowing the transducers to be mounted on a live line.

Initial testing for these transducers showed a sufficient frequency response. Field experience with these devices has shown that the frequency response, even at 60 Hz, depends on the amount of current, the temperature, and the length of the secondary cable. This makes it challenging to utilize this kind of equipment for precise power quality monitoring. These transducers must be carefully matched to the equipment.

In order to get precise results throughout the appropriate frequency spectrum, all principal sites should generally be monitored using metering class VTs and CTs. Although a circuit outage will be necessary for installation, it may be minimized using practical designs for pole-top installations. Monitoring at the secondary of a distribution transformer that isn't in use as power is another method for keeping an eye on main locations.

This will provide accurate results up to 3 kHz at the very least. While the current transducers are not helped by this choice, there are certain circuit places where it is feasible to function without the currents. This method, where the monitor may be positioned on the secondary of a pad-mounted transformer, may be especially appealing for subterranean lines.There are several CT manufacturers that provide primary wound CTs. Any primary wound CT with a single turn or relatively few turns should have a frequency response up to 10 kHz. Both clamp-on CTs and metered CTs may be used to measure currents. There are several different turn ratios of clamp-on CTs. The manufacturer often announces the frequency range.

Data from Power Quality Measurement are evaluated:

The data administration, analysis, and interpretation tasks have emerged as the most critical issues in the entire power quality monitoring endeavor as utilities and industrial clients have extended their power quality monitoring systems. The work of data administration and analysis has become even more crucial as power quality monitoring has moved from off-line benchmarking to online operation with automated detection of faults and concerns. Power quality data analysis is divided into two categories: offline and online analyses. As the name implies, the central processing centers conduct off-line power quality data analysis. The online data analysis, on the other hand, is done inside the instrument itself enabling instantaneous information transmission. both kinds of data on power quality evaluation.

Offline data quality evaluation

The evaluation of off-line power quality data is done independently of the monitoring tools. For this, specialized computer software is used. Software designers and application programmers often face a difficult set of constraints while working on large-scale monitoring projects that need vast amounts of data to be analyzed. The software must, first and foremost, work effectively with monitoring devices and the many productivity tools now on the market. An effective and well-suited database is needed to store the enormous amounts of disturbance and steady-state measurement data. It is necessary to design data management systems that can classify and load power quality data fast, and it is also necessary to combine analytical tools with the data base. The architecture must allow for future growth and customization as well as facilitate automated data management and report production chores[8], [9].

The Power Quality Data Interchange Format, a new industry standard for exchanging power quality data, makes sharing data across various monitoring systems easier. As a result, other parties may create apps for data management and analysis, and measurement data from a range of monitoring systems can be accessed by these systems. An example of this kind of external application is PQView. It describes the PQDIF standard [10].

CONCLUSION

Electrical engineers and personnel working in the area of electrical engineering may make effective use of harmonic and spectrum analyzers. The frequency content and harmonic components of electrical signals are measured and analyzed using this equipment, enabling engineers to spot and treat problems with power quality and system dependability. While harmonic analyzers are especially designed to measure and evaluate harmonic distortion, power factor, and other factors related to power quality, spectrum analyzers are used to visually show the frequency content of a signal. Both tools are employed in industrial and commercial settings to verify adherence to power quality standards and to recognize and address harmonic problems that may result in equipment damage or inefficiency.

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CHAPTER 26

ON-LINE POWER QUALITY DATA ASSESSMENT

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ABSTRACT:

On-line power quality data assessment is a crucial aspect of maintaining the reliability and quality of electrical power systems. It involves the continuous monitoring of power quality parameters, such as voltage fluctuations, harmonic distortion, and frequency variations, in real-time, allowing engineers and technicians to quickly identify and diagnose issues that can cause equipment damage or system failures. On-line power quality data assessment is typically done using specialized instruments, such as power quality analyzers and monitoring systems, which can measure and record power quality parameters over extended periods of time. These instruments can provide engineers with valuable insights into the performance of power systems, helping to identify issues that may require attention, such as voltage sags or swells, harmonic distortions, and other power quality issues.

KEYWORDS:

Autonomous, Capacitor Bank, Harmonic, Power Quality, Signal.

INTRODUCTION

Online data quality analysis examines data while it is being captured. The analysis's findings are instantly accessible for quick dissemination. Software design requirements for online assessments are often more complex than those for offline assessments. The majority of functionality found in off-line analytic software may easily be added to an online system. Online data analysis has a number of benefits, one of which is the ability to give immediate messages to users informing them of particular occurrences of interest. After receiving the alerts, users may act right away. 11.28 A user received a straightforward message informing him or her that a capacitor bank upstream of the data gathering node "DataNode H09_5530" had been powered on on May 15, 2002, at 04:56:11 A.M. Along with the relative position of the capacitor bank from the data acquisition node, the message also includes information about the transient characteristics, including their amplitude, frequency, and duration.

It displays the statistical distribution of a fifth-harmonic current magnitude combined with its temporal trend. A typical Web browser is used to view the data and its processing. The user may examine the most recent data here. This online system has the capacity to perform a complete range of transient, harmonic, and steady-state characterization along with an examination of their statistical distribution equivalent to that performed during off-line evaluation analysis[1], [2].

Use of Intelligent Systems

Numerous cutting-edge power quality monitoring systems include sophisticated off-line or online algorithms that analyze disturbances and system conditions and draw conclusions about the root cause of the issue or even foresee issues before they arise. Engineers can quickly assess the system condition thanks to the use of intelligent systems or autonomous expert systems in monitoring equipment[3], [4].This is crucial for resuming service after significant disruptions. Since an intelligent system inside a monitoring instrument may produce information instead of merely collecting data, it can dramatically boost the value of a monitoring application. The intelligent systems are organized into discrete autonomous expert system modules, each of which carries out certain tasks. Examples include a module for an expert system that analyzes capacitor-switching transients and pinpoints the position of the capacitor bank. Another module pinpoints the location of the problem that is generating a voltage spike. The methodology used in creating an autonomous expert system for power quality data evaluation and provide instances of application.

DISCUSSION

Basic design of an expert system for monitoring applications

Before the expert system module is designed, the functionalities or objectives of the module must be clearly defined. The development of an autonomous expert system calls for many approaches, such as signal processing and rule-based techniques along with the knowledge-discovery approach commonly known as data mining. To put it another way, the designers or developers of the expert system module must be explicit about the information they want to glean from vast amounts of unprocessed measurement data. This is crucial since it will eventually decide how the expert system module is designed overall. Information extraction from chosen data, information assimilation, and report presentation are all steps in the process of converting raw measurement data into knowledge. These actions are often referred to as data mining or knowledge discovery[5].

The initial stage in knowledge discovery is to choose acceptable measurement amounts and ignore alternative measurement kinds that don't provide relevant data. Additionally, preparatory studies are often performed throughout the data-selection phase to guarantee the accuracy of the measurement. As an example, measurements of the instantaneous three-phase voltage and current waveforms must be made accessible for an expert system module that is being constructed to get a certain response. Before moving on to the next stage, the data-selection job is in charge of making sure that the necessary phase voltage and current waveform data are accessible. This stage may sometimes require the interpolation or extrapolation of data. The correctness of the information revealed depends on the quality of the data, therefore further preliminary exams should include looking for any outlier magnitudes, missing data sequences, corrupted data, etc.

The second stage is to project the data into areas where it is more likely that a solution will be found. Power system analysis and signal processing methods are used. Transforming data into a different domain where the information may be found is an example of this phase. The wavelet transform is used to identify the temporal and frequency information for transient signals, the fourier transform is used to reveal frequency information for steady-state signals, and other transforms may also be used. We are now prepared to extract the necessary data since the data have already been projected onto other domains or spaces. Finding the maximum value in the transformed signal or counting the number of points where the magnitude of a voltage waveform exceeds a predetermined threshold value are two examples of simple information extraction techniques. More complex methods include pattern recognition, neural networks, and machine learning. Finding harmonic frequencies in a waveform that has been deformed is one example. The waveform is changed using the Fourier transform in the next step, producing a frequency-domain signal. By first calculating the noise level in the frequency-domain signal and then assigning a threshold value to a multiple of the noise level, it is possible to perform a straightforward harmonic frequency extraction method. Any magnitude greater than the threshold value can be a sign that harmonic frequencies are present. Usually, the data mining stage yields fragments of information. Knowledge is created by assimilating these bits of information. Because certain bits of knowledge clash with one another, assimilation of information is sometimes difficult. The value of the solution may be restricted if the contradictory facts cannot be reconciled. Knowledge interpretation and report presentation are the last steps in the chain.

Examples of expert system applications

A sophisticated power quality monitoring system may be built using one or more autonomous expert system modules. All modules will be called when a power quality event is collected. Each module will make an effort to find the particular knowledge that it is intended to seek for. Users will have access to view the newly discovered unique knowledge after it has been found. The information may be seen on a regular browser or distributed through fax, pager, or email. We provide several examples of autonomous expert systems. Module for voltage sag direction. Some of the most important disruptions to utility networks are voltage sags. They may also be brought on by a malfunction within end-user facilities, although distant faults on the power system are mainly what trigger them. Finding the source of the defect that caused the voltage sag may help avoid them in the future and help identify who is responsible for fixing the issue. For instance, executing contracts that contain voltage sag performance standards requires determining the location of the defect.

Sags brought on by issues with the client facility would not be the supplier's problem. This is particularly crucial when attempting to compare the distribution system's performance to that of the transmission system in order to determine what causes voltage sag occurrences that may have an adverse effect on client operations. The locations of the faults may be used to identify areas that need maintenance or system modifications or to predict potential future issues. In any of these situations, an expert system to pinpoint the problem site might be useful. The voltage sag direction module, an autonomous expert system module, was created specifically to do exactly that—to detect and recognize a voltage sag event and then locate its source. If a data collection node is put at a customer PCC, the utility or the customer side of the meter will either be the cause of the voltage sag. The distribution system or the transmission system will be the cause of the voltage sag if the monitoring point is at a distribution substation transformer.

Comparing the magnitudes of the current and voltage rms both before and after the sag occurrence is how the voltage sag direction module operates. It monitors changes in phase angle between prefault and postfault. The origin of the voltage sag event may be precisely determined by combining data from the rms magnitude comparison and the phase angle behavior. The voltage sag direction module also has algorithms to rate the accuracy of the information or solution found. If the response is accepted as correct, it will be supplied as an output; if not, it will be disregarded and no response will be sent. Inaccurate or erroneous information may be reduced in this manner. Missing data and unresolved contradictory qualities are the two main causes of inaccurate knowledge. The voltage sag direction module's outputs may be seen on a computer screen using Web browser software, printed on paper, transmitted to a pager, or sent as an email. a voltage sag direction expert system module's output. The first column gives the event time, the second the monitor identification, the third the event types, the fourth the triggered channel, and the fifth the characteristics of the event and the outputs of the answer module.

Module for locating radial faults. Radial distribution feeders may experience both symmetrical and asymmetrical short-circuit occurrences, such as single-line-to-ground, double-line-to-ground, and line-to-line faults. These system flaws may be caused by a variety of factors, including human mistake, equipment failure, and natural causes including harsh weather and animal interaction. Cost-effective system repair depends on quickly locating and addressing issues. Sending a lineperson to patrol the suspected feeders is the current procedure to find the issues. Although this approach has been tested, it is certainly not the most economical technique to restore electricity.

To calculate the distance to a fault site from the measurement point, an expert system module known as the radial fault locator is built. This module's unique selling point is that it may be used with the sequence impedance data from the main distribution feeder and only a set of three-phase voltages and currents from a single measurement site. In order for the module to function, a permanent fault event must first be identified using the ground fault and phase fault pickup current thresholds. The answer module setup window allows users to input these settings. Once a permanent fault event has been located, the apparent impedance technique is used to estimate the distance to the problem. The estimated distance to the issue is subsequently shown on a computer screen with an illustration of a web browser or communicated to a lineperson through a pager. The lineperson can locate the problem fast. This is an example of a new trend in smart power quality monitoring, which involves gathering data on power quality and formulating information for users to take the appropriate measures. Utility capacitor bank energizing may cause transients that can spread to client facilities. Switching transients often cause sensitive machinery, such as adjustable-speed drives and other electronically controlled loads, to trip off. Capacitor banks may also be included in certain bigger end-user facilities to support voltage and reactive power.

Knowing the location of the capacitor bank, whether it is on the utility side or at the customer facility, is crucial if a sensitive load goes off as a result of capacitor-switching transients. A capacitor-switching direction expert system module is made to find a capacitor-switching event, recognize it, and calculate the capacitor bank's relative position in relation to the measurement point. To complete the aforementioned duties, just a certain combination of three-phase voltages and currents is needed. This module may assist engineers identify the accountable parties, such as the utility or the customer, and locate the problematic capacitor bank. This is how the transient direction module with capacitor switching works. The module will take the data from an event and portray it in areas where detection and identification are more advantageous. The time-, frequency-, and time-scale domains are where the information is expressed. The response module will go on to establish the capacitor bank's most likely location if a capacitor bank energization was the primary cause of the incident. Upstream or downstream are the only two places that might be in relation to the monitoring point. With grounded, ungrounded, delta-configured, and wye-configured capacitor banks, the expert system module performs well. Back-to-back capacitor banks may also benefit from it. Algorithms are included in the capacitor-switching transient direction module to assess the value of the data it unearths. As a result, the module could provide an uncertain solution. A right response is unquestionably preferable than this one.

Analyzing data captured from a data collection node situated at the service entrance of an office complex is an example use of the response module. The analysis's output is a screenshot of a typical Web browser. Any capacitor-switching transients must come from the utility side, which is upstream of the data collecting node since the office complex lacks capacitor banks. The capacitor bank's relative placement is determined by the module appropriately. Be aware that the expert system sometimes failed to pinpoint the precise placement of the capacitor bank. It is evident from the events' time stamps that capacitor bank energizations take at about 5:00 A.M. and 7:00 P.M. every day. Module for inspecting the functioning of a capacitor switch. As said, capacitor-switching transients, which are the end consequence of capacitor bank energization process, are the most frequent source of transient events on the power system. A fuse blowing is one frequent issue that may arise with a capacitor bank. Before utility workers identify a problem with one or more capacitor banks, the capacitor bank may have been malfunctioning for months. Driving down the line and physically examining the capacitor bank is how routine maintenance is often carried out.

Given the large number of capacitor banks on most power systems, this expert system module can be of great help to power systems engineers in identifying issues and correlating them with capacitor-switching even if the operation was not successful. An autonomous expert system was developed for substation applications to analyze downstream transient data and determine if a capaci- tor-switching operation is performed successfully and display a warning message if the operation was not successful. A constant rise in kvar on each phase that adds up to the capacitance kvar size is a sign of a successful capacitor bank energization. For instance, when a 1200-kvar capacitor bank is activated, each phase should experience reactive power of around 400 kvar. Calculating individual phase kvar changes from the current and voltage waveforms before and after the switching operation will provide the overall kvar increase. The real or physical capacitor bank kvar given by the user is then contrasted with the overall calculated kvar change. If the anticipated kvar was not attained, there may be an issue with the capacitor bank's switching mechanism. the integration of a commercial monitoring system with a capacitor-switching operation inspector expert system. All capacitor banks along feeders are downstream of the monitoring site since the monitoring location is at the substation. Two of the capacitor's phases are malfunctioning, according to the initial capacitor-switching occurrence. Either the switch is malfunctioning or the fuses have blown. A successful capacitor-switching process may be seen in the second occurrence.

Module for correlating lightning. In the United States, weather-related events like thunderstorms are to blame for the bulk of power drops and outages. For instance, lightning is responsible for up to 45% of the system's problems on TVA's roughly 17,000 miles of transmission lines. The lightning correlation expert system module is intended to link lightning strikes to recorded occurrences of measured power quality and to provide that data in real time right at the location of the recording. Engineers may assess the source and effects of voltage sags for a single customer at a specific monitoring point as well as assess the effects on all customers for a given occurrence using the correlation findings. The lightning correlation module uses the Internet to search a lightning database when it discovers a voltage sag or transient occurrence. The United States provides the lighting statistics. Global Atmospheres, Inc. runs the National Lightning Detection Network. If the query yields a result set, the lightning correlation module will save this data together with the disturbance data in the monitoring system database for further dissemination. The lightning information includes the strike's occurrence time, latitude and longitude, current magnitude, and number of strokes.

Future Applications

The notion of intelligent power quality monitoring has various applications. This section is a list of some of the most significant uses.

Industrial uses for Measuring Power Quality

Assessments of harmonics to spot potential difficulties with equipment functioning, sources of harmonics, transformer loading issues, and resonance issues related to power factor correction. Evaluation of the effects of voltage sag to identify vulnerable equipment and potential areas for process ride-through improvement. Assessment of power factor correction to determine appropriate functioning of capacitor banks, switching issues, resonance issues, and performance optimization to reduce electricity costs. Evaluation of the functioning of the protective devices, inrush current concerns, and switching issues during motor startup. Evaluation of short-circuit protection based on time-current curves, short-circuit current characteristics, etc. to determine if protective devices are functioning properly.

Benchmarking and performance evaluation of power systems

Analysis and trending of steady-state power quality metrics are performed to look for performance patterns, correlate them with system circumstances, and spot any issues that should be addressed. To determine the cause of the voltage sags and to describe the occurrences for categorization and analysis, voltage sag characterization and evaluation is performed. Identification of the transient's source, location of the capacitor bank, and characterisation of the events for database management and analysis. Calculations and reporting of performance indices for system benchmarking and investment prioritization in system maintenance and enhancement.

Applications for operations, dependability, and system maintenance

One of the most significant advantages of the monitoring systems is this. It may significantly speed up the time it takes to repair circuits and discover situations that might lead to many faults developing over time in the same place. Performance evaluation of the capacitor bank. Applications with intelligence may detect fuse blowing, can failures, switch issues, and resonance issues. Evaluation of the voltage regulator's performance to spot odd operations, arcing issues, regulation issues, etc. Evaluation of the performance of distributed generators. Smart systems should be able to detect connectivity difficulties including coordination issues with protective devices, issues with harmonic injection, islanding issues, etc. According to research, current discharges often take place weeks before cable problems and arrester faults occur. This is the perfect application for an expert system in the monitoring system. Transformer loss of life concerns connected to loading may be assessed by transformer loading assessments, which can also take into account the effects of harmonic loading in the computations. Evaluation of the functioning of the feeder breaker might reveal coordination issues, appropriate short-circuit operation, unneeded tripping, etc.

Internet Monitoring of Power Quality

Power quality monitoring systems have been deployed by several utilities to continuously check system performance and provide quicker reaction to system issues. It is obvious that the effectiveness of these systems has depended heavily on information availability through intranet and the Internet. The outcome of research started by TVA and EPRI is an example of a fully Web-based power quality monitoring system. With the assistance of each member of the EPRI Power Quality Target group, the system's specifications were created to accommodate the variety of applications that such a system must serve. As a consequence, a modular system with an entirely open design that can connect with many different platforms was created.

After contributing to the system's development, TVA is implementing the web-based monitoring systems at significant clients and sub-stations throughout their network. Distributors for TVA are also benefiting from the scheme. It already has a sophisticated power quality monitoring infrastructure in place, and the new system is connected with it at the level of central data management.

This gives you the opportunity to deliver information on power quality throughout the whole system. Integration with additional data-collection tools in the plant and substation is in these systems' future. The information is shared via standardized interfaces like COMTRADE and the Power Quality Data Interchange Format, and communications are carried out using standardized protocols like UCA. Depending on the situation, the intelligent applications mentioned will be used at both the substation level and the company level[6]–[8].

Power quality monitoring is swiftly becoming into a crucial customer service and an essential part of general distribution system monitoring. Monitoring for energy management, assessing the performance of protection devices, and distribution automation activities are all being integrated by power producers. Customers should have access to the power quality data to assess their facility's power conditioning needs, and it should be made accessible across the firm through the intranet. In order to assist consumers better understand system performance and to help prioritize system expenditures, the power quality information has to be examined and condensed. As a result, the sensitivity of client equipment should serve as the basis for power quality indices. The voltage sag SARFI index is a great illustration of this idea.

A broad variety of situations and disturbances are included in power quality. Consequently, as stated, the requirements for the monitoring system may be extremely onerous. The fundamental needs in relation to the various power quality fluctuations. The data from power quality monitoring systems may assist increase system operation effectiveness and customer operations dependability. These are advantages that should not be disregarded. Power quality monitors' capabilities and uses are constantly developing. On many websites on the Internet, ongoing development and new applications are mentioned.

CONCLUSION

In summary,an essential instrument for preserving the dependability and quality of electrical power systems is online power quality data evaluation. Engineers and technicians can immediately detect and diagnose problems by continually monitoring power quality indicators in real-time, which helps to decrease downtime, costs, and maintain regulatory compliance. Engineers and technicians may save downtime and repair costs by proactively addressing problems before they result in system failures or equipment damage by monitoring on-line power quality data. Additionally, by verifying that systems are functioning within permissible boundaries, online power quality data evaluation may assist enterprises in adhering to regulatory criteria pertaining to power quality.

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