PRACTICAL POWER SYSTEM PROTECTION

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CHAPTER 1

FAULT PROTECTION OF GENERATOR

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ABSTRACT:

The safe and dependable operation of generators depends heavily on fault protection. This chapter provides an overview of fault protection strategies for generators with an emphasis on different methods and tools used for fault detection and mitigation. The objective is to better comprehend fault protection mechanisms and the role they play in preserving generator integrity. The report also analyses fault protection's difficulties and suggests future lines of inquiry and improvement in this area. Rotor earth fault protection is essential for preventing damage to generators and guaranteeing their dependable operation. When the rotor winding of a generator comes into touch with the earth or the ground, it creates a rotor earth fault, which can put the system at risk. In order to stop additional damage and guarantee the safety and dependability of the generator, rotor earth fault protection systems are made to quickly detect and mitigate these problems.

KEYWORDS:

Earth Fault Protection, Induction Type Negative Sequence Relay, Negative Sequence Relay, Rotor Earth Fault.

INTRODUCTION

Detecting the presence of a defect is the first stage in rotor earth fault protection. Rotor earth faults are found using a variety of techniques, both direct and indirect. While indirect methods infer the fault from associated characteristics like neutral voltage displacement or negative-sequence current, direct methods measure the earth fault current directly from the rotor circuit.

Fault Localization: Finding the exact position of the faulty part is essential after a rotor earth fault has been identified. Impedance-based techniques, travelling wave-based techniques, or time-domain reflectometry are all used in fault localization techniques to determine the fault site. Correct fault localization speeds up fault repair and reduces downtime [1]–[3].

Fault Mitigation: To lessen the impact of the problem on the generator and the power system, suitable mitigation measures are used when the issue has been identified and localized. Unintentional harm can be avoided by starting an automatic trip system that disconnects the generator from the network. To isolate the defective area and return the generator to normal functioning, fault clearing methods such rotor circuit breakers or contactors are also used. Rotor earth fault protection involves a number of difficulties and factors, including:

Sensitivity and Selectivity: Rotor earth fault protection systems must be selective to prevent false alarms or superfluous trips brought on by outside influences while also being sensitive enough to identify minor fault currents properly.

System Dynamics: In order to achieve accurate problem detection and localization, fault prevention systems must take into account variations in load, voltage levels, and system topologies. Generators run under a variety of conditions.

Coordination with Other Protection Systems: To achieve thorough and coordinated fault detection and mitigation, Rotor Earth Fault Protection should be coordinated with other protective systems including Differential Protection, Overcurrent Protection, and Distance Protection.

Fault Resistance: The performance of rotor earth fault prevention systems is impacted by the existence of fault resistance. Fault resistance can affect the accuracy of fault localisation, fault detection thresholds, and fault current magnitude. To ensure reliable fault identification and localization, protection algorithms should take into consideration variations in fault resistance. The following are potential directions for rotor earth fault protection:

(i) **Advanced Fault Detection Algorithms:** Development of sophisticated algorithms for fault detection that can reliably identify rotor earth faults under various operating circumstances and reduce false alarms.

(ii) **Intelligent Monitoring and Analysis:** Integrating sophisticated monitoring and analysis tools, such as machine learning and data analytics, will improve the accuracy of problem detection and provide early warning signals of future issues.

(iii) **Enhanced Coordination and Communication**: Enhancing coordination and communication amongst protective devices using cutting-edge communication technologies like IEC 61850 to enable quicker and more effective fault localization and mitigation is known as enhanced coordination and communication.

(iv) **Advanced Sensors:** Examining the application of cutting-edge sensors, such as fiber-optic sensors or non-intrusive sensors, to raise the sensitivity and precision of fault localization.

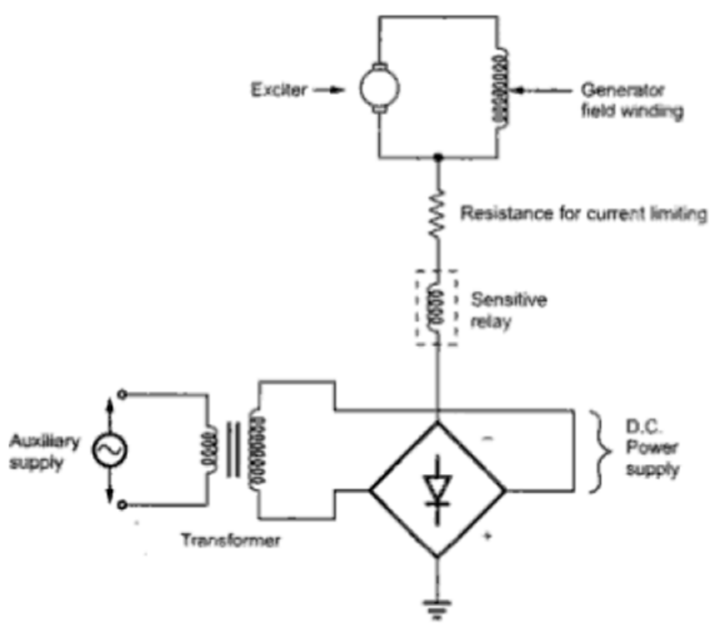

Figure 1: Rotor earth fault protection.

Sustaining the safe and dependable operation of generators requires rotor earth fault prevention. Generators can be safeguarded from the destructive effects of rotor earth faults, guaranteeing an uninterrupted power supply and reducing downtime, by using efficient fault detection systems, precise fault localization procedures, and appropriate fault mitigation tactics. To address issues, boost protection system performance, and combine cutting-edge technology for improved rotor earth fault protection, more research and development is required in this area. The rotor earth protection is illustrated in figure 1.

Protection against loss of excitation:

Safeguarding generators and ensuring their dependable functioning require protection against loss of excitation. When the field current in a generator's excitation system is insufficient or nonexistent, loss of excitation happens, which results in a reduction or total loss of the generator's output voltage. As a result, the power system may become unstable, suffer generator damage, or both. Protection systems are put into place to quickly identify and mitigate loss of excitation conditions, stopping additional damage and ensuring the generator's dependability. The following are the primary goals of protection against excitation loss:

Fault Detection:

Identifying a malfunction or other aberrant circumstance that results in insufficient or no field current is the first step in loss of excitation protection. Monitoring the generator's terminal voltage, field current, and other performance indicators for the excitation system are only a few of the techniques used to identify loss of excitation. A loss of excitation state is indicated by departures from expected values or predetermined criteria.

Fault Mitigation:

When a loss of excitation condition is identified, the proper mitigation techniques are put into place to restore and stabilize the generator's performance. The method that is most frequently used to stop further harm is to start an automatic trip system that disconnects the generator from the network. As additional corrective measures, an automated voltage regulator (AVR) reaction can be started to restore the field current or to activate different sources of stimulation to keep the voltage stable. Loss of excitation protection is complicated by a number of factors, including:

- **(i)** **Sensitivity and Selectivity:** Protection systems should be selective enough to identify loss of excitation conditions quickly and sensitive enough to detect minute variations in terminal voltage and field current. To distinguish between true loss of excitation events and brief fluctuations or load variations, they must be selective at the same time.
- **(ii)** **System Dynamics:** Generators operate under dynamic circumstances with varying loads, system setups, and reactive power requirements. To provide accurate loss of excitation detection and mitigation, protection systems must take these dynamics into consideration.
- **(iii)** **Coordination with Other Protection Systems**: To provide thorough and coordinated fault detection and mitigation, loss of excitation protection should be coordinated with other protective devices, such as overcurrent protection, under frequency protection, and voltage protection.
- **(iv)** **AVR Performance and Monitoring:** Automatic Voltage Regulators (AVRs) are essential for preserving stable generator voltage and field current. To guarantee that AVRs are effective in averting loss of excitation situations, performance monitoring and evaluation are crucial.

Future developments in the defense against excitation loss include:

Advanced Protection Algorithms: Developing sophisticated protection algorithms that can precisely identify excitation loss circumstances under various operating conditions and reduce false alarms brought on by transitory events or system disturbances [4]–[6].

Wide-Area Monitoring and Control: Making use of systems that give real-time data on system dynamics, generator performance, and field current conditions. With the help of this information, loss of excitation detection may be improved, and coordinated mitigation techniques can be implemented across various generators and system parts.

Adaptive Protection Settings: Implementing adaptive protection settings can increase protection system performance and lower false trips by adjusting threshold levels and reaction parameters in response to changes in load, real-time operating conditions, and system characteristics.

DISCUSSION

Enhanced Communication and Data Analytics:

Advanced communication technologies and data analytics are integrated to improve coordination, problem identification, and decision-making in loss of excitation protection systems. Safeguarding against excitation loss is essential for preserving reliable generator performance and averting potential power system issues. Generators can be safeguarded from the destructive consequences of loss of excitation conditions by applying efficient fault detection systems and sensible mitigation procedures, hence assuring dependable power supply and reducing system instability. In order to address issues, boost protection system performance, and include cutting-edge technologies for improved loss of excitation protection, ongoing research and development in this area is required.

Negative sequence relay:

In electrical power systems, negative sequence relays are safety devices that are used to identify and address issues brought on by unbalanced circumstances, particularly unbalanced voltages or currents. By identifying and reacting to negative sequence components, which signify system asymmetry or failures, these relays play a critical part in preserving the stability and dependability of the power system. Positive and negative sequence components of voltages and currents are equal in magnitude but opposite in phase under normal balanced conditions, according to the theory on which negative sequence relays are based. The negative sequence component, however, becomes predominate in faults or unbalanced situations, such as phase-to-phase or phase-to-ground faults, signifying an aberrant circumstance. Negative sequence relays' main features and operations are as follows:

Fault Detection: Negative sequence relays continuously check for the existence of negative sequence components in voltages and currents in order to detect faults. They evaluate the phasor data to assess the degree of unbalance. The relay activates and starts a preventative operation if the unbalance rises above a set threshold.

Protection Coordination: To achieve thorough fault detection and selective tripping, negative sequence relays collaborate with other protective devices like overcurrent relays and distance relays. For the purpose of properly isolating the faulty part and avoiding needless trips, coordination between various relays is essential.

Localization of the Fault: Negative sequence relays might reveal the location of the Fault in the Power System. The relay can determine the approximate position of the fault by examining the phase angle and size of the negative sequence component, assisting in quick fault clearance and reducing downtime.

Voltage Regulation: Negative sequence relays can help to maintain voltage regulation in addition to fault detection. The relay can detect abnormal voltage situations and start remedial actions to restore proper voltage levels by continuously monitoring the negative sequence voltage.

Motor Protection: Negative sequence relays are frequently employed for motor protection in order to safeguard against imbalanced situations and stator winding errors. These relays have the ability to identify negative sequence currents in motor windings and start protection processes to stop motor damage.

System Stability: If imbalanced conditions are not corrected right away, the power system may become unstable. By identifying and addressing unbalanced circumstances, avoiding voltage instability, and lowering the possibility of cascading failures, negative sequence relays help maintain the stability of the system.

Negative sequence relays will likely advance in the following ways:

Advanced Algorithms: Creation of sophisticated algorithms that can precisely analyses the negative sequence component, differentiate between real imbalanced circumstances and momentary disruptions, and minimize false trips.

Enhanced Communication: Better coordination and fault detection acro ss the power system are made possible by the integration of sophisticated communication technologies, such as IEC 61850, which allows for faster and more efficient information flow across relays.

Wide-Area Monitoring: The use of systems for capturing data in real-time from various points across the power system. The accuracy of defect localization and detection in negative sequence relays can be improved using this data.

Intelligent Protection Systems: Adaptive protection settings and predictive fault detection are made possible by intelligent protection systems, which integrate artificial intelligence and machine learning approaches to enhance the performance and reliability of negative sequence relays.

The stability and dependability of electrical power systems are significantly maintained by negative sequence relays, which are essential protective devices. These relays help the electricity system run safely and effectively by identifying imbalanced circumstances and responding quickly to malfunctions. The accuracy and efficiency of negative sequence relays will continue to be improved through ongoing research and development in this area, allowing for better problem detection, localization, and system protection.

Induction type negative sequence relay:

A protection device called an induction type negative sequence relay is used in electrical power systems to identify unbalanced circumstances, specifically negative sequence components in voltages or currents, and to take appropriate action. It is primarily made to guard against harm brought on by unbalanced conditions and operates on the basis of the electromagnetic induction concept. The following are the main characteristics and operating ideas of an induction type negative sequence relay:

Operation: A magnetic field is created in the stator winding when the relay detects a negative sequence component in the monitored voltage or current. Eddy currents are created when this magnetic field interacts with the rotating aluminium disc in the rotor assembly. The torque created by the interaction of the induced magnetic field and eddy currents causes the rotor assembly to rotate [7]–[9].

Construction: A stator winding and a rotor assembly make up an induction type negative sequence relay. In order for the stator winding to detect the negative sequence components, it is often connected in parallel with the equipment that needs protection. The negative sequence magnetic field's impact causes an aluminium disc and a laminated iron core, which make up the rotor assembly, to rotate.

Tripping Mechanism: The rotor assembly's rotation triggers the relay's tripping mechanism, which starts a protective action like tripping a circuit breaker or unplugging the equipment. Based on the intended sensitivity to negative sequence components and the necessary level of protection, the relay's actuation threshold is established.

Sensitivity Adjustment: An induction type negative sequence relay's sensitivity adjustment feature lets the user change how the relay reacts to various imbalance levels. This adjustment can be made by altering the stator winding's number of turns or by employing auxiliary tools like taps or resistors.

Coordination with Other Protection Devices: To provide selective tripping and fault isolation, induction type negative sequence relays collaborate with other protective devices including overcurrent relays and differential relays. In order to reduce the effects of uneven conditions and avoid making extra visits, coordination is crucial.

Applications: Generators, motors, and other equipment that is susceptible to imbalanced circumstances are frequently protected by induction type negative sequence relays. They offer defense against faults such voltage asymmetries, unbalanced loads, and phase-to-phase or phase-to-ground failures [10].

Digital negative sequence relays, which use microprocessor-based algorithms for more precise and flexible protection, are a result of technological advancements. Advanced communication capabilities, self-diagnosis, and adaptive protection settings are qualities that digital relays provide. Induction type negative sequence relays are crucial safeguards that identify imbalanced conditions in electrical power systems and take appropriate action. These relays are essential for avoiding equipment damage and preserving system stability because they detect the negative sequence components and start the necessary protective measures.

CONCLUSION

In conclusion, fault protection is essential for preventing damage to generators and maintaining their continuous functioning. To quickly and accurately identify problems, a number of fault detection techniques are used, including differential protection, overcurrent protection, and frequency-based protection. To lessen the effect of defects on generator performance, fault mitigation measures, including as fault clearing mechanisms, automatic trip systems, and coordinated protection schemes, are put into place. However, there are a number of difficulties in designing and putting into practice effective fault prevention systems, such as the requirement for accurate and reliable fault detection algorithms, coordination with other protection systems, and system dynamics. Future research should concentrate on creating sophisticated fault detection methods, incorporating clever fault prediction algorithms, and improving coordination and communication across protective devices. The dependability and safety of generator systems can be greatly increased by resolving these issues and looking into new options, resulting in an uninterrupted power supply and less downtime.

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CHAPTER 2

AN OVERVIEW ON TRANSFORMER PROTECTION

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ABSTRACT:

For electrical systems to operate reliably and safely, transformer protection is essential. An overview of transformer protection methods and the importance of these methods in power systems is given in this abstract. It examines the many techniques used to protect transformers, such as Buchholz relay protection, differential protection, and overcurrent protection. The significance of appropriate coordination and settings for efficient transformer protection is also covered in the abstract. The incorporation of cutting-edge technologies like numerical relays and intelligent electronic devices (IEDs) is just one of the trends it emphasises for transformer protection. Power system operators can reduce the chances of transformer failures and improve the overall dependability of the power grid by implementing strong protection measures. These techniques must be able to identify faults, isolate the problematic machinery, and lessen the damage the fault causes to the transformer and the entire power system. Transformer protection systems are made to react to unexpected situations quickly and precisely, minimising damage to the transformer, averting power outages, and protecting crew safety.

KEYWORDS:

Buchholz Relay, Earth Fault Protection, Leakage Overload Protection, Transformer Protection.

INTRODUCTION

Transformers play a key role in the efficient transmission and distribution of electrical energy in electric power systems. They perform the crucial task of increasing or decreasing voltage levels to fulfil the particular needs of diverse electrical networks. Transformers must be protected against faults and irregularities due to their crucial function and expensive cost in order to assure their dependable operation and avoid catastrophic failures. In order to protect transformers, a wide range of techniques, tools, and systems must be used. Transformers are completely enclosed, static, and typically submerged in oil. Therefore, it is quite unlikely that they would develop flaws. However, if the transformer is not immediately unplugged from the system, even a minor problem could have disastrous results.

This calls for effective automatic protection against potential failures for transformers. Instead of using circuit breakers, small distribution transformers are typically connected to the supply system using series fuses. As a result, no automatic protective relay machinery is needed. However, there is unquestionably a higher likelihood of problems with power transformers, therefore automatic protection is essential. Typical transformer faults The only abnormal circumstances that can occur in power transformers, as opposed to generators, are: (i) open circuits; (ii) overheating; and (iii) winding short-circuits, such as earth faults, phase-to-phase faults, and inter-turn faults [1]–[3].

Unwanted heating may result from an open circuit in one of a three-phase transformer's phases. Due to the relative safety of open circuits, relay protection is not typically offered against them.

When such a fault occurs, the transformer can be manually unplugged from the system. Transformer overheating is typically brought on by prolonged overloads or short circuits, while the breakdown of the cooling system does occur very infrequently. Thermal accessories are typically utilised to activate an alarm or manage fan banks; relay protection is not given against this scenario. Transformer winding short-circuits, also known as internal defects, are caused by the winding insulation deteriorating through overheating or mechanical damage. A rapid disengagement from the system is required when a transformer experiences an internal fault because a protracted arc inside the transformer could result in an oil fire. Relay protection is thus unavoidably required for internal failures.

Types of Transformer Faults: Before discussing the necessity of transformer protection, it is crucial to understand the different types of faults that can develop inside a transformer.

Overcurrent Faults: Excessive load currents, short circuits, or ground faults can result in overcurrent circumstances. These defects stress the transformer mechanically and thermally by exposing it to high currents that exceed its design capability. A transformer's insulation may deteriorate over time through exposure to overcurrent circumstances, which can also lead to overheating and eventually physical harm to the transformer.

Overvoltage Faults: Overvoltage circumstances can develop as a result of switching activities, lightning strikes, or system flaws. High voltages can result in insulation failures and damage to the transformer as a result of insulation breakdown. To maintain the safe operation of transformers and avoid failures due to insulation, overvoltage protection is essential.

Transformer Internal Faults: Internal flaws in the transformer, such as failing winding insulation, core faults, or tap changer issues, can result in serious damage if not swiftly identified and fixed. These flaws may be the result of poor maintenance, ageing, or manufacture flaws. To limit the possibility of cascading failures and avoid the transformer from suffering severe damage, it is essential to identify and isolate internal faults.

Protective Devices and Schemes: Transformer protection systems use a variety of protective devices and strategies to identify faults quickly and respond appropriately. Several frequently employed safety measures and plans include:

Buchholz Relay: For the safety of oil-filled transformers, Buchholz relays are frequently used. By keeping an eye on the flow of gas and oil inside the transformer tank, they can spot internal issues and take action. Depending on the severity of the malfunction, the relay sends alarm or trip signals, enabling prompt isolation of the defective transformer.

Differential Protection: One of the most popular and efficient transformer protection strategies is differential protection. In order to identify internal faults, it compares the current flowing into and out of the transformer windings. Differential protection strategies provide rapid internal fault separation and identification, minimising the harm done.

Overcurrent Protection: To safeguard transformers from overcurrent failures, overcurrent relays and fuses are used. In order to protect the transformer from heat and mechanical damage, these devices are programmed to trip whenever the current reaches a specific threshold. To accomplish correct discrimination and selectivity, overcurrent protection devices are often coordinated with other protective devices.

Voltage Protection: Transformers are protected against overvoltage circumstances brought on by lightning strikes or switching surges using voltage relays and surge arresters. By diverting too much voltage away from the transformer, these devices safeguard its insulation and stop insulation breakdown.

Restricted Earth Fault Protection: Systems for detecting ground faults inside transformer windings are known as restricted earth fault protection. This system offers dependable protection against winding insulation failures by keeping track of the differential current between the primary and secondary windings.

Advanced Techniques for Transformer Protection: New and more advanced methods for transformer protection have emerged as a result of technological breakthroughs. Transformer protection systems are more dependable and effective thanks to these cutting-edge technologies. Some significant developments include:

Transformer Thermal Monitoring: Temperature sensors inserted into the transformer's windings and fluid allow for real-time monitoring of the temperature of the transformer. This system offers proactive maintenance and prompt identification of abnormal operating circumstances, reducing thermal damage to the transformer by continuously monitoring the temperature rise.

Dissolved Gas Analysis (DGA): To find potential problems, DGA examines the gases dissolved in the transformer oil. Certain gases are produced as faults grow inside the transformer, signalling deterioration in the insulation or internal arcing. Early fault identification made possible by DGA permits the implementation of preventative measures prior to significant harm.

Intelligent Electronic Devices (IEDs): IEDs offer improved coordination and communication capabilities by combining numerous protection functions into a single device. Advanced fault detection techniques, remote monitoring, and quick information transmission are made possible by them. IEDs facilitate quicker fault identification, isolation, and restoration, which enhances overall transformer protection and system reliability.

Condition Monitoring Systems: Condition monitoring systems can be used to continuously monitor variables including winding currents, voltages, oil levels, and moisture content. These devices offer useful information about the transformer's condition, enabling proactive maintenance and lowering the possibility of unanticipated breakdowns. Condition monitoring systems enable proactive actions to be taken, reducing the chance of transformer failure by identifying early indicators of degradation or irregularities.

To ensure their dependable performance, avoid damage, and preserve the overall stability of electric power systems, transformers must be protected. Transformers can be protected against a variety of defects, including overcurrent, overvoltage, and internal faults, by combining protective devices, plans, and cutting-edge technology. The creation of more effective and dependable protection systems is facilitated by ongoing improvements in protection approaches, allowing for the uninterrupted and smooth flow of electrical energy while ensuring the durability and integrity of transformers.

DISCUSSION

Protection system for transformer:

Merz-Price circulating-current system is without a doubt the best option for generator protection. Despite the fact that this is generally true for transformer protection, there are some situations in which circulating current systems are either not significantly superior to other systems or are simply not feasible due to the challenging conditions imposed by the wide range of voltages, currents, and earthing conditions that are inextricably linked with power transformers. In such cases, alternative preventative measures. It is common to employ systems that are just as efficient as the circulating-current system. The main systems and relays for protecting transformers are:

(i) Buchholz devices that offer protection against all types of incipient failures, or defects that take time to manifest, such as winding insulation failure, core heating, a drop in oil level as a result of leaking joints, etc.

(ii) Earth-fault relays that exclusively offer protection from earth-faults.

(iii) Overcurrent relays, which offer protection primarily from overloading and phase-to-phase problems.

(iv) A differential system (also known as a circulating-current system) that offers defence against phase and earth faults [4].

Typically, a combination of these systems is needed for total transformer protection. The choice of a certain system combination may be influenced by a number of variables, including (a) the size of the transformer, (b) the cooling method, (c) the placement of the transformer in the network, (d) the type of load delivered, and (e) the significance of the service for which the transformer is needed. The aforesaid systems of protection will be covered in detail in the sections that follow.

Buchholz relay:

For protection against all fault types, Buchholz relays are gas-actuated relays fitted in oil-immersed transformers. It is used to disconnect the transformer from the supply in the event of serious internal defects and to sound an alarm in the case of incipient (slow-developing) problems in the transformer. Buchholz is the name of the device's creator. As depicted in Figure 1, it is typically fitted in the conduit that connects the conservator to the main tank. Use of Buchholz relays is standard procedure for any such oil-immersed transformers with ratings in excess of 750 Kva [5]–[7].

Construction: A Buchholz relay's construction is depicted in detail in Figure 2. It takes the shape of a dome-shaped vessel that is inserted into the conduit that connects the conservator and main tank. The gadget consists of two parts. An attached float and a mercury-type switch make up the upper component. A mercury switch installed on a hinged flap in the lower element is in the direct path of the oil flow from the transformer to the conservator. The bottom element is designed to trip the circuit breaker in the event of serious internal faults, whilst the upper element is designed to close an alert circuit during impending failures.

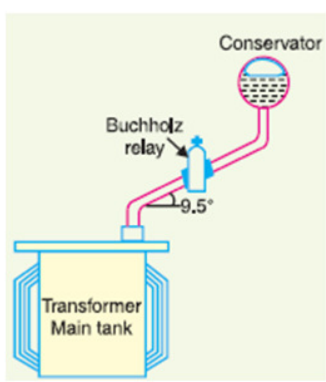

Figure 1: Illustrate the Buchholz relay.

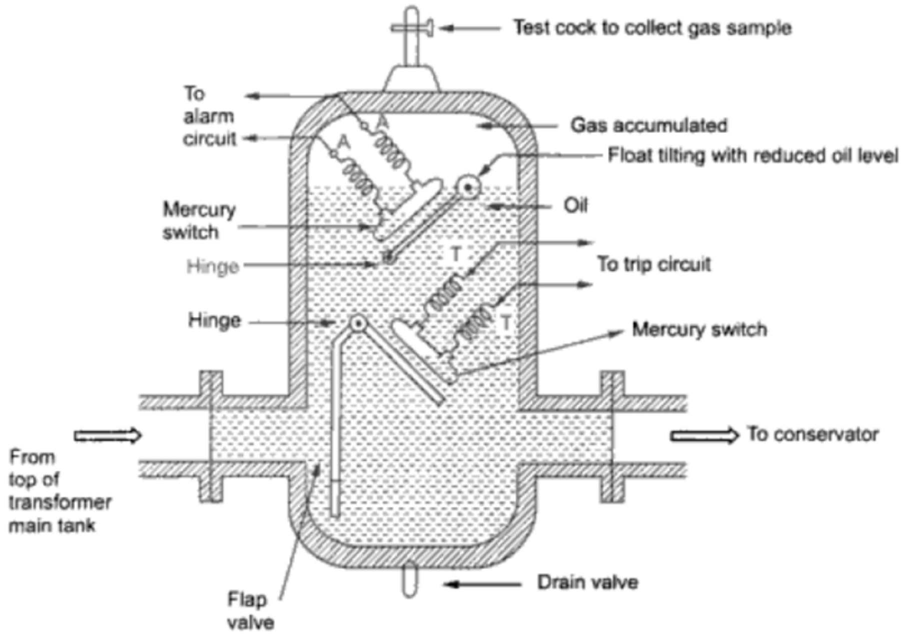

Figure 2: Buchholz relay construction.

Operating: The Buchholz relay functions as follows:

(i) In the event of transformer faults in the early stages, the heat generated by the fault leads to the breakdown of some transformer oil in the main tank. More than 70% of the hydrogen gas in decomposition's by products is hydrogen. Being light, the hydrogen gas seeks to enter the conservator but becomes stuck in the top portion of the relay chamber. When a specific volume of gas builds up, it presses down on the float to the point where it tilts and closes the contacts on the mercury switch that is connected to it. The alarm circuit is now complete, and an alarm will now sound.

Advantage:

(i) The main tank produces a significant volume of gas if the transformer develops a serious problem. Through the Buchholz relay, the oil from the main tank rushes towards the conservator, tilting the flap to seal the connections on the mercury switch. The circuit trip that opens the circuit breaker controlling the transformer is now complete.

(ii) Benefits include the fact that it is the most basic type of transformer protection.

Disadvantage:

(i) It identifies potential problems considerably earlier than other forms of protection are able to. It can only be used with oil-immersed transformers that have conservator tanks.

(ii) The instrument can only identify defects in the transformer below the oil level. As a result, special protection is required when connecting cables.

Earth fault or leakage protection:

An earth fault typically involves some degree of insulation breakdown in the windings leading to the earth. Leakage current as a result is far lower than short-circuit current. Before becoming a short-circuit and being eliminated from the system, the earth-fault may continue for a long period and do significant harm. Employing earth-fault relays to ensure the early disconnection of an earth-fault or leak is profitable in these instances. When an earth-fault or leak forms, an earth-fault relay, which is effectively an overcurrent relay with a low setting, activates. The core-balance leakage protection shown in Figure 3 is one technique for shielding a transformer against earth-faults.

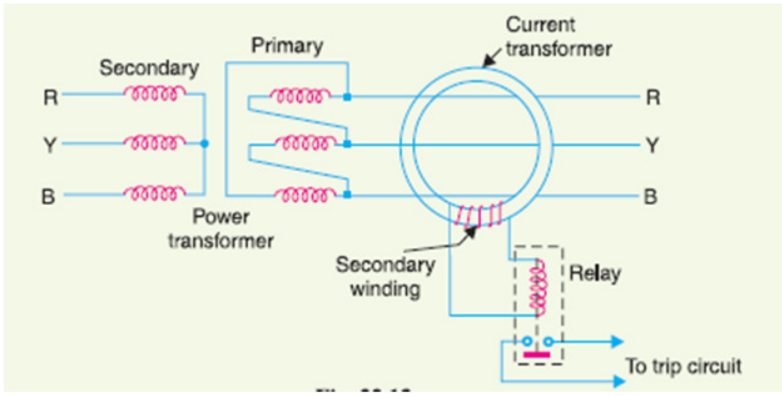

Figure 3: Earth fault or leakage protection

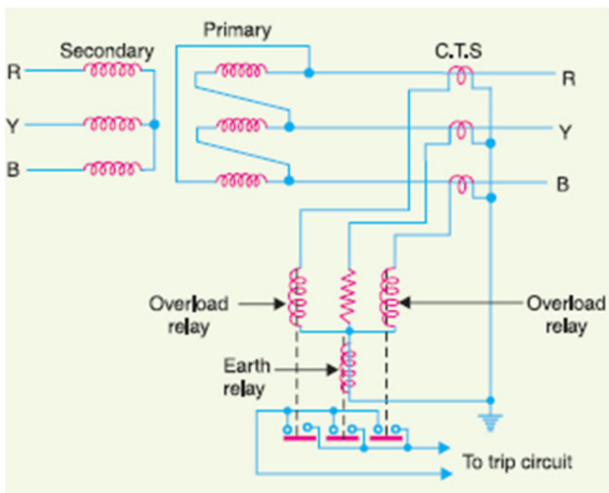

Figure 4: Combined Leakage and Overload Protection.

The core of a current transformer, which carries a single secondary winding, is passed through by the three leads of a power transformer's primary winding. This secondary is wired up to a relay's operational coil. No matter how much the load is out of balance, there is no consequent flux in the core of the current transformer under normal circumstances (i.e., no fault to earth), when the vector sum of the three phase currents is equal to zero. As a result, there is no current passing through the relay, and it is inactive. But when an earth fault occurs, the vector sum of the three phase currents is no longer zero. The resulting current induces e.m.f. in the secondary winding by creating flux in the C.T.'s core. The relay is activated, tripping the circuit breaker and removing the defective transformer from the system.

Combined Leakage and Overload Protection:

The limitation of the core-balance protection mentioned above is that it cannot offer overload protection. The core-balance relay won't work if there is a failure or leakage between phases. Combining leakage and overload protection for transformers is standard procedure. The earth relay only functions when there is an earth or leakage fault and has a low current setting. The overload relays are set up to function against faults between the phases and have high current settings. The schematic layout of the combined leakage and overload protection is shown in Figure 4. Two overload relays and one leakage or earth relay are linked as indicated in this protective system. Phase-to-phase fault protection can be provided by the two overload relays. Overload relay trip contacts and earth fault relay trip contacts are connected in parallel. The circuit breaker will trip as a result of the overload relay or earth relay being activated.

Applying circulating current system to transformers:

Power transformers are frequently protected against earth and phase defects using the Merz-Price circulating-current method. Although there are certain complicating factors that are not present in the generator application, the system as it applies to transformers is fundamentally the same as that for generators. Below is a brief summary of the problematic elements and their corrective actions:

(i) Currents in the primary and secondary of a power transformer should be compared. Due to the fact that these two currents are often different, using identical transformers with the same turn ratio will provide differential current and enable the relay to work even when there is no load. Different turn ratios of CTs are used to make up for the variation in the amount of currents in the primary and secondary of the power transformer. If T is the power transformer's turn-ratio, then the turn-ratio of the CTs on the low-voltage side is T times that of the CTs on the high-voltage side. If this requirement is met, under typical load conditions, the secondary's of the two CTs will carry identical currents. As a result, the relay won't receive any differential current and stays inoperative.

(ii) The primary and secondary currents of a 3-phase power transformer often have a phase difference. A differential current may pass through the relay under normal circumstances and cause relay operation, even when CTs with the right turn ratio are utilised. By properly connecting CTs, the phase discrepancy can be corrected. The power transformer's CTs on one side are wired together so that the resulting currents fed into the pilot wires are out of phase with the individual phase currents in the same direction as the phase shift between the power-transformer's primary and secondary currents, and by an angle equal to that phase shift. The sort of connections for CTs that should be used to account for the phase difference between the primary and secondary currents of power transformers are shown in the table below.

(iii) The fact that most transformers have the ability to change the tap makes this issue much more challenging. Even in normal operation, tap altering will result in differential current flowing through the relay. By modifying the turn-ratio of CTs on the side of the power transformer equipped with taps, the aforementioned issue is resolved.

(iv) The magnetising in-rush current also adds complexity to transformer protection. The magnetising current is quite tiny under typical load circumstances. However, the magnetising or in-rush current can be quite high for a brief period of time when a transformer is activated after it has been taken out of service. Magnetising current appears to differential relays as a fault current and may result in relay operation because it indicates a current entering the transformer without an equal amount leaving. Differential relays are configured to work at a somewhat high level of unbalance in order to overcome the aforementioned challenge. The relays' sensitivity is decreased by using this technique. In actuality, the presence of a strong second-harmonic component in the early in-rush currents is exploited. As a result, it is possible to create a scheme that uses second-harmonic bias features that, because they are only tuned to the second harmonic, practise restraint during energising to prevent malfunction. The aforementioned safety measures are required when using the circulating current principle to protect transformers in order to prevent accidental relay activation.

Circulating current scheme for transformer protection:

The Merz-Price circulating-current protection strategy for a three-phase delta/delta power transformer against phase to ground and phase-to-phase faults is shown in Figure 5. Keep in mind that the CTs on the transformer's two sides are connected in a star pattern. This corrects the phase discrepancy between the main and secondary of the power transformer. One relay is utilised for each pair of CTs, which are connected to each other on the two sides by pilot wires [8]–[10]. It's important to remember that this system also protects against short circuits occurring between turns on the same phase winding. The power transformer's turn-ratio changes when a short-circuit happens between the turns, which throws off the balance between the current transformer pairs. A substantial differential current may flow through the relay to activate it if the power transformer's turn-ratio is adjusted. Buchholz relays, however, are more effective at preventing such short-circuits.

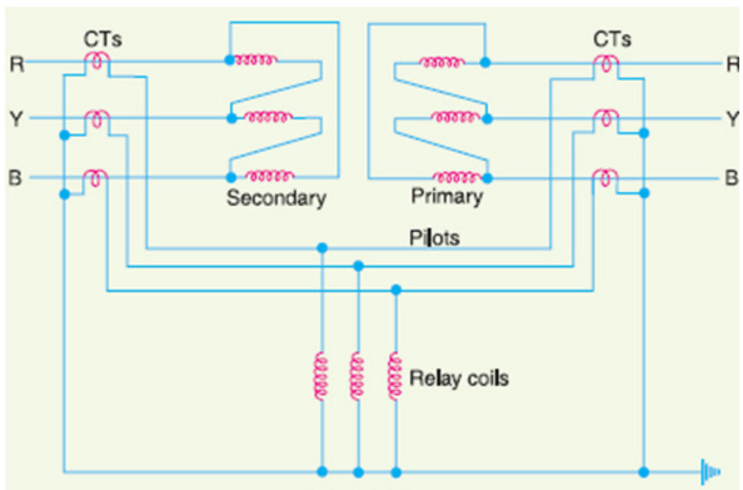

Figure 5: Circulating current scheme for transformer protection.

Percentage differential protection of transformer:

A common method for identifying and defending against internal problems in power transformers is percentage differential protection of transformers. When a large imbalance is found, the percentage differential protection mechanism compares the currents entering and leaving the transformer windings and sends out an alarm or trip signal. The foundation of this protection system is the idea that the vector sum of the currents entering and exiting the transformer should be zero under typical operating conditions. A current transformer (CT) is fitted on the transformer's primary and secondary sides in order to provide percentage difference protection. A differential relay is then used to compare the currents that these CTs have detected. The relay computes the percentage difference in currents and assesses it against a predetermined threshold.

The relay triggers a trip signal to disconnect the transformer from the system if the percentage difference exceeds the threshold, signifying a fault condition. The percentage differential protection plan has a number of benefits. It offers sensitive and trustworthy internal fault detection, including turn-to-turn, phase-to-phase, and phase-to-ground defects. In order to ensure complete protection coverage, through-defects and internal faults can be detected when percentage differential protection is used. However, percentage differential protection comes with some difficulties. Accurate CT compensation to account for the transformer's vector group's phase shift and magnetising current is one challenge. To prevent unneeded tripping during external problems, the technique also requires precise synchronisation with other protective devices, such as overcurrent relays, as shown in figure 6. To ensure dependable performance, the percentage differential relay must be configured properly. The setting is determined by the transformer's properties, including the winding impedance and the rated current. The setting must be carefully calibrated to prevent false trips brought on by typical operating circumstances or small transient currents, while still offering enough sensitivity to find real defects. In real life, the 10% to 30% range is usually used for the percentage disparity setting. The precise setting value is determined by the size of the transformer, the setup of the system, and the desired level of sensitivity. To account for their innate operating circumstances and transient inrush currents during energization, large power transformers may have higher settings. Overall, percentage differential protection is a popular and reliable method for protecting transformers. It contributes to the safe and dependable functioning of power systems and offers reliable internal problem detection.

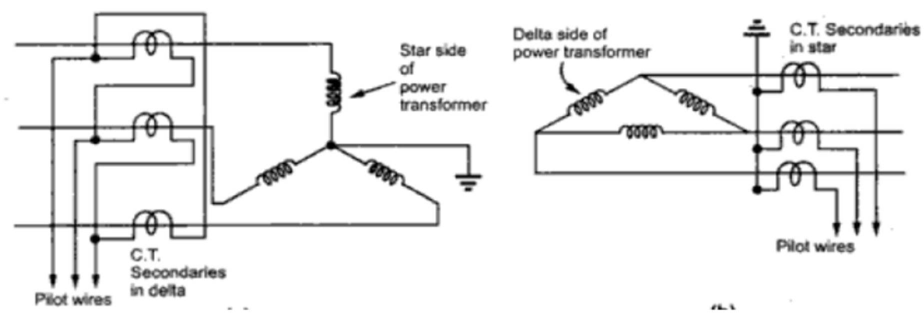

Figure 6: percentage differential protection of Transformers.

CONCLUSION

For electricity systems to remain stable and intact, transformer protection is essential. Operators can prevent catastrophic failures, cut downtime, and lessen the impact of problems on the power system by implementing the proper protective measures. The quick diagnosis of internal defects in the transformer is made possible by differential protection, which provides precise and selective protection. While Buchholz relay protection identifies impending faults and gives early warning indications, overcurrent protection guards against external faults and overloads. Only the necessary components are separated during a malfunction with proper coordination of protective devices, minimising disturbances to the entire power system. Transformer protection has undergone a revolution thanks to the development of cutting-edge technology such clever electronic devices and numerical relays. These gadgets have more functionality, adaptability, and communication capabilities, which makes it possible to create defence strategies that are more focused and effective. They improve transformer maintenance and performance evaluation by enabling real-time monitoring, fault investigation, and data logging. Future advancements in transformer protection will further incorporate this cutting-edge technology and make use of ideas like machine learning and artificial intelligence to improve problem diagnosis and preventative maintenance. In conclusion, the operation and dependability of the power system depend greatly on transformer protection. Power system operators can maintain the safe and effective operation of transformers and consequently contribute to the overall stability of the power grid by combining traditional protective techniques with technology improvements.

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CHAPTER 3

AN OVERVIEW ON INDUCTION MOTOR PROTECTION

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ABSTRACT:

Electric motor reliability and efficiency are critically dependent on motor protection. This article gives a general overview of motor protection techniques, covering both software- and hardware-based strategies. The main goal is to avoid damaging the motor as a result of flaws and unusual operating circumstances. The study examines important facets of motor protection, including heat, voltage, overload, and short circuit protection. Current relays, heat sensors, and motor protection relays are only a few of the methods for motor protection that are investigated. The chapter also discusses the significance of routine maintenance and routine testing to guarantee the efficacy of motor protection systems. Overall, this chapter emphasizes the value of motor protection in maintaining the durability and effectiveness of electric motors. These flaws cause the motor's windings to heat up, which shortens the motor's lifespan. The external power supply n/w can cause situations that result in faults in the driven plant or the motor, which can lead to faults in the motor. The induction motor's degree is determined by the applications and motor costs.

KEYWORDS:

Motor Protection Relays, Protection Techniques, Short Circuit Protection, Thermal Protection.

INTRODUCTION

In the current era of automation, the electric motor is the most important drive. These motors are employed in a variety of industrial settings. However, in order to support their objectives, these motors can be shielded against a variety of mechanical and electrical problems. In this article, an embedded microcontroller-based safety system against emergent problems for induction motors is discussed. Electrical problems with the induction motor include phase reversal, single phasing, overload, unbalanced voltage, overvoltage or under voltage, and unbalanced voltage.

The most often utilized motor in a variety of applications is either an induction motor or an asynchronous motor. Mainly because these motors never operate at synchronous speed. Synchronous speed is the rate at which the magnetic field in the stator is revolving. Depending on the kind of input supply, induction motors can be divided into two categories: single-phase induction motors and three-phase induction motors. Split-phase induction motors, capacitor start induction motors, capacitor start capacitor run induction motors, and shaded pole induction motors are the four categories into which induction motors fall. Additionally, three-phase induction motors are divided into two types based on the rotor type: wound type and squirrel cage motor [1]–[3]. This project's primary objective is to build an induction motor protection system that will shield the motors from any defects caused by single phasing and over-voltage situations. In many industrial applications, the induction motor is a crucial tool. These motors operate with a three-phase power source and a constant temperature to maintain the desired conditions for the loads. However, if any phase is lost or the temperature of the windings increases, the motor will suffer. Thus, by instantly cutting off power to the electric motor if any of the three phases are missing or if the temperature of the motor rises above a certain threshold, the suggested method aids in protecting the motors in the industrial setting.

The suggested system makes use of a three-phase power source that is connected to three single-phase transformers. Operational amplifiers are employed in the project as comparators to compare input voltages. By connecting to the induction motor's body, a thermistor can measure the temperature of the induction motor. The primary relay, which is operated by a different set of relays by detecting single phasing and over-temperature situations, is switched to operate this motor. This project can be improved in the future by adding current sensors and a phase-sequence sensor to prevent overloads and to prevent the motor from running in the incorrect phase sequence. A smooth operating induction motor extends its lifespan and efficiency by protecting it from single phasing, over-voltage, under-voltage, overheating, and phase reversal. These failures typically occur when a supply system exceeds its rating. These failures won't occur if the motor is operating at its rated current, load, and voltage. Generally speaking, the load, which is decided by the motor, should also be under the stated limit in order for the motor to work smoothly. This is all about the project for the induction motor protection system and how it functions. We hope that the material in this post will be very helpful to you in grasping this topic better. The following are a few of the abnormal circumstances that need to be addressed:

1. Twirling Ground faults and phase defects in the stator
2. Overwhelm
3. Speeding
4. Unusual frequencies and voltages
5. Starting a vehicle
6. Locked rotor and stalling
7. A solitary phase

Of course, there is some overlap here, especially when it comes to overloads versus faults, unbalanced currents, single-phasing, etc. Relays used for one hazard may therefore work for others. Care must be made to ensure the appropriate treatment is applied because not all failures or anomalies share the same solution correct a particular issue. In certain cases, tripping the unit is necessary; in other situations, reducing the load or removing a specific piece of equipment is the right course of action. We now look at each category of failure in more depth. Several of these abnormal conditions don't need to trip the machine automatically because they can be fixed at a properly staffed station while it's still in use. As a result, some safety mechanisms only sound alarms.

Other issues, including short circuits, necessitate an immediate removal of the unit from service. The choice of whether to trip or alarm varies significantly between utilities, and even within a single utility or even between power plants or individual units within a single plant. A justified resistance to adding more automated tripping equipment than is strictly essential is what causes the disagreement. More equipment calls for more upkeep and increases the chance of malfunction. In terms of overall system performance, the loss of a generator in today's systems could be more costly than the delayed removal of a machine. On the other hand, delaying the correction of a fault or other irregularity may result in substantial damage and a longer, more costly outage. The choice is not straightforward and is not the same in every circumstance. The protection engineer and the proper operational and plant staff must use judgement and work together.

Stator faults:

Phase fault protection:

It is common practice to utilize differential protection for short circuits in a stator winding on generators rated at least 1000 kVA and on motors rated at least 1500 hp or at 5 kV. Rotating equipment offers a classic example of this type of protection in use because the equipment and all associated peripherals, such as breakers and current transformers (CTs), are typically located close to one another, reducing the burden and potential for error associated with long cable runs. Additionally, because there is just one voltage present, the CT ratios and kinds might be identical and have comparable properties. Without carefully examining the impact on CT performance, they should only be utilized with other relays, metres, instruments, or auxiliary transformers on dedicated circuits. The buses and leads next to the generator winding are nearly always where the CTs for the generator differential are situated.

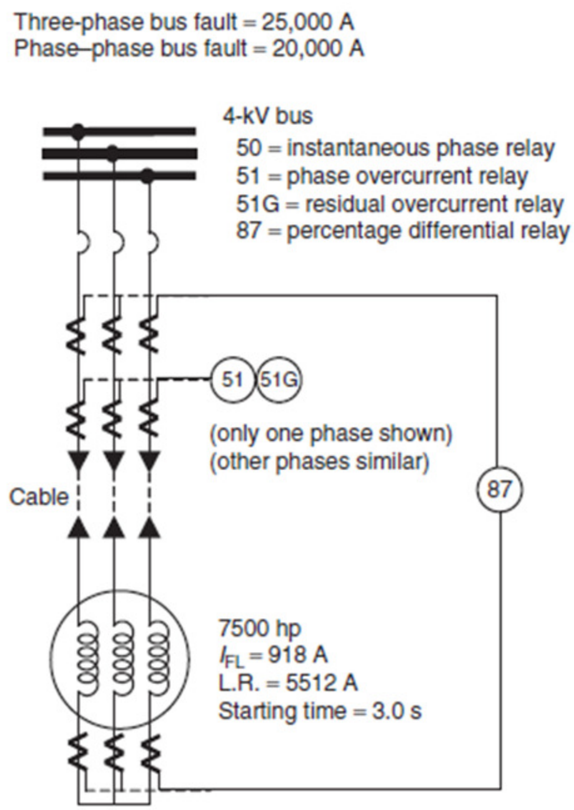

Figure 1: Protection for 7500 hp motor.

This is done to restrict the zone of protection, allowing for speedy damage assessment, repair, and service restoration in the event of a generator breakdown. Typically, the buses themselves are a part of either their own differential or a larger differential plan. In order to include the motor cables within the protective zone in motor differential circuits, three CTs should be installed within the switchgear. The neutral connection of the motor is where the other three CTs are situated. Referring to Figure 1, six leads need to be pulled out of the motor: three on the incoming cable side to connect to the switching device, and three on the motor neutral to accommodate the CTs before the neutral connection is established. This is common production practice when the horsepower is beyond 1500. When purchasing a motor with less than 1500 horsepower, the provision and connections for the CTs must be specified [4]–[6].

DISCUSSION

For the purpose of powering machinery and equipment, induction motors are frequently utilized in numerous industries. It is essential to safeguard these motors from defects and unusual operating situations in order to guarantee their dependable and effective operation. This article offers a thorough overview of induction motor protection techniques, covering both software- and hardware-based strategies. The major goal is to guard against motor damage and lengthen induction motors' useful lives. Key elements of induction motor protection, including overload protection, short circuit protection, voltage protection, and thermal protection, are covered in the article. We examine a number of motor protection methods and tools, such as current relays, heat sensors, and motor protection relays.

Additionally, the significance of routine maintenance and periodic testing is emphasized for determining the efficacy of motor protection devices. The importance of induction motor protection in preserving the productivity and dependability of industrial processes is generally highlighted in this article. Due to their durability, simplicity, and affordability, induction motors are frequently employed in industries. These motors are crucial for powering machinery and equipment, therefore maintaining uninterrupted functioning requires their protection. In order to prevent overheating, insulation breakdown, mechanical stress, and eventually motor failure, motor protection seeks to shield the motor from faults and abnormal situations. This article offers a thorough examination of the numerous safety strategies used to guarantee the safe and effective operation of induction motors.

Protection from Overload:

Induction motors frequently experience overload, which happens when the motor is exposed to excessive current for an extended length of time. In order to avoid motor damage, overload protection seeks to identify and alleviate this circumstance. heat overload prevention, which makes use of heat sensors included into the motor windings, is one extensively utilized technique. These sensors track the temperature increase and shut off the motor if it rises above a certain limit. Utilizing current relays, which monitor the motor's current and trip the motor if it exceeds a predetermined level, is an alternative strategy [7]–[9].

Short Circuit Protection:

Insulation failure, phase-to-phase faults, and ground faults are all potential causes of short circuits in induction motors. Such errors may result in excessive current flow and serious motor damage. The employment of protective tools like fuses or circuit breakers, which stop the flow of electricity in the case of a fault, is a key component of short circuit protection techniques. These tools are made to identify aberrant current levels and promptly isolate the problematic area, protecting the motor from further harm.

Voltage Protection:

Induction motors can suffer from voltage alterations, overvoltage, or under voltage situations. Undervoltage can cause lower motor performance and overheating, while overvoltage can cause insulation to break down. Voltage monitoring devices that continuously track the supply voltage are among the voltage protection techniques. These devices can set off alarms, trip the motor, or engage remedial actions to lessen the effects of voltage changes if the voltage is above or below acceptable limits.

Thermal Protection:

Motor failure is frequently caused by overheating, and thermal protection is essential in limiting excessive temperature rise. Other techniques include the use of thermal sensors or resistance temperature detectors (RTDs), which measure the motor's winding temperature in addition to thermal overload prevention. These sensors offer real-time information on the motor's thermal status, enabling prompt action if the temperature goes above acceptable levels. Advanced algorithm-equipped motor protection relays can also analyses thermal behavior and foresee future overheating conditions.

Motor Protection Devices:

Depending on the complexity and importance of the application, several devices and relays are utilized for motor protection. By keeping an eye on the motor's current levels, current relays offer reliable protection against overload and short circuit circumstances. When the current reaches a certain limit, these relays can be programmed to trip the motor. Thermal sensors, such RTDs, installed in the motor windings keep an eye on the temperature and add another layer of security.

Relays for motor protection integrate numerous safety features, such as overload, short circuit, and thermal protection. These relays offer increased features such improved motor protection and diagnostics, communication capabilities, self-diagnosis, and advanced algorithms.

a) **Protection circuit for Induction motor:** An induction motor protection circuit is made to guard against defects and anomalies that could cause failure or damage to the motor. Here is a quick rundown of the elements and capabilities that are frequently present in an induction motor protection circuit:
b) **Overload Protection:** To keep the motor from running for an extended period of time under conditions of excessive current, overload protection is crucial. Overload protection techniques frequently used include:
c) **Thermal Overload Relays:** These devices use thermal sensors to monitor the motor's temperature and trip the motor if the temperature rises above a predetermined threshold.
d) **Current Relays:** Current relays monitor the motor's current and shut off the motor if it rises above a set limit.
e) **Protection from Short Circuits:** Short circuits can result in excessive current flows through the motor, which can cause damage or failure. Methods for short circuit protection include:
f) **Fuses:** Fuses are safety mechanisms that stop the flow of current when a short circuit is discovered. When the current hits a certain threshold, they are intended to melt or blow.
g) **Circuit breakers:** Circuit breakers are switches that instantly flip open in the event of a short circuit, stopping the flow of current.
h) **Voltage Protection:** Protecting the motor from voltage alterations, overvoltage, and under voltage situations is voltage protection. The following are typical voltage protection features and components:
i) **Relays for voltage monitoring:** These relays continuously check the supply voltage and trip the motor or sound an alarm if it rises or falls outside of permitted ranges.
j) **Devices for Surge Protection:** Surge protectors aid in preventing voltage spikes or surges brought on by lightning strikes or other electrical disturbances [10].
k) **Under/Overvoltage Protection:** To detect and reduce severe voltage circumstances, additional safety measures, such as under voltage relays or overvoltage relays, can be implemented.

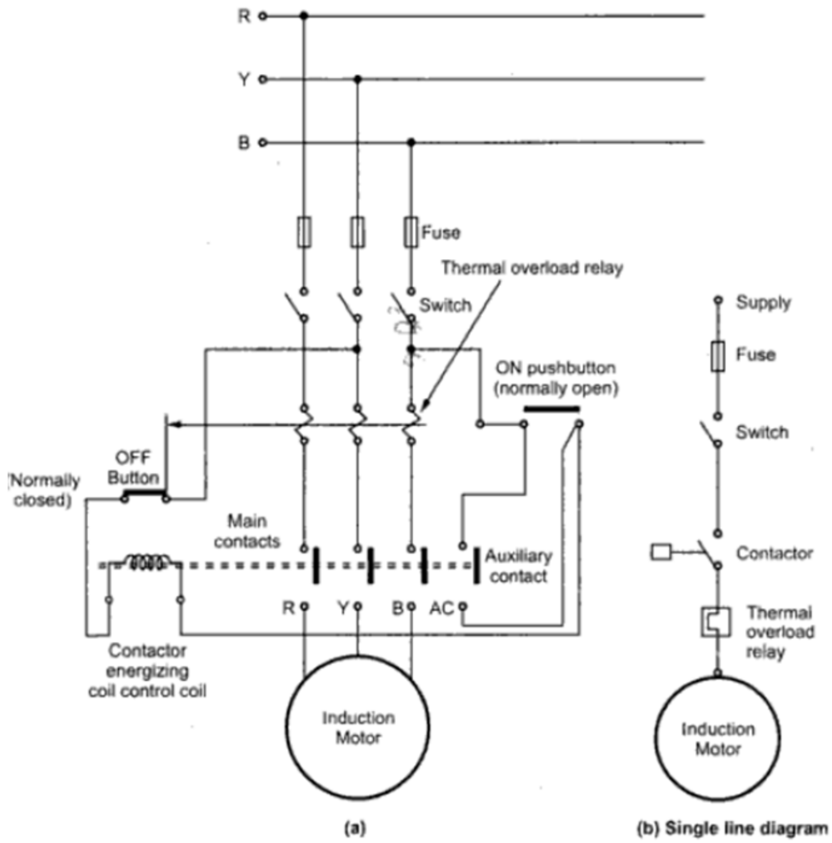

Figure 1: protection circuit for Induction motor.

Single phase preventer:

An electrical device known as a single-phase preventer is used to safeguard single-phase motors against potential harm brought on by phase loss or phase imbalance. It makes certain that the motor only runs when each phase is present and balanced. Pumps, air conditioners, refrigeration systems, and other equipment that depends on single-phase motor operation are just a few examples of applications where this device is frequently used. A single-phase preventer's shown in Figure 1 and figure 2 main job is to spot any irregularities in the voltage supplied to the motor. It analyses the voltages across the power supply's three phases and keeps track of them to look for any major variances. The single-phase preventer engages a protection mechanism when the voltage of one phase falls below a predetermined threshold or when there is a significant imbalance between the phases. Usually, the protective mechanism consists of an output relay and a time delay relay. Before implementing any preventive measures, the time delay relay inserts a predetermined time delay. This delay gives a brief window to make sure the voltage anomaly isn't just a fleeting fluctuation.

The output relay is activated if the fault continues after the time delay has passed, disconnecting the motor from the power source and stopping it from turning on or working. The motor is protected by this disconnection from potential harm caused by operating under abnormal voltage levels. A single-phase preventer considerably lowers the possibility of motor damage brought on by phase loss or phase imbalance in a motor-driven system. It assists in avoiding problems including overheating, decreased motor efficiency, and early motor failure. In order to guarantee the dependable and secure operation of single-phase motors, this protective device is essential. It is significant to note that the application, size, and operating circumstances of the motor may affect the specific design and features of single-phase preventers. The choice and installation of a single-phase preventer should be carried out in accordance with the instructions provided by the motor manufacturer and with the assistance of qualified experts in the field of electrical engineering.

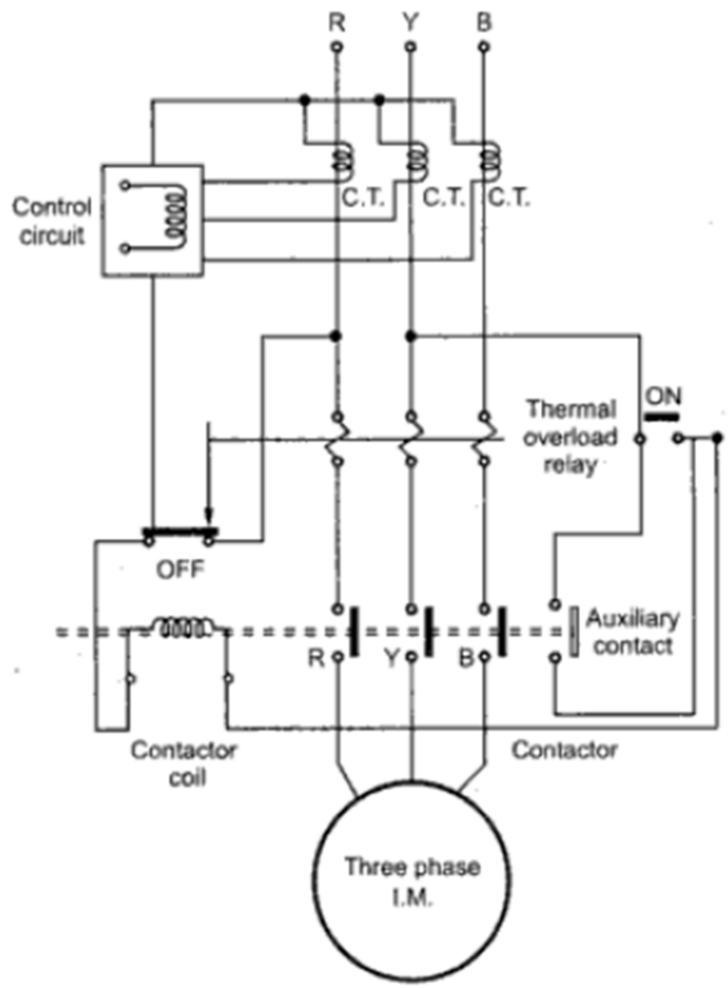

Figure 2: Single phase preventer

CONCLUSION

In order to ensure the dependability and operational efficiency of electric motors, motor protection is of the utmost importance. Key topics like overload, short circuit, voltage, and thermal protection were covered along with an introduction of several motor protection techniques. It has been investigated to use both software- and hardware-based strategies, such as motor protection relays and heat sensors. It is obvious that putting in place a thorough motor protection system is essential to stop motor damage and guarantee safe operation. For the purpose of assessing the efficacy of motor protection systems and identifying any potential problems, routine maintenance and periodic testing are necessary. Organizations may considerably lengthen the lifespan and improve the performance of their electric motors by putting a high priority on motor protection, which will increase productivity and decrease downtime.

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CHAPTER 4

BUS, REACTOR AND CAPACITOR PROTECTION

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ABSTRACT:

For electrical power systems to operate reliably and safely, bus systems, reactors, and capacitors must be protected. An overview of the main elements of bus, reactor, and capacitor protection, including the difficulties encountered and the various protection strategies used. One of the most important system components is a bus. It serves as the connection point for a wide range of components and gearbox lines, and any malfunction would result in the loss of every component. This would result in the same terrible results as many simultaneous faults. Without bus protection, however, distant terminals of lines would need to be tripped in the event of a bus fault. For two reasons, this might actually result in a worse condition than if all of the bus's components were loss. Additionally, the chapter emphasises how crucial good protection techniques are for reducing equipment breakdowns, cutting down on downtime, and ensuring system stability.

KEYWORDS:

Bus Protection, Capacitor Bank Protection, Shunt Reactor Protection, Static Compensator.

INTRODUCTION

Bus protection: Because there are fewer variables, bus protection systems are simpler than transformer protection systems. There is no noticeable inrush, change in the ratio, or phase angle. Contrary to popular belief, bus protection has historically been the most challenging to install due to the serious consequences of a mistake on the system's integrity [1]–[3]. The current transformers' (CTs) uneven core saturation has been the main issue with bus protection. Due to a potential wide range in current intensity and residual flux in each of the system's individual transformers, there is an uneven core saturation. One CT will specifically see the entire contribution from the bus for a close-in external failure, while the other CTs will only see the contribution from the individual lines. The fundamental prerequisite is that the entire plan will offer the level of selectivity required to distinguish between an internal and an external defect.

1. If the remote ends are lost, the intermediate loads will also be lost.
2. As systems get stronger, it gets harder for the remote ends to see all infeed-related errors.

Differential relaying is almost often used to protect the substation buses. The Kirchhoff's Law, which states that all currents entering or leaving a location (the substation bus) must sum vectorially to zero, is used in this method. This form of protection is actually achieved by balancing the CT secondary current of all bus-connected circuits and then bridging this balanced circuit with a relay operating coil.

Overcurrent relays:

It is necessary to connect CTs in each phase of each circuit in parallel with an overcurrent relay for that phase in order to perform differential relaying using overcurrent relays. The fundamental bus differential connection for one phase of a three-phase system is shown in Figure 1. When everything is in order, the bridge is balanced and the relay working coil is not current-carrying. The CTs may not accurately replicate the primary current under large loads, and an error current will flow through the operational coil. This value must be raised higher on the relay. When an external fault occurs, the bridge is balanced as in the typical scenario, and no current flows in the relay working coil if all of the CTs accurately recreate the primary current.

The bridge won't be balanced, the erroneous current will flow in the operational coil, and an incorrect trip will happen if one of the CTs saturates, as was previously discussed. This balance is likewise broken by an internal problem, as we would anticipate, and current passes through the operational coil. Despite the incorrect CT performance, this is a case that calls for a trip. In general, this type of protection should only be used in places that are electrically remote from producing stations that can produce significant DC offset fault currents with lengthy time constants, similar to how we discussed transformer differential relays. The overcurrent relay may be adjusted to be less sensitive or with a time delay to reduce the likelihood of improper operations. These relays are less susceptible to DC and to the harmonic parts of the differential current thanks to the induction disc principle. Designs for solid-state and digital relays must take these elements into account.

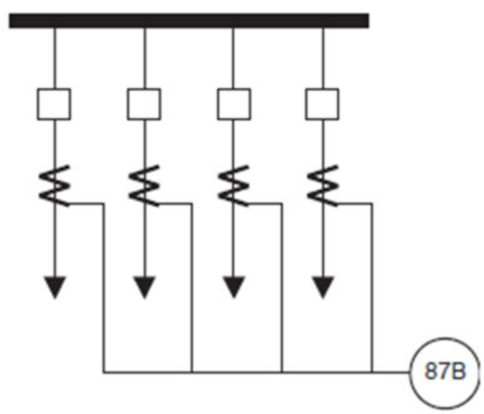

Figure 1: Differential with overcurrent relays

Directional comparison:

When replacing or adding CTs for an existing substation would be too expensive, it is occasionally beneficial to provide bus protection. In such a scenario, bus fault protection might be provided using the current line CTs. We talked about directional relays that can assess the direction of current flow in every bus-connected circuit. An external fault exists if the current flow in one or more circuits isn't towards the bus. An internal bus problem exists if the current flow is into the bus in every circuit.

The system needs a timer, fault detectors, and directional relays. On each circuit connected to the bus, directional relays—typically an admittance relay—are utilised, and they are programmed to look past the current bus and into the connected circuits. The relays are set using the same logic as the zone 2 settings because they must operate for all bus problems. On some circuits, though not necessarily all, fault detectors are used to show that a fault is present.

immediate overcurrent Relays are frequently used for this. The relays are linked to reliable sources and the bus tie breaker in case of phase faults. The relays are attached to the power transformer neutrals in case of ground failures. In order to offer contact coordination, the timer is necessary. All of the directional relays must have a chance to close before a trip signal is issued because they are all connected in series. When comparing the direction of current rather than current amplitude, as is done in other bus protection techniques, CT saturation is typically not a concern. The CTs in each circuit can be utilised for various tasks like relaying and metering and do not necessarily need to have the same ratio. The line protection's directional components may be applied in particular circumstances. As a result of the quantity of relay contacts, the circuitry is intricate and necessitates thorough, routine inspection and maintenance. To ensure contact coordination, the timer should be set for at least four or five cycles. It is important to verify the contact bounce of electromechanical relays, especially at large fault current magnitudes. Every time a system update is made close to the protected bus, the relay application and settings must be checked. The connection to the load in Figure 2 is not protected by a circuit breaker or CT. As a result, the bus differential relay must be set above this value because this load causes a constant error current to flow through it. A problem with this feeder is equivalent to a problem with the bus.

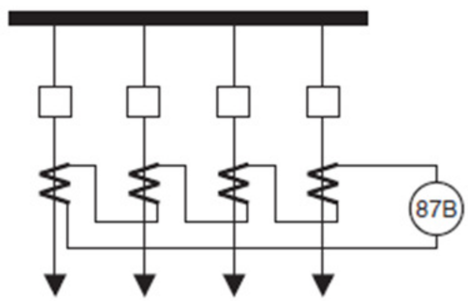

Figure 2: directional bus protection

DISCUSSION

Shunt reactor protection:

Either a series connection or a shunt connection is used to link reactors to a power grid. The system reactance is changed by the series reactor, mostly to lessen the available short-circuit current. Reactors in series are protected, and this is explored. In order to adjust the system voltage and account for the transmission line capacitance, the shunt reactor is used. Reactor protection generally resembles transformer protection quite a bit. Two configurations are taken into account while thinking about shunt reactor protection:

1. Dry-type, connected to an ungrounded wye, and connected to a power transformer's tertiary.
2. A transmission system that is oil-immersed, wye-connected, and has a neutral that is either impedance-grounded or securely grounded. There are two more factors that affect protection for both types of reactor construction.
3. Single-phase reactors, where each phase is contained within a separate tank. Typically, these are used on EHV transmission lines. Although a phase-to-phase fault can arise in the bus and bushings, it is not possible to have one inside the reactor enclosure.
4. Three-phase reactors with a single tank containing all three windings. Usually, these are used with lower voltages.

Dry type reactor: The following are the defects seen in dry-type reactors:

1. Tertiary bus phase-to-phase faults that produce high-magnitude phase current. Given that the reactor's phases are physically separated from one another, these problems are uncommon.

2. Phase-to-ground faults on the tertiary bus that, depending on the size of the grounding transformer and resistor, produce low-magnitude fault current. Since the reactors are mounted on insulators or supports with common clearances, these problems are also uncommon.

3. Reactor bank turn-to-turn faults, which cause a very slight variation in phase current. Failures of the insulation in a winding may start as tracking brought on by the degeneration of the insulation before affecting the entire winding, as hsown in figure 3. A phase-to-neutral fault as a result causes the current in the unfaulted phases to grow up to approximately three times the typical phase current [4]–[6].

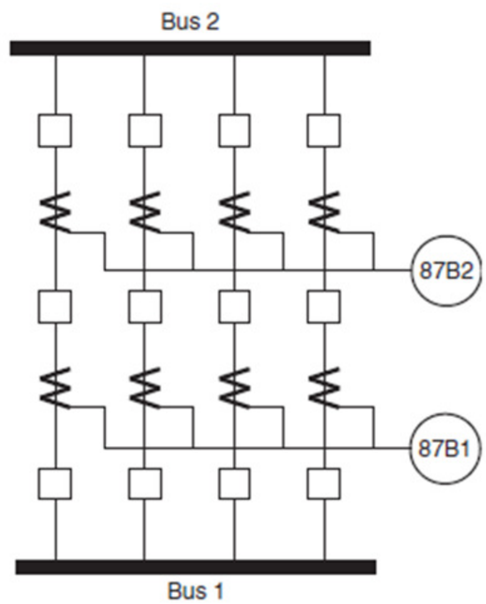

Figure 3: Dry type reactor.

Oil immersed reactor: The following are the failures that occur with oil-immersed reactors:

1. Faults that cause significant fluctuations in the phase current's magnitude, such as failures of insulation or bushings. Phase-to-ground faults are possible due to the winding's close proximity to the core and tank; the severity of the fault depends on where it is in relation to the reactor bushing.

2. Reactor winding turn-to-turn defects that cause slight variations in the phase current's magnitude.

3. Other failures, such as cooling or oil loss.

Overcurrent, differential, and distance relaying are typically used in combination to provide relay protection for faults that generate significant amounts of phase current. Each of these safety measures has restrictions. A differential relay cannot detect a turn-to-turn problem, therefore overcurrent relays must be adjusted above the normal load current. Since a shunt reactor's 60Hz impedance significantly decreases in the presence of shorted turns, an impedance relay can detect them. The connection for an impedance relay. The use of pressure, temperature, or flow devices comparable to those described will protect against mechanical failure or low-level defects affecting the oil system. False relay operation during the energising or de-energizing of the iron core is one of the main challenges with shunt reactor protection. When this happens, DC offsets with lengthy the majority of the issues are caused by time constants and low-frequency elements of the reactor energization current. Instead of low-impedance relays, high-impedance differential relays are advised if this issue arises.

Capacitor bank protection: In power systems, capacitors are also implemented as either a series or a shunt component. The main purpose of the series capacitor is to alter the transmission line reactance for stability or load flow purposes. The protection of the series capacitor and how it affects the line's protection. Understanding the abilities and constraints of the capacitors and the related switching devices is necessary for the protection of fixed or switched shunt capacitor banks. Protection for capacitor banks must be provided against a number of dangers.

1. Overcurrents brought on by bus and capacitor bank errors. The typical overcurrent relay installed at the breaker feeding the capacitor bank provides the protection.
1. Voltages during system surges. The standard surge arresters and spark gaps are used as protection.
2. Overcurrents due to individual capacitor unit failure. The essential fuses to blow in case of an internal unit failure are supplied by the manufacturer. The fuse link must be able to carry 125–135% of the rated capacitor current continuously.
3. Constant overvoltages in capacitor units.

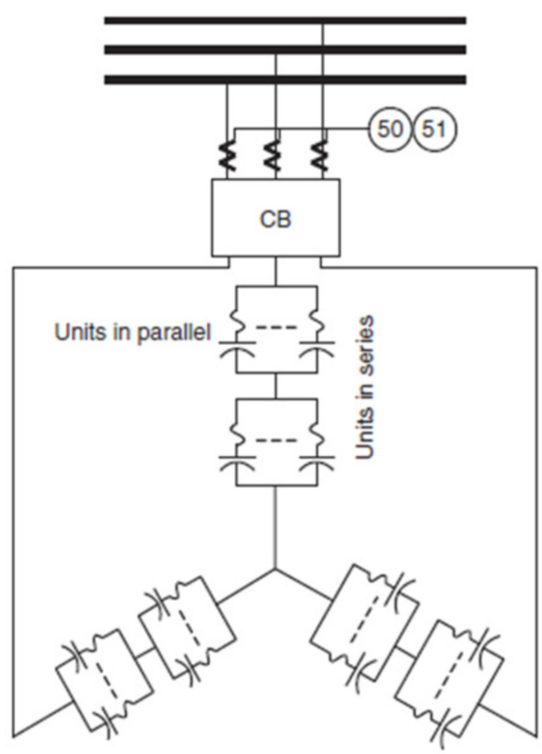

Figure 4: General arrangement for a high-voltage capacitor bank

A high-voltage capacitor bank's overall configuration is shown in Figure 4 and consists of parallel units to offer the necessary current capability and series units to achieve the needed capacitive rating. When one or more capacitor units fail, an overvoltage can be imposed over the remaining units, typically due to the activation of a unit fuse. The higher impedance of the series section where the defective unit was removed is what caused the overvoltage. The impedance of that portion rises when units are removed. The effect of the higher impedance in one section does not, however, reduce the phase current in the same relative proportion because there are numerous sections connected in series. A greater voltage is observed across the remaining units in that segment as a result of the slightly lower current flowing through the more pronouncedly increased resistance. Take the scenario where one capacitor experiences a short and its fuse blows, taking it out of the circuit [7]–[9].

That group's effective parallel impedance is 0.5, and the combined impedance of the three groups is 0.5 + 0.333 + 0.333 or 1.16 pu. There is 1.0/1.16 = 0.86 pu A of total current. In general, relay protection against over voltages is exceedingly challenging. If money were A relay system could be created utilising potential transformers across each series section if resources were limitless and the requirement was severe enough. Nevertheless, operating guidelines have been developed that acknowledge voltages above 110% can be tolerated in emergency or sporadic short-term settings. Several commercial techniques can identify a voltage unbalance if there are two banks operating in parallel, as shown in Figure 5.

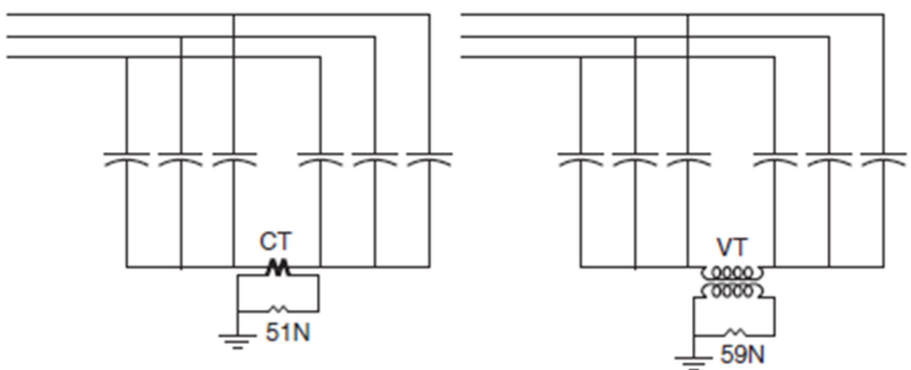

Figure 5: Neutral current and voltage unbalance detection

Static var compensator protection:

Static var compensators (SVCs) are components that modify their susceptance to make up for reactive power shortages in order to manage the voltage at their point of connection to the power grid. Shunt reactors and shunt capacitors are the fundamental reactive elements of SVCs. Thyristors are either used to switch or control reactor controls. Either fixed or thyristor-switched capacitors are available. The system impedance will experience a fluctuating voltage drop as the load changes. The majority of this impedance is reactive. The voltage at the load bus will vary even if the generator voltage doesn't change. The reactive load current component, system, and transformer reactance all influence the voltage. An SVC can maintain constant voltage and account for load fluctuations by managing the thyristors' gating during each cycle. Leading or lagging current can be supplied to the bus and will correct the voltage drop or rise using fixed capacitors and variable reactors. There are several zones that make up the SVC protection plan. In some circumstances, a zone defect should cause the SVC system to go down completely. In other situations, the relaying can be planned so that only the faulted zone is repaired and the SVC is kept running with a restricted set of capabilities. These defensive capabilities may occasionally be offered by the user or as a component of the integrated protective system supplied by the manufacturer. The manufacturer and the user must coordinate the settings in either scenario [10].

Static compensator:

This voltage source inverter uses gate turnoff thyristors. STATCOM generates leading reactive power if the voltage source's terminal voltage is higher than the bus voltage. STATCOM produces lagging reactive power if the voltage is lower than the bus voltage. SVCs have typically shown to have reduced losses and cheaper equipment costs. When there are concerns about visual impact, auditory noise, or land limits, STATCOMs have been employed in transmission. While an SVC needs separate branches for capacitors for var generation and reactors for var absorption, STATCOM can offer both reactive power absorption and production capacity.

CONCLUSION

In conclusion, sustaining the integrity and stability of electrical power systems depends critically on the protection of bus systems, reactors, and capacitors. To avoid equipment failures and save downtime, effective protection techniques, including proper protection plans, are crucial. Bus, reactor, and capacitor protection concerns must be carefully considered, and ongoing improvements in protection systems are required to handle new problems. Overall, it is essential to have a thorough and well-designed protective system to ensure the safe and dependable functioning of electrical power systems and to lessen the effect of errors on system performance. Inductors or capacitors are not used in a static compensator (STATCOM), which offers variable reactive power from lagging to leading. This is accomplished by adjusting the converter's terminal voltage. The STATCOM consists of a voltage source inverter that generates an alternating voltage source that is in phase with the transmission voltage and is connected to the line by a series inductance.

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CHAPTER 5

CARRIER AIDED PROTECTION AND STATIC RELAYS

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ABSTRACT:

Static relays and carrier-aided protection are two crucial components of today's power system protection. In contrast to static relays, which use solid-state electronics for precise and dependable protection tasks, carrier-aided protection makes use of high-frequency carrier signals to improve fault detection and discrimination. In order to ensure system dependability and save downtime, this abstract highlight the principles, benefits, and uses of carrier-aided protection and static relays in electrical power systems. In electrical power systems, a technology called carrier-aided protection is utilized to improve the precision and speed of fault isolation. This protection method makes use of carrier signals, which are often high-frequency signals, to help identify and separate errors. We will go over the main elements and how they work together to provide carrier-aided protection in this block diagram.

KEYWORDS:

Current Carrier Protection, Microprocessor Based Relay, Static Relay, Static Differential Relay, Static Distance Relay.

INTRODUCTION

The signal source, which creates the carrier signal, is where the block diagram begins. The carrier signal, which is superimposed on the power system signals, is commonly a high-frequency sinusoidal waveform. To reduce interference, the carrier frequency is carefully selected to be substantially higher than the power system frequency. The power system signals use a modulation technique, such as amplitude modulation (AM) or frequency modulation (FM), to change the carrier signal. The carrier signal is combined with the signals from the power system during the modulation process, which encodes information about the state of the power system into the carrier signal [1]–[3].

Transmission: The modified carrier signal is subsequently sent through the electrical grid. This can be done in a number of ways, like connecting the carrier signal to the power lines or using specialized channels for communication.

Receiving and Demodulation: To recover the original power system signals, the modulated carrier signal is received and demodulated at the receiving end. The encoded information is retrieved by the demodulation process, which separates the carrier signal from the power system signals.

Processing and Filtering: After the power system signals have been demodulated, noise and undesirable components are removed using filters. Filtering aids in signal quality improvement and false alarm reduction.

Fault Detection and Discrimination: distinct algorithms and approaches are used to analyse the filtered power system signals in order to detect faults and differentiate between distinct fault kinds. In order to do this, the power system signals' properties must be compared against thresholds or patterns that correspond to normal and abnormal system circumstances.

Fault Localization: Localization of the problem: When a problem is discovered, the protection strategy seeks to pinpoint the issue's position within the power system network. Techniques like time-based fault localization algorithms or impedance-based fault location methods can be used to accomplish this.

Trip Signal Generation: The protection scheme creates trip signals that are sent to circuit breakers or other protective devices based on the results of fault identification and localization. The trip signals start the power system's damaged part being isolated, which lessens the impact of the failure and stops additional damage.

Supervision and Monitoring: In order to continuously evaluate the state and effectiveness of the carrier-aided protection scheme, the block schematic also includes supervision and monitoring capabilities. This comprises checking the protection system's proper operation, analyzing system characteristics, and keeping an eye on the carrier signal's quality.

HMI (Human-Machine Interface): The interface between the protection system and human operators is crucial to carrier-aided protection. The HMI provides alarms for fault detection, visual and audio signals of system conditions, and pertinent data for decision-making.

The carrier-aided protection block diagram illustrates the main parts and how they work together to execute this protection strategy. This strategy improves problem detection and discrimination in electrical power systems, enabling quicker and more precise fault isolation. It does this by utilizing carrier signals and modulation techniques. The stable and effective operation of carrier-aided protection in power system applications depends on the proper implementation and integration of each component.

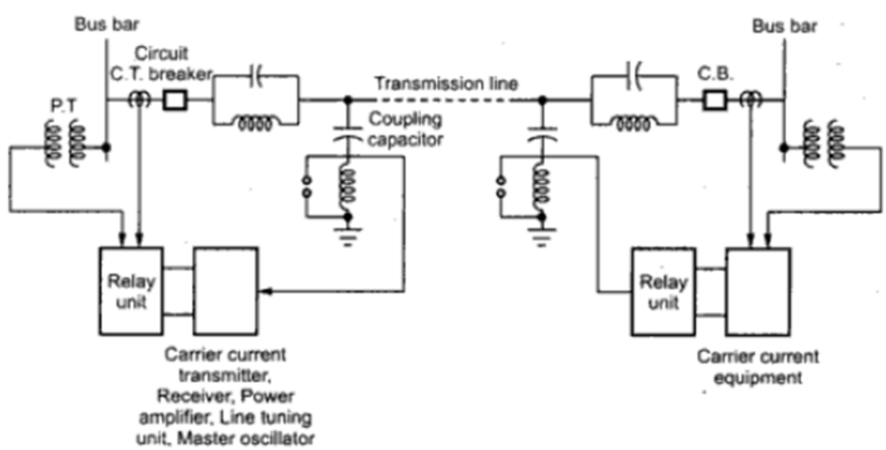

Figure 1: Carrier aided protection.

Current carrier protection: .

In order to identify and isolate faults in power transmission and distribution networks, current carrier protection, often referred to as current differential protection, is a form of protective relay mechanism used in electrical power systems. To detect anomalous events, such as short circuits or faults, this protection method compares the current magnitudes and directions at various points throughout the network. In current carrier protection, carrier signals are used to send the primary current signals from multiple sites, such as transformers or circuit breakers, to a central relay station. These carrier signals, which are superimposed on the principal current signals, are typically high-frequency sinusoidal impulses. The carrier signals serve as a channel for safely and efficiently sending the current data across great distances. The received carrier signals are demodulated at the central relay station to obtain the original primary current signals. Following that, differential algorithms are used to compare the demodulated current signals to see whether there is any variation in the magnitude or direction of the currents at various sites. The current magnitudes and/or directions will differ dramatically in the event of a failure, such as a short circuit, which will cause the protective relay to start the proper steps, such as tripping circuit breakers to isolate the faulty portion.

Current carrier protection has several major benefits, including fast operation, precise fault detection, and wide geographic coverage. The protective relays can immediately identify faults and distinguish between internal and exterior defects by employing carrier signals, allowing for speedier fault isolation and reducing the impact on the power system. Additionally, current carrier protection offers dependable performance even in noisy or challenging operating environments and is less vulnerable to electromagnetic interference. There are several restrictions on present carrier protection, though. The carrier signals must be transmitted via specialized communication channels or carrier equipment, which might complicate and increase the cost of the protection plan. Furthermore, reliable functioning depends on the precise synchronization of the carrier signals at various places, and any synchronization flaws might cause false tripping or the failure to identify faults. Current carrier protection is still a popular and efficient protective relay scheme in power systems despite these obstacles. It provides quick problem detection and differentiation capabilities, which improve the overall stability and dependability of electrical power networks. The performance and dependability of current carrier protection are continuously being improved by relay algorithms and communication technology, ensuring its relevance and utility in contemporary power system protection tactics.

Advantages of current carrier protection:

The following are some benefits of current carrier protection in electrical power systems:

High-Speed Fault Detection: Current carrier protection has the ability to identify problems quickly, allowing for quick action to be taken in the event of a fault or other unusual circumstances in the power system. The protective relays can swiftly compare the current magnitudes and directions at various sites, immediately spot deviations, and then start the necessary protective operations by using carrier signals and differential algorithms.

Accurate Fault Discrimination: By discriminating between internal and exterior problems within the power system, current carrier protection enables accurate fault discrimination. The protective relays can identify the type of problem and its location by examining changes in current magnitudes and directions, assisting in fault isolation and reducing the impact on the rest of the network.

Vast Geographic Coverage: Power systems with a vast geographic coverage can benefit from current carrier protection. The protective relays can monitor the current circumstances at many distant sites since the carrier signals may be relayed over long distances without suffering from considerable loss or distortion. For transmission networks or networks with widely scattered generation and load centres, current carrier protection is especially beneficial in light of this.

Immunity to Electromagnetic Interference: Current carrier protection uses carrier signals that, in most cases, are immune to electromagnetic interference. This ensures that the system will function correctly even in noisy or high-interference conditions. This immunity reduces the possibility of false tripping or missed fault detection owing to outside disturbances and enables accurate and reliable fault detection.

Enhanced Selectivity: Current carrier protection provides increased selectivity for fault isolation and detection. The protective relays can distinguish between faults within the protected zone and faults occurring elsewhere in the network by focusing on the comparison of currents at specified places. Selectivity reduces wasteful tripping and more precisely isolates errors, increasing system reliability and decreasing downtime.

Compatibility with Communication Technologies: Compatible with a variety of communication technologies, including fiber-optic cables and digital communication systems, current carrier protection can be implemented. This compatibility enables effective and dependable carrier signal transmission, enabling precise and prompt information interchange between protective relays and central control stations. The benefits of current carrier protection are generally its fast operation, precise fault discrimination, adaptability for wide coverage areas, and immunity to electromagnetic interference, improved selectivity, and compatibility with communication systems. These advantages minimize downtime and improve system stability while also assisting in the efficient protection and dependable operation of electrical power systems.

DISCUSSION

Static relay:

Static relays are protective relays that carry out protection tasks in electrical power systems by using solid-state electronic components including transistors, integrated circuits, and microprocessors. Static relays provide many benefits over conventional electromechanical relays, which rely on mechanical moving elements. These benefits include quicker response times, greater precision, increased reliability, and improved functionality. Here are some essential characteristics and benefits of static relays:

Rapid Response: Static relays react more quickly than electromechanical relays do. Since there are no mechanical parts and electronic circuits are used, fault conditions can be detected and processed quickly, allowing for the immediate initiation of preventative measures.

High Accuracy: Static relays provide great precision in electrical quantity measurement and fault detection. Solid-state electronic components enable accurate detection of aberrant circumstances by providing exact and dependable measurements of variables like current, voltage, power, and frequency.

Wide Range of Protection Functions: Differential protection, distance protection, voltage protection, and frequency protection are just a few of the many protective features that static relays can implement. These relays offer thorough and flexible protection for components of the power system since they can be programmed to carry out various protection functions at once.

Flexible and programmable: Static relays have a great degree of adaptability and programmability. They enable for customization and optimization of protection settings because they are simply configured and tailored to certain protection requirements. Complex logic and protection methods can be implemented thanks to programmable logic and microprocessors.

Self-Diagnostics and Fault Recording: Many static relays have the ability to do self-diagnostics, which enables them to keep track of their own health and identify any internal flaws or malfunctions. Furthermore, static relays frequently include fault recording capabilities that record and store event data, aiding post-incident analysis and troubleshooting.

Compact and Lightweight Design: Static relays feature a compact and lightweight construction because they don't have any large mechanical components. They are simpler to install, take up less room, and require less maintenance thanks to this characteristic.

Immunity to Mechanical Wear and Vibration: Static relays are immune to mechanical wear and vibration since they do not rely on mechanical parts, therefore they are not harmed by movement or vibration induced by mechanical components. As a result, the relay becomes more dependable and durable, requiring less regular maintenance and replacement. Static relays, in comparison to conventional electromechanical relays, provide a number of benefits, including quick reaction times, high accuracy, a variety of protection functions, flexibility, self-diagnostics, small design, and interoperability with digital communication systems. These benefits make static relays the go-to option for modern power system protection, helping to increase system performance, reliability, and the effectiveness of fault isolation [4]–[6].

Power Supply: Static relays need a power supply to run the internal parts of the device. This can be accomplished either by using separate auxiliary power sources, like batteries or external power supplies, or by drawing power directly from the power system itself, generally through voltage or current transformers.

Together, these fundamental parts carry out the operations and protection duties of a static relay. Every component is essential to the measurement of input signals, processing of data, running of protection algorithms, regulating of outputs, interacting with other devices, and enabling user interaction and monitoring. These factors work together to guarantee precise and dependable protection for electrical power systems, a shown in figure 2.

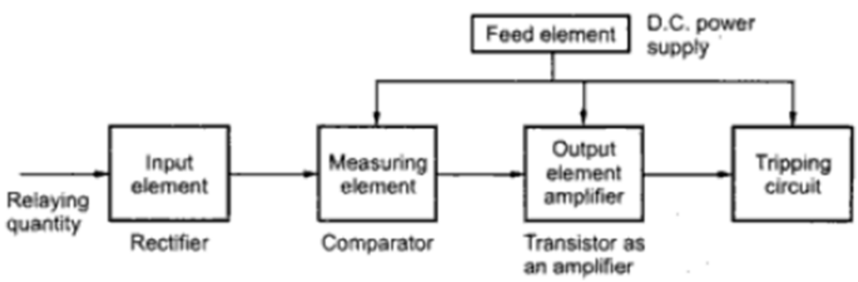

Figure 2: Illustarte the block diagram of static relay.

Comparison of static and electromagnetic relay:

Relays come in two different varieties that are utilized for power system protection: static relays and electromagnetic relays. Based on a number of variables, the following is a comparison between static relays and electromagnetic relays:

Technology: Solid-state electronic devices like transistors, integrated circuits, and microprocessors are used by static relays to operate. To carry out protection functions, they rely on programmable logic and digital signal processing. Relays that function using electromagnetic fields, such as coils and contactors, are known as electromagnetic relays. Their operation is based on electromagnetic principles.

Speed and Response Time: Thanks to their solid-state electronic components and digital processing skills, static relays have quick response times. They can start defensive measures and rapidly identify flaws. Relays with mechanical moving parts, such as electromagnetic relays, have slower response times than static relays. Due to the time it takes for the mechanical mechanism to operate, the response time is often longer.

Accuracy: Static relays offer extremely accurate electrical quantity measurement and fault detection. Due to the use of solid-state electronic components, they provide accurate measurements and computations. Although electromagnetic relays are accurate, there may be a small amount of variance over time owing to things like contact wear and mechanical component ageing.

Reliability: Relays with no moving parts are known as static relays, and they are typically more dependable than electromagnetic relays. Because they are less prone to wear and tear, there is a lower chance that they may malfunction mechanically. Electromagnetic Relays: As a result of the mechanical movement of their parts, electromagnetic relays can deteriorate with time. Contacts could deteriorate, resulting in decreased dependability and probable failures.

Programmability and adaptability: Relays that are static have a high degree of flexibility and programmability. They are easily customizable and adaptable to various protective needs. Complex logic and protection methods can be implemented thanks to programmable logic and microprocessors. Electromagnetic Relays: Compared to static relays, electromagnetic relays are typically less customizable and adaptable. Their mechanical construction and predetermined qualities are the extent of their functionality.

Dimensions and Weight: Due to the lack of any mechanical components, static relays are small and light in design. They are simpler to handle and take up less room when installed. Due to the inclusion of mechanical components, electromagnetic relays are frequently bigger and heavier. Although static relays are normally more expensive, they provide benefits such quick response times, high precision, flexibility, and reliability. In general, electromagnetic relays are less expensive but have longer response times, a reliance on mechanical parts, and less flexibility. The decision between static relays and electromagnetic relays is based on the needs of the individual application, the available budget, and the desired performance traits.

Limitation of static relay: Static relays have a lot of benefits, but they also have some drawbacks that need to be taken into account. The following are some static relays' drawbacks: **Complexity and Technical competence:** Compared to electromagnetic relays, static relays demand a higher level of technical competence for installation, configuration, and maintenance. They require the utilization of sophisticated electronic components, methods for digital signal processing, and programming expertise. To ensure correct operation and troubleshooting of static relays, adequate training and specialized knowledge are required.

Initial Cost: Compared to electromagnetic relays, static relays often have a greater initial cost. Their higher price is a result of the sophisticated electrical components and microprocessor-based designs. This cost issue could be a problem, especially for initiatives with tight budgets or smaller scopes.

Sensitivity to Electrical Noise: When compared to electromagnetic relays, static relays may be more susceptible to electrical noise and electromagnetic interference. Static relays' solid-state electronic components could be harmed by high-frequency noise, harmonics, or transient voltage spikes. It may be necessary to take appropriate steps, such as shielding and filtering, to lessen the impacts of electrical noise.

Dependence on Power Source: Static relays require a consistent and dependable power source to function. Relay functionality may be lost in the event of a power supply interruption or failure. To ensure that static relays continue to function even during power outages or other disruptions, backup power systems or redundancy measures may need to be put in place.

Limited Mechanical Interlocking: Static relays are incapable of mechanical interlocking, in contrast to electromagnetic relays. In electromagnetic relays, mechanical interlocks offer physical blocking mechanisms that stop competing protection functions from operating at the same time. Interlocking must be done in static relays using software or logic-based techniques, which could not offer the same level of dependability and fail-safe operation [7]–[9].

Sensitivity to Environmental Factors: Extreme environmental factors like high temperatures, humidity, or vibrations may be hard on static relays. To guarantee dependable performance of static relays in challenging operating conditions, adequate protection measures must be put in place. These protection measures include suitable enclosure design and cooling systems.

Compatibility with Legacy Systems: Static relays may encounter difficulties when it comes to their compatibility with existing or legacy systems. It may be necessary to build more interfaces, make changes, or make modifications in order to integrate static relays with previous protection systems or retrofit them into older infrastructure, which will increase the implementation's complexity and expense. When considering whether to use static relays for power system protection, it is critical to evaluate these restrictions as well as unique application needs, technical capabilities, and financial restraints. The benefits of static relays frequently outweigh the drawbacks, but careful planning is required to assure successful placement and operation.

Static time current relay:

A static time-current relay, commonly referred to as a static overcurrent relay, is a safety feature that detects and reacts to overcurrent conditions in electrical power systems. It functions according to the amount and duration of the current passing through the system, offering trustworthy and targeted defense against errors and abnormal operating circumstances. A static time-current relay's operation is based on comparing the measured current to a predetermined set of curves or characteristics. These curves, commonly referred to as time-current characteristics or curves, specify the response time of the relay for various current densities. The tripping time of the relay for a specified magnitude of current is shown by each curve, which represents a particular time-current characteristic. These curves can be chosen based on the desired level of protective coordination and are normally provided by the manufacturer. The static time-current relay starts the protective action when the measured current exceeds the limit indicated by the chosen curve. The characteristics of the curve and the overcurrent's strength affect the tripping time. The relay frequently has a programmable time delay to enable synchronization with other security measures in the system. In order to isolate the problem and lessen the impact on the rest of the system, this coordination makes sure that the nearest protection device activates first. There are various benefits of using static time-current relays to safeguard the power system. First of all, they offer precise and trustworthy overcurrent detection. Static relays' solid-state electronic components and exact measuring methods produce reliable current measurements that lessen the possibility of erroneous tripping or missed fault detection. To provide optimum fault isolation and system reliability, they also provide configurable time delays, enabling selectable coordination with other protective devices like fuses, circuit breakers, or other relays.

This synchronization ensures effective fault clearance while reducing the amount of disturbance brought on by problems. The adaptability of static time-current relays is an additional benefit. They can be programmed and set up to fulfil particular security needs. To fit the features of the protected system, the relay parameters, including the threshold current levels and the time-current characteristics, can be changed. This adaptability enables performance customization and improvement of the relay, improving the whole protective system. Furthermore, compared to their electromechanical equivalents, static time-current relays often respond more quickly. Rapid fault detection and tripping are made possible by the employment of solid-state electronics in place of mechanical parts. This quick response time increases system dependability and reduces equipment damage. Static time-current relays have certain drawbacks despite their benefits. Compared to electromechanical relays, they demand a higher level of technical skill for installation, configuration, and maintenance. To ensure appropriate functioning and troubleshooting, adequate training and specialized knowledge are required. Additionally, static relays could be more vulnerable to electromagnetic interference and electrical noise, necessitating extra precautions like shielding and filtering.

Static time-current relays are useful safety equipment used in the defense of power systems. They provide more rapid response times, flexible programming, configurable time delays for selective coordination, and accurate and reliable overcurrent detection. Static time-current relays can be used effectively for improved power system protection by understanding their principles of operation and taking into account their benefits and drawbacks.

Inverse time current relay:

The size and duration of the current flowing through an electrical power system determine how an inverse time current relay functions as a protective relay. It offers selective protection and works in tandem with other protective devices to provide time-delayed tripping for different current levels. An inverse relationship between the tripping time and the current magnitude is the foundation of the operation of an inverse time current relay. This concept states that as the current magnitude increases, the tripping time reduces. Or, to put it another way, the relay offers quicker tripping for greater currents and slower tripping durations for lesser currents. A time-current characteristic curve is used by inverse time current relays to calculate the tripping time for various current levels. Longer tripping durations occur from the curve's design, which has a gradual slope at lower current values and a steeper slope at higher current values. With this feature, the relay is guaranteed to be more sensitive to higher fault currents and to respond more quickly to faults that pose a larger risk to the system.

The definite minimum time (DMT), very inverse (VI), and extremely inverse (EI) are three examples of popular inverse time characteristics used in relays. These features enable for customization depending on particular application requirements by offering various degrees of sensitivity and tripping time variation. The timing circuit of the relay is normally made up of a variety of electronic parts, such as resistors, capacitors, and current transformers, to produce the inverse time characteristic. By using current transformers to measure the system's current flow and comparing the results to the characteristic curve, the tripping time may be calculated. The relay has programmable options that can be used to change the sensitivity and response time, as well as to coordinate with other safety measures. Relays that use inverse time current have a number of benefits for safeguarding electrical systems.

They provide selective coordination with other protective devices to make sure the closest device clears the issue first. The total reliability is increased and the system disturbance is reduced thanks to this collaboration. A fair compromise between sensitivity to fault currents and the capacity to distinguish between fault situations and regular system operation is offered by the inverse characteristic. In addition, inverse time current relays are appropriate for a variety of applications, including both high-voltage transmission networks and low-voltage systems. They are frequently incorporated into protection plans for generator, transformer, feeder, and motor protection. Inverse time current relays may not always offer the best protection against some fault scenarios, it is crucial to note. Additional relay types, such as differential relays or distance relays, may be required in situations when a more specialized and selective protection scheme is needed. In conclusion, inverse time current relays are frequently employed to offer time-delayed tripping based on the current magnitude in power system protection. They provide flexible application options, selective coordination, and a harmony between sensitivity and discrimination. Inverse time current relays for dependable power system protection can be used effectively if their principles of operation are understood and their benefits and drawbacks are taken into account.

Directional static overcurrent relay: A protective relay called a directional static overcurrent relay is used in electrical power systems to recognize and react to directional overcurrent conditions. By tripping the circuit breaker solely for faults occurring in a certain direction of current flow, it is intended to provide selective protection. A directional overcurrent relay's principal function is to distinguish between fault currents that flow in the desired direction, such as faults inside a protected zone, and currents that flow the other way, which may signal faults in neighboring zones or infeed from other sources. The relay aids in localizing faults and reduces wasteful tripping by selectively tripping the circuit breaker depending on the direction of current flow. Current transformers (CTs) and solid-state electronic components are used to give a static overcurrent relay directional sensitivity. The CT current is measured by the relay and compared to a predetermined reference value.

Static differential relay:

To detect and react to differential current circumstances between two or more electrical circuits or components, static differential relays are protective relays used in electrical power systems. The differential current, which is used to compare the currents entering and leaving the protected zone to find flaws or irregularities, is the basis for how it works. A static differential relay's primary job is to protect delicate and specific pieces of machinery including transformers, generators, motors, and busbars. The relay is able to identify internal faults within the protected zone and start the necessary protective procedures, like tripping the circuit breaker, by continuously monitoring the difference between the incoming and outgoing currents. Utilizing solid-state electronic devices like operational amplifiers and digital signal processing methods, a static differential relay works by comparing the currents. The relay is supplied with current inputs from current transformers (CTs) that are normally linked in series with the incoming and outgoing circuits on both sides of the protected zone. The currents moving across the corresponding circuits are proportionally represented by these CTs. The differential current, which is the difference between the incoming and departing currents, is calculated by the relay. The presence of a fault or abnormal condition within the protected zone is indicated if the differential current surpasses a predetermined threshold or reaches a predefined percentage of the nominal current.

Static distance relay:

In electrical power systems, a static distance relay also called a distance protection relay is a protective relay used to identify and address faults depending on the impedance or distance to the fault location. To establish the distance to the fault and start the necessary preventive action, it works by comparing the observed voltage and current phasors at the relay position. A static distance relay's primary job is to protect power system components like gearbox lines quickly and accurately. It works on the premise that the apparent impedance detected by the relay is precisely proportional to the impedance or distance to the location of the problem. The relay can identify the distance to the problem and start the required preventive action by monitoring the voltage and current phasors and computing the impedance. A static distance relay goes through numerous stages of functioning. By connecting voltage and current transformers (VTs and CTs) at the relay position, the relay first measures the voltage and current phasors. The apparent impedance or the distance to the fault location are determined using these data. The estimated impedance is contrasted by the relay with a predetermined impedance characteristic, sometimes referred to as the reach or reach characteristic. The reach characteristic is often represented as a circle or ellipse in the impedance plane, with the radius or major/minor axis denoting the maximum reach distance and the centre designating the location of the relay. The fault is within the protected zone if the estimated impedance satisfies the reach characteristic. In order to isolate the fault, the relay may trip the related circuit breaker as the appropriate precautionary step. The fault is outside the protected zone if the computed impedance exceeds the reach characteristic, and the relay does not operate in response. In order to increase their functionality and dependability, static distance relays frequently have extra functions. These features may have programmable options for zone interlocking, sensitivity, reach characteristics, and time delays. Based on the required reach distance and system configuration, reach characteristic options enable modification. Sensitivity settings allow the relay's responsiveness to fault conditions to be precisely adjusted.

Microprocessor based relay:

An advanced protection tool used in electrical power systems is a microprocessor-based relay, commonly referred to as a digital relay or numerical relay. It uses a microprocessor as its primary component to process electrical inputs, run intricate algorithms, and come to reliable conclusions about system control and protection. Microprocessor-based relays provide many advantages over conventional electro-mechanical or static relays in terms of functionality, adaptability, and performance. A microprocessor-based relay's capacity to quickly and accurately digitize and sample electrical data is one of its primary features. Precision measurements and analyses of numerous electrical parameters, including current, voltage, power, frequency, and phase angles, are made possible by this digital processing capabilities. Real-time data acquisition via the relay makes it possible to gather crucial data for system diagnostics, power quality monitoring, and fault analysis. The adaptive protection algorithms of microprocessor-based relays are another important benefit. These relays analyses electrical data using complex mathematical models and algorithms to find defects or unusual conditions. They are adaptable to various system setups and operating environments, which gives them versatility and the ability to manage intricate protection schemes. These relays' adaptive nature ensures precise and dependable fault detection while reducing false tripping. Relays with microprocessors also have better networking and communication capabilities. The versatility and programmability of microprocessor-based relays are further advantages. Based on the requirements of a particular application, engineers can programmer and customize protection settings, coordination parameters, and control logic. Complex protection schemes can be more easily implemented thanks to this flexibility, which also makes it simple to adjust to system changes. In addition to enabling remote firmware updates, the programmability capability also allows for physical relay intervention to be avoided. Microprocessor-based relays also have the ability to log events and report faults [10].

CONCLUSION

In conclusion, static relays and carrier-aided protection are crucial components of contemporary power system protection schemes. High-frequency carrier signals are used in carrier-aided protection to increase the accuracy and speed of fault detection and discrimination. This method enhances fault diagnosis and reduces false alarms by embedding power system information into the carrier signal. On the other hand, solid-state devices are used by static relays for accurate and dependable protective functions. Fast response times, great precision, and insulation from electromagnetic interference are just a few benefits these gadgets have to offer. Static relays and carrier-aided protection both improve the overall performance and reliability of electrical power systems. They are essential for reducing downtime, avoiding equipment damage, and preserving system stability. In order to address new challenges in power system protection, such as the integration of renewable energy sources, the growing complexity of power grids, and the need for improved fault detection and discrimination capabilities, carrier-aided protection techniques and static relay technology are continuously improving. In conclusion, static relays and carrier-aided protection are essential elements of contemporary power system protection schemes. Their use in electrical power systems promotes dependable and secure operation, improving system performance and shortening outage times. Future advancements in electrical power systems will be possible thanks to ongoing research and development in these fields, which will also increase the effectiveness and efficiency of power system protection.

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CHAPTER 6

EXPLORING THE METHODS OF ELECTRICAL SYSTEM SAFETY AND RELIABILITY

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ABSTRACT:

Circuit breakers play a pivotal role in safeguarding electrical systems, ensuring safety, and maintaining reliable power distribution. This study explores the significance, principles, types, and applications of circuit breakers, which are essential devices designed to protect electrical networks and equipment from overloads, short circuits, and other electrical faults. Circuit breakers serve as crucial components within electrical systems, interrupting excessive currents and preventing damage to equipment and infrastructure. They function by detecting abnormal current levels and tripping open to disrupt the flow of electricity, effectively isolating faulty sections and preventing further damage. Electrical systems must include circuit breakers to safeguard against overloads and short circuits. When abnormal circumstances arise, they function as switches that automatically interrupt the flow of current. An overview of circuit breakers' operation and significance in electrical systems is given in this chapter.

KEYWORDS:

Arc Extinction, Arc Resistance, Circuit Breaker, Di Electric Strength, Fault Current, Short Circuits.

INTRODUCTION

It is frequently desired and required to turn on and off different circuits (such as transmission lines, distributors, generating plants, etc.) during the functioning of a power system in both normal and exceptional circumstances. A switch and a fuse connected in series with the circuit used to serve as this purpose in the past. Such a method of control, however, has two drawbacks. First of all, it takes a while to replace a blown fuse and get power back to the clients. Second, new high-voltage and big capacity circuit faults produce massive fault currents that a fuse cannot effectively interrupt. The employment of switches and fuses is restricted to low-voltage, small-capacity circuits where frequent operations are not anticipated, such as for the switching and protection of distribution transformers, lighting circuits, branch circuits of distribution lines, etc. due to these drawbacks.

The lines and other equipment run at extremely high voltages and carry substantial currents thanks to the development of the power system. In such high-capacity circuits, the placement of switches and fuses cannot perform the desired function of switchgear. This calls for the adoption of a more dependable kind of control, like that provided by circuit breakers. Using a circuit breaker, a circuit can be made or broken manually or automatically in all situations, including no-load, full-load, and short-circuit situations. This feature of the circuit breaker has made it an extremely practical device for switching and protecting different power system components. The many kinds of circuit breakers and their expanding use as control devices will be covered in this chapter.

Circuit breaker: A circuit breaker is a piece of equipment that can (i) make or break a circuit manually or remotely under normal conditions (ii) automatically break a circuit during a fault (iii) manually make a circuit manually or remotely during a fault Thus, a circuit breaker includes both manual (or remote control) and automatic control for switching functions, the latter of which uses relays and only functions during a fault [1]–[3].

Circuit breakers are essential parts of electrical systems because they protect circuits from overloads and short circuits by acting as protective devices. They are essential in stopping the flow of electricity when unexpected circumstances arise, protecting equipment, lowering the risk of electrical fires, and guaranteeing the dependability and safety of electrical systems. This in-depth essay examines the principles of operation, varieties, uses, and developments of circuit breakers, emphasizing their role in contemporary electrical infrastructure. Modern life is mostly powered by electricity, which runs our homes, businesses, and industries. However, because overloads and short circuits are a possibility, it also carries some risks. Circuit breakers are used as essential components in electrical systems to reduce these hazards and guarantee their dependability and safety. The definition, function, and importance of circuit breakers in the electrical infrastructure are all covered in detail in this introduction. An electrical switching mechanism known as a circuit breaker is used to safeguard electrical circuits and equipment from high current situations like overloads and short circuits. When abnormal circumstances arise, it functions as an automated on-off switch to stop the flow of electricity, averting any potential harm or dangers. As they provide the effective and safe distribution of electrical power, circuit breakers are a crucial component of electrical systems.

Circuit breakers' main function is to protect electrical circuits from harm by spotting and stopping abnormal electrical conditions. They are in charge of cutting off problematic circuits from the rest of the system to guard against fires, electrical mishaps, and equipment damage. Fuse replacement is required once a fuse has operated, therefore circuit breakers are an alternative. Circuit breakers, in contrast to fuses, can be manually reset or, when the fault has been fixed, automatically reset.

Working principle of circuit breaker:

Essentially, a circuit breaker is made up of electrodes, or moving and stationary contacts. These contacts are closed when the system is functioning normally, and they won't automatically open until there is a problem with the system. The contacts can, of course, be opened manually or remotely anytime required. The circuit breaker's trip coils become activated in response to a fault in any component of the system, and some mechanism pulls apart the movable contacts to open the circuit. An arc is created between the contacts of a circuit breaker when they split due to a failure. As a result, the current can flow until the discharge stops. Arc generation not only slows down the process of interrupting the flow of current, but it also produces a great deal of heat that could harm the circuit breaker or the entire system. Therefore, the key challenge in a circuit breaker is to put out the arc as quickly as possible so that the heat it produces doesn't reach a harmful level.

The idea behind how circuit breakers work is that they have current sensing and trip mechanisms. They are made up of a switch, a trip unit, and a protective mechanism, which are its three primary parts. Current goes via the circuit breakers switch mechanism as it travels across an electrical circuit. Normally, the switch is shut, allowing the current to flow freely. The protection mechanism is activated when the current exceeds the predetermined threshold due to an abnormal condition, such as an overload or short circuit. A circuit breaker's trip unit is in charge of monitoring the current and starting the trip mechanism when anomalous conditions are found. Trip units come in a variety of forms, such as thermal, magnetic, and electronic. Thermal trip units work by applying heat from an excessive current to a bimetallic strip, which then deforms. The trip unit is triggered by the deformation to engage the trip mechanism, which opens the switch and stops the current flow. High currents provide a magnetic field that magnetic trip units use to activate the trip mechanism. The magnetic field activates the trip device, disconnecting the circuit, when the current reaches a predetermined level. The more modern electronic trip devices use electronic sensors to track the current. They provide better precision as well as other features including movable trip settings and communication options. When an abnormal state is found, the trip mechanism is in charge of physically opening the switch and stopping the current flow. It guarantees that the circuit is cut off from the power source, safeguarding the electrics and stopping further harm.

Arc phenomenon:

Before the protection mechanism opens the contacts of the circuit breaker in the event of a short circuit, a significant current is flowing through them. The contact area rapidly reduces as the contacts start to separate, and a strong fault current produces an increase in current density and, ultimately, a rise in temperature. The heat generated in the media (often oil or air) between contacts is sufficient to ionise the air or vapourize and ionise the oil. An arc is created between the contacts as a result of the ionised air or vapour acting as a conductor. The p.d. between the contacts is very modest and just enough to keep the arc going. Since the arc offers a low resistance path, the circuit's current flows unhindered for as long as the arc does.

The current flowing between the contacts during the arcing phase is dependent on the arc resistance. The amount of current that travels between the contacts decreases with increasing arc resistance. The following elements affect the arc resistance:

(i) Level of ionization: As the quantity of ionised particles between the contacts decreases, arc resistance rises.

(ii) Arc length: As the arc length, or the distance between contacts, grows, so does the arc resistance.

iii) Cross-section of the arc: As the cross-sectional area of the arc decreases, arc resistance rises.

DISCUSSION

Principle of Arc extinction:

Examining the elements responsible for the maintenance of the arc between the contacts is required before considering the techniques for arc extinction. Which are:

(i) The distance between contacts

(ii) Ionised particles between contacts, item.

Following each of these,

(i) When the contacts are close together, the p.d. between them is enough to keep the arc going. Separating the contacts so far apart that p.d. is no longer sufficient to maintain the arc is one approach to put out the flame. However, in high voltage systems where a separation of many metres may be necessary, this solution is impractical.

(ii) The arc is typically maintained by the ionised particles between the contacts. The arc extinction will be made easier if the arc path is deionized. The arc can be cooled or the ionised particles can be physically removed from the area between the contacts.

Method of Arc extinction: In circuit breakers, there are two ways to put out an arc: 1. the high resistance method. The current-zero technique or low resistance.

High resistance method: The high resistance approaches this technique causes the arc resistance to build up over time such that the current is decreased to a level that cannot sustain the arc. As a result, the current is cut off or the arc is put out. The main drawback of this technology is the significant energy loss in the arc. Because of this, it is exclusively used in low-capacity a.c. and d.c. circuit breakers.

(i) **Lengthening the arc**: The arc's resistance can be raised by lengthening it, as resistance is directly proportional to arc length. By widening the space between contacts, the arc's length can be extended.

(ii) **Cooling the arc:** Cooling the arc aids in deionizing the medium in between the contacts.

The arc resistance is raised as a result. Through the use of a gas blast directed at the arc, effective cooling can be achieved.

(iii) **Reducing the arc's X-section:** Increasing the voltage required to keep the arc in place if the arc's X-section area is reduced. In other words, the arc path experiences more opposition. The arc's cross-section can be decreased by having smaller contact areas or by allowing the arc to pass through a small opening.

(iv) **Splitting the arc:** Dividing the arc into a number of smaller arcs in sequence might increase the resistance of the arc. Each of these arcs experiences a cooling and lengthening impact. By inserting some conducting plates between the contacts, the arc may be separated.

Low resistance or Current zero method: Only arc extinction in a.c. circuits is achieved using the low resistance or current zero method. This approach prevents arc re-ignition despite increased voltage between the contacts by maintaining low arc resistance until current is zero, at which point the arc automatically extinguishes. This technique for arc extinction is used by all contemporary high power a.c. circuit breakers.

The arc won't restart and the current will be cut off if, right after current zero, the dielectric strength of the medium between the contacts builds up more quickly than the voltage across the contacts. The following methods can be used to quickly raise the dielectric strength of the medium near current zero:

(A) Bringing about the recombination of ionised particles into neutral molecules in the area between contacts.

(b) Removing the ionised particles with a vacuum and substituting unionized particles

In order to prevent the space between contacts from being broken down by the growing contact voltage or the restriking voltage, the major challenge in a.c. arc interruption is to quickly deionize the medium between contacts as soon as the current drops to zero. The medium can be made to become less ionised by:

(i) **Extending the gap:** The dielectric strength of the medium is inversely correlated with the distance between the contacts. Therefore, a higher medium dielectric strength can be produced by quickly opening the connections.

(ii) **High pressure:** As the pressure rises around the arc, the density of the particles making up the discharge rises as well. The medium between contacts has a higher dielectric strength as a result of the higher rate of de-ionization brought on by the increased particle density.

(iii) **Cooling**: If ionised particles are allowed to cool, natural combination occurs more quickly. As a result, cooling the arc can enhance the dielectric strength of the medium between the contacts.

(iv) **Blast effect:** The dielectric strength of the medium can be significantly improved if the ionised particles between the contacts are swept away and replaced by unionized particles. This can be accomplished by driving oil into the contact space or by firing a gas blast along the discharge.

Important terms: The following key words that are frequently used in circuit breaker analysis are:

(i) **Arc voltage:** This is the voltage that appears across the circuit breaker contacts while an arc is occurring.

An arc is created as soon as the circuit breaker's contacts separate. Arc voltage refers to the voltage that develops across the contacts while an arc is occurring. Except for the time when the fault current is at or close to the zero current point, it has a low value. At zero current, the arc voltage rises quickly to its maximum value, and this maximum voltage has a tendency to keep the current flowing in the form of an arc.

(ii) Restriking voltage: During the arcing period, this transient voltage appears across the contacts at or close to current zero [4]–[6].

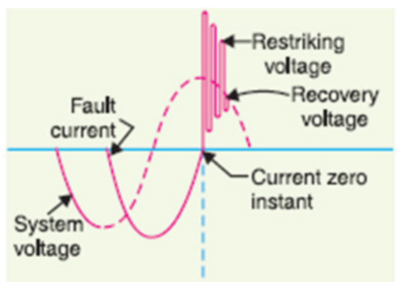

Figure 1: Restriking voltage.

The rapid energy transfer between the magnetic and electric fields associated with the plant and transmission lines of the system causes a high-frequency transient voltage to develop across the connections at zero current. Restriking voltage is the term for this transient voltage as shown in Figure 1. This voltage determines the circuit's current interruption. The arc will continue for another half-cycle if the restriking voltage rises faster than the dielectric strength of the medium between the contacts. On the other hand, if the medium's dielectric strength increases faster than the restriking voltage, the arc won't relight and the current will be cut off.

(iii) **Recovery voltage:** Following final arc extinction, the normal frequency (50 Hz) r.m.s. voltage is visible across the contacts of the circuit breaker. It roughly matches the voltage of the system. Every half cycle when a circuit breaker's contacts are opened, the current drops to zero. At some current zero, the contacts are suitably spaced apart, and the elimination of ionised particles increases the dielectric strength of the medium between the contacts to a high value. The medium between the contacts is strong enough to stop the breakdown caused by the restriking voltage at that precise moment. As a result, the final arc extinction occurs and the circuit current is cut off. The voltage that occurs across the connections has a transient component right away after the final current interruption (see Fig.1). However, because of the system resistance's dampening effect, these transitory oscillations quickly stop, and normal circuit voltage starts to show across the contacts. Recovery voltage is the term for the normal frequency voltage across the contacts.

Classification of circuit breakers:

The circuit breakers can be categorized in a number of different ways. The medium utilized for arc extinction, however, provides the basis for the broadest classification. Arc extinction typically uses oil, air, Sulphur hexafluoride (SF6), or vacuum as the medium. Circuit breakers can therefore be categorized as follows:

(i) Oil circuit breakers that use transformer oil or other insulating oil for arc extinction.

(ii) Air-blast circuit breakers, in which the arc is put out by a high-pressure air blast.

(iii) Sulphur hexafluoride (SF6) gas is utilized for arc extinction in Sulphur hexafluoride circuit breakers.

(iv) Vacuum circuit breakers, which employ vacuum to put out an arc.

Every sort of circuit breaker has benefits and drawbacks of its own. We will go over the design and operation of these circuit breakers in the sections that follow, paying particular attention to how the arc extinction is made possible.

Significance of circuit breaker in Electrical Infrastructure: Circuit breakers are essential for maintaining the dependability and safety of electrical systems. The following views might be used to comprehend their significance:

a) **Equipment Safety:** Circuit breakers stop the flow of excessive current, preventing harm to electrical equipment. Overloads can cause overheating and harm to wires, motors, transformers, and other components when the current exceeds the circuit's capability. On the other hand, short circuits happen when two conductors form a low-resistance channel, causing a quick surge in current. Circuit breakers quickly identify such anomalous conditions and stop the current, preventing damage to the equipment.

b) **Fire Prevention:** Electrical fires are more likely to start as a result of overloads and short circuits since they can produce a lot of heat. Circuit breakers reduce the risk of fires caused by excessive heat accumulation by rapidly cutting the current flow during unexpected circumstances. In order to protect people and property from electrical fires, they offer a crucial line of defense.

c) **Personnel Safety:** When people come into contact with live electrical components or faulty circuits, electrical hazards like electric shocks might happen. By quickly cutting off faulty circuits, circuit breakers contribute to worker safety by averting unintentional electrocution or accidents. They support a secure workplace, particularly in commercial environments with high voltage equipment.

d) **System Reliability:** Electrical systems depend on numerous circuits operating correctly and coordinating with one another. A problem in one circuit has the potential to affect the entire system, resulting in equipment failure or power outages. Circuit breakers help to maintain system dependability by isolating problematic circuits and confining problems to lessen the impact on the overall electrical infrastructure.

e) **Flexibility and Convenience:** Circuit breakers have the benefit of resettable operation, unlike fuses. Circuit breakers can be manually or automatically reset after a problem has been fixed in order to resume normal current flow. This prevents the need for frequent fuse replacement, saving money and providing ease.

Advantages and disadvantages of Circuit breaker: Circuit breakers are essential parts of electrical systems and provide several benefits in terms of convenience, safety, and system dependability. However, they do have some restrictions and drawbacks, just like any other technology. We shall thoroughly examine the benefits and drawbacks of circuit breakers in this section.

The benefits of circuit breakers are:

1. **Overload and Short Circuit Protection**: Protection from Overload and Short Circuits: Circuit breakers are made expressly to guard against overloads and short circuits in electrical circuits. They have the ability to detect excessive current and automatically break the circuit, protecting the wire and equipment from harm. This lowers the possibility of electrical fires while ensuring the security of electrical systems.
2. **Quick Response Time**: Circuit breakers can detect and stop aberrant circumstances within milliseconds because to their quick response times. This quick reaction cuts down on the length of the fault current flow, lowering the possibility of equipment damage and increasing system reliability overall.
3. **Resettable Operation:** Circuit breakers have the benefit of resettable operation in contrast to fuses. Circuit breakers can be manually or automatically reset when a problem has been fixed, resuming normal current flow without the need for replacement. This reduces the amount of time, work, and money needed to change fuses.
4. **Selective Coordination:** Circuit breakers enable selective coordination, which means that only the problematic circuit is shut down while the remainder of the electrical system is kept running. By preventing a problem in one circuit from causing a widespread power loss or interruption, this feature increases the dependability and accessibility of electrical power.
5. **Flexibility and customizable Settings:** Circuit breakers frequently have a trip setting that is customizable, allowing for flexibility based on the requirements of a particular application. They can adjust to fluctuating electrical loads because to their versatility, which also guarantees that various systems and pieces of equipment are well-protected.
6. **Remote Control and Monitoring:** Advanced circuit breakers have digital and intelligent capabilities that allow for remote control and monitoring. With the use of this capacity, system administration may be improved with features like remote tripping, status monitoring, and diagnostic capabilities. Effective system optimization, maintenance, and troubleshooting are made possible through remote control and monitoring.
7. **Enhanced Safety Features:** Circuit breakers offer enhanced safety measures in addition to the fundamental overload and short circuit protection. Arc fault circuit interrupters, for instance, can identify and stop electrical arcs, lowering the danger of fire brought on by arcing faults. Similar to this, ground fault circuit interrupters (GFCIs) offer safety from electrical shocks in locations with moisture or water.

Negative aspects of circuit breakers:

1. **Initial Cost:** Compared to fuses, circuit breakers can be more expensive up front. Circuit breakers may demand a larger initial expenditure, particularly for high-voltage or specialized applications. Circuit breakers' ability to be reset and reused, however, can make up for this expense over the course of their useful lives.
2. **Complexity:** Circuit breakers are more complicated than fuses in terms of design. They are made up of a variety of parts and systems, such as trip units and safety features.

Because of its intricacy, installation, maintenance, and troubleshooting may need for specialized skills.

3. **Limited Fault Clearing Capacity:** Circuit breakers are efficient at interrupting low amounts of fault current, but they are limited in their ability to handle high levels of fault current. To provide efficient fault clearing and system protection in such circumstances, additional protective devices like current-limiting fuses or protective relays may be required.
4. **Sensitivity to Environmental Conditions:** Circuit breakers may be sensitive to environmental conditions such as temperature, humidity, dust, or corrosive atmospheres, especially in outdoor or harsh locations. If these conditions are not sufficiently addressed through suitable enclosure and protective measures, they may impact the performance and dependability of circuit breakers.
5. **Maintenance Requirements:** Circuit breakers, like all electrical equipment, need to be regularly inspected and maintained to ensure good operation. Tests on the trip units, mechanical integrity inspections, and coordination checks with other safety measures are also part of this process. The overall operational cost and effort may increase as a result of routine maintenance.
6. **Limited Fault Detection Precision:** Circuit breakers are capable of detecting overloads and short circuits, but their capacity to pinpoint the precise position or origin of a fault may be constrained. It may be required to use additional diagnostic tools or systems to pinpoint the exact issue site in order to perform successful troubleshooting and maintenance.

In terms of electrical safety, system dependability, and convenience, circuit breakers offer a number of benefits. Modern electrical systems cannot function without them because of their flexibility, quick response times, ability to be reset, and protection against overloads and short circuits. Circuit breakers do, however, have several drawbacks, such as high startup costs, complexity, and upkeep needs. To choose the best protection option and guarantee the best functioning of electrical systems, it is essential to comprehend both the benefits and drawbacks of circuit breakers.

Factors affecting circuit breaker: Circuit breakers are crucial parts of electrical systems because they act as safeguards to stop the flow of current under abnormal circumstances. Circuit breakers' efficiency and performance can be affected by a number of things. For effective circuit breaker selection, installation, and maintenance in electrical infrastructure, it is essential to comprehend these elements. We will go over the main elements that have an impact on circuit breakers in this part.

1. **Electrical Load Characteristics:** The electrical load characteristics significantly affect the choice and operation of circuit breakers. Circuit breakers' tripping characteristics and rating can be impacted by elements such the load current's size, duration, and existence of inrush currents or transient spikes. Circuit breakers with sufficient withstand capacities may be needed in applications involving high inrush currents, such as motor starting or capacitor charging.
2. **Fault Current Levels:** The greatest current that can flow in the event of a fault, such as a short circuit, is known as the fault current level. It is very important in determining the coordination and interrupting power of circuit breakers. Circuit breakers should be chosen so that they have a high enough interrupting capacity to safely interrupt fault currents without endangering themselves or other system components. The configuration of the system, the capacity of the transformer, and the fault clearing systems employed can all affect the fault current levels.

3. **System Voltage:** When choosing and designing circuit breakers, the system voltage is an important consideration. There are numerous kinds of circuit breakers available for low-voltage, medium-voltage, and high-voltage applications. To ensure appropriate operation and safety, the voltage rating of the circuit breaker must match the system voltage.
4. **Environmental Aspects:** The circuit breakers' performance and dependability can be considerably impacted by the environment in which they are located. Circumstances including temperature fluctuations, humidity, dust, vibration, and corrosive environments can affect how well and how long a circuit breaker lasts. It could be necessary to use specialized enclosures, sealing methods, and protective coatings to lessen the effects of unfavorable environmental factors.
5. **Operational Conditions:** Circuit breakers' performance and lifespan can be affected by the operational circumstances in which they function. Circuit breakers may wear out more quickly or more slowly depending on variables including operating frequency, duty cycle, and ambient temperature. Circuit breakers with improved thermal characteristics may be needed for high-duty cycle applications to prevent overheating. Similar to applications with frequent switching operations, high mechanical durability circuit breakers may be required.
6. **Maintenance and Testing:** For circuit breakers to operate dependably, proper maintenance and routine testing are essential. Issues like loose connections, mechanical wear, or contaminant buildup can be found and fixed with the help of routine inspections, lubrication, and cleaning. It is crucial to test the trip units, insulation resistance, and timing properties of circuit breakers to ensure their correctness and operation. Circuit breakers that are not regularly maintained and tested may malfunction, compromising protection.
7. **Standards and Regulatory Compliance:** To guarantee their dependability and safety, circuit breakers must adhere to industry standards and legal requirements. Circulars for the design, testing, and operation of circuit breakers are provided by standards including those of the International Electro technical Commission (IEC), the National Electrical Manufacturers Association (NEMA), and local electrical codes. Circuit breakers must adhere to these standards in order to achieve minimum performance and safety requirements.

Circuit breakers in electrical systems can behave and be effective differently depending on a number of variables. There are many important aspects to take into account, including electrical load characteristics, fault current levels, system voltage, ambient circumstances, operational conditions, maintenance and testing, and standard compliance. For electrical infrastructure to work at its best and be safe and reliable, these elements must be properly understood and taken into account when choosing, installing, and maintaining circuit breakers.

D.C. circuit breaking:

Direct current (DC) circuit breaking is the process of stopping or stopping the flow of DC in an electrical circuit. The safe operation of DC power systems and the prevention of equipment damage are both crucial components of electrical protection systems. The distinct properties of DC current are handled by DC circuit breakers, which also offer dependable protection against faults and overcurrent situations [7]–[9].

Diverse voltage and current ratings of DC circuit breakers are available to suit diverse applications, from low-voltage circuits in homes and businesses to high-voltage circuits in industrial and utility systems. Based on the system's unique needs, such as the voltage level, current capacity, fault characteristics, and compatibility with other protective devices, it's critical to choose the right DC circuit breaker. To ensure their dependable performance and ongoing protection of the electrical system, DC circuit breakers must be installed, maintained, and tested on a regular basis.

A.C circuit breaking: Alternating current (AC) circuit breaking is the process of stopping or stopping the flow of AC in an electrical circuit. In the event of an overcurrent, short circuit, or other fault condition, an AC circuit breaker is a protection device used to open the circuit and stop current flow. They are essential for preserving the security and dependability of AC power systems.

Transient recovery voltage: The voltage that occurs across a circuit breaker's contacts following the interruption of a fault or the opening of a circuit is known as transient recovery voltage (TRV). It is a crucial factor in the design of circuit breakers and the protection of electrical systems. Understanding TRV behavior is crucial for ensuring the steady operation of circuit breakers and the general stability of the power system. TRV is defined by its amplitude, frequency, and duration. The current flowing through a circuit is quickly terminated when a circuit breaker stops a fault or opens a circuit. The TRV phenomenon is a brief occurrence brought on by this disruption. The system setup, fault kind, and characteristics of the connected equipment are just a few of the variables that affect the size and length of the TRV. The system's inductance and capacitance release energy throughout the interruption process, which causes a sharp increase in voltage across the circuit breaker contacts. The TRV normally lasts between a few microseconds and a few milliseconds, and its amplitude can be several times greater than the system voltage.

The system's reaction to the interruption and the properties of the associated loads have an impact on how TRV behaves. Due to the energy stored in their magnetic fields, inductive loads like transformers or motors can cause greater TRV magnitudes. On the other hand, capacitive loads may cause the TRV to climb more quickly. In order to guarantee the circuit breakers' dependable operation and to avoid restrikes or re-ignition of the fault, proper TRV control is essential. Restrikes happen when the voltage across the contacts is inadequate to extinguish the arc, re-establishing the circuit and perhaps damaging the equipment. Circuit breakers are made with appropriate interrupting mechanisms, such as arc chutes, magnetic blowouts, or quenching chambers, to quickly put out the arc and survive the TRV levels, in order to lessen the consequences of TRV. When designing and testing circuit breakers, TRV analysis and calculations are used. The interrupting capacity of the circuit breaker must specifically match the TRV characteristics that are anticipated in the electrical system. To confirm the functionality and suitability of circuit breakers under various TRV settings, testing techniques like the TRV testing are carried out. To sum up, transitory Recovery Voltage (TRV) is a transitory phenomenon that happens when a fault is interrupted or a circuit is opened by a circuit breaker. The design and operation of circuit breakers in power systems depend heavily on an understanding of TRV's features. In order to maintain overall system stability and protection, proper management and mitigation of TRV help to reliably interrupt faults and avoid restarts [10].

Resistance switching: Resistance switching is a phenomena whereby an external stimulus, such as an electric field, voltage, current, or temperature, can drastically change a material's electrical resistance. It is a characteristic found in specific kinds of materials and the foundation for many electronic gadgets and technology.

Resistance switching primarily takes one of two forms:

Memristive Switching: Memristors, which are two-terminal devices that alter resistance in response to applied voltage or current, show a phenomena known as memristive switching.

Memristors have a special property known as "memristance," which depends on the charge or flux flowing through the component. The memristor can be made into a non-volatile memory element by switching between high and low states by altering the voltage or current applied to it. Potential uses for this memristor characteristic include neuromorphic computing, resistive random-access memory (RRAM), and other high-tech electrical devices.

Phase Change Switching: A reversible phase transition between the two states of amorphous and crystalline causes phase change materials (PCM) to have resistance switching capabilities. The material exhibits a high electrical resistance in its amorphous form and a low resistance in its crystalline condition. The material experiences a phase change that causes a resistance switch between the two states when a current pulse is applied or the PCM is heated. Phase change memory (PCM) devices, which provide quick switching speeds and non-volatile storage capacities, take advantage of this behaviour.

CONCLUSION

Circuit breakers are essential for keeping electrical systems safe and dependable. They reduce the possibility of electrical fires and protect equipment by spotting and stopping high currents. Circuit breakers are made to manage various current levels and react fast to unforeseen circumstances, ensuring that electrical circuits operate as intended. Their broad application in domestic, business, and industrial contexts demonstrates how crucial they are to the current electrical infrastructure. A circuit breaker is a type of electrical safety device intended to guard against overcurrent, overload, and short circuit damage to an electrical circuit. It is a crucial safety feature in contemporary houses and buildings, guarding against potential fires and other dangers brought on by minor wiring issues and equipment breakdowns. Circuit breakers, in contrast to fuses, can be manually or automatically reset to resume normal operation after they have been in use.

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CHAPTER 7

INTEGRATION OF CIRCUIT BREAKERS IN POWER SYSTEMS: A REVIEW STUDY

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ABSTRACT:

A circuit breaker is a crucial part of electrical systems because it shields equipment and circuits from harm brought on by high currents or short circuits. Circuit breakers' core characteristics, such as their types, workings, and uses, are examined in this classification. The chapter offers a succinct synopsis of the classification's major themes. The circuit breakers can be categorized in a number of different ways. The medium utilized for arc extinction, however, provides the basis for the broadest classification. Arc extinction typically uses oil, air, Sulphur hexafluoride (SF6), or vacuum as the medium. Every sort of circuit breaker has benefits and drawbacks of its own. We will go over the design and operation of these circuit breakers in the sections that follow, paying particular attention to how the arc extinction is made possible. These breakers forbid interruptions at high speeds. Plain-break oil circuit breakers are only utilised in low-voltage applications where high breaking capacities are not crucial due to these drawbacks. Such breakers are often used in modest capacity systems with voltages no higher than 11 kV.

KEYWORDS:

Air blast circuit breaker, Arc quenching, Circuit breaker, Low oil circuit breaker, Oil circuit breaker.

INTRODUCTION

Such circuit breakers use insulating oil as an arc quenching medium, such as transformer oil. Under oil, the contacts are made, and an arc is then created between them. The surrounding oil is dissociated into a significant volume of gaseous hydrogen under high pressure by the arc's heat, which also evaporates the oil. The volume of the hydrogen gas is nearly a thousand times larger than the volume of the broken-down oil. As a result, the oil is forced away from the arc, and the arc zone and nearby contacts are encircled by a growing hydrogen gas bubble as shown in Figure 1.Two processes in particular help the arc to extinguish. First off, because hydrogen gas cools the arc and conducts heat well, it helps the medium between the contacts de-ionize. Furthermore, the gas creates turbulence in the oil, pushing it into the gap between the contacts and removing the arcing byproducts from the arc route. Arc is put out as a result, and circuit current is disrupted [1]–[3].

Types of oil circuit breaker: The electricity system makes heavy use of oil circuit breakers. These fall into the following categories:

(i) Circuit breakers made of bulk oil, which utilize a lot of oil. There are two uses for the oil. In addition to isolating the current-conducting components from one another and from the earthed tank, it also puts out the arc that forms when contacts are opened. These circuit breakers can be divided into the following categories: a) Plain break oil circuit breakers (b) Circuit breakers for arc control oil. The contacts in the old type are immediately exposed to all of the oil in the tank and no additional measures are available for controlling the arc. To acquire the advantageous action of the arc as effectively as possible, however, special arc control mechanisms are used in the later type.

(ii) Low oil circuit breakers are those that consume the least quantity of oil. These circuit breakers solely employ oil to extinguish arcs; air, porcelain, or organic insulating materials are used to insulate the current-conducting components.

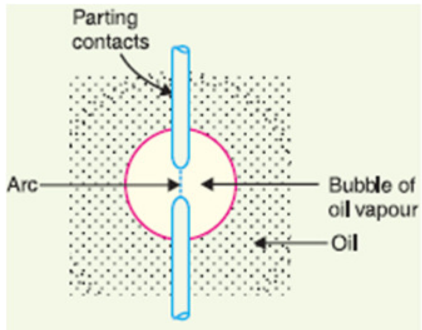

Figure 1: Oil Circuit breaker.

Plain break oil circuit breakers: A straightforward oil circuit breaker involves isolating the contacts underneath the entire amount of oil in the tank. Other than the lengthening brought on by the separation of contacts, there is no unique mechanism for arc control. When a specific critical separation between the contacts is reached, the arc extinguishes. The earliest sort of circuit breaker from which all others have evolved is the plain-break oil circuit breaker. Its construction is quite straightforward. It is made up of stationary and movable contacts encased in a sturdy, weather-tight earthed tank that can hold oil up to a particular level and an air cushion above the oil level. The air cushion gives the arc gases enough room to enter without creating a hazardous amount of pressure inside the circuit breaker's dome. Additionally, it muffles the mechanical shock caused by the oil's ascent. A double break simple oil circuit breaker is depicted in Figure 2.

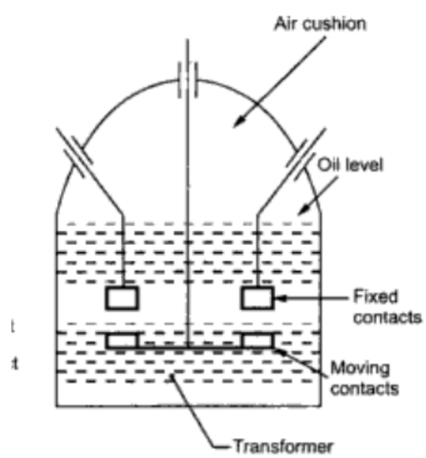

Figure 2: Plain break oil circuit breaker.

Because it provides two breaks in succession, it is referred to as a double break. The fixed and movable contacts are kept closed during normal operation, and the circuit current flows normally through the breaker. When a fault develops, the protective system pulls down the moving contacts, and an arc is hit, vaporising the oil primarily into hydrogen gas. The following processes help the arc to extinguish:

(i) The hydrogen gas bubble that forms around the arc cools the arc column and helps the medium between the contacts become deionized.

(ii) The gas creates turbulence in the oil, which aids in clearing the arc's path of arcing by products.

(iii) The medium's dielectric strength increases as the arc lengthens as a result of the separating contacts.

These activities cause the arc to be extinguished and the circuit current to be halted at a crucial gap length.

Disadvantages:

(i) The arc cannot be controlled in any unique way other than by lengthening when the moving contacts are separated. Therefore, a long arc length is required for successful interruption.

(ii) The arcing times of these breakers are lengthy and variable.

DISCUSSION

Arc Control Oil Circuit Breakers:

There is virtually little artificial control over the arc in the case of the plain-break oil circuit breaker mentioned above. In order for the turbulence in the oil created by the gas to aid in quenching it, somewhat long arc length is necessary. However, it is essential and ideal for the final arc to be extinguished while the contact distance is still small. Arc control is used for this purpose, leading to the name "arc control circuit breakers" for the breakers. These breakers come in two different varieties, namely:

(i) Self-blast oil circuit breakers: These circuit breakers use the arc itself to effectively extinguish themselves in order to achieve arc control through internal means.

(ii) A mechanical device outside of the circuit breaker is used to provide arc control in forced-blast oil circuit breakers.

(i) Self-blast oil circuit breakers:

The gases created during arcing are constrained to a narrow space in self-blast oil circuit breakers by the employment of an insulating stiff pressure chamber or pot surrounding the contacts. Since the chamber limits the amount of area the arc gases can occupy, a very high pressure must be created to force the oil and gas through or around the arc in order to put out the flame. The value of the fault current that must be halted determines the amount of pressure that develops. These breakers are sometimes referred to as self-generated pressure oil circuit breakers since the pressure is produced by the arc itself. In comparison to a plain-break oil circuit breaker, the pressure chamber has a lower final arc extinction gap length and arcing time. A handful of the pressure chamber designs also known as explosion pots—that have been created are listed below:

(a) Plain explosion pot:

A basic explosion pot, which encloses both the fixed and movable contacts and is made of an insulating substance as shown in Figure 3. A cylindrical rod serving as the moving contact travels through a small aperture at the bottom that is referred to as the throat. The contacts become disjointed and an arc is created between them when a fault develops. In the pot, the arc's heat transforms oil into a gas under extremely high pressure. Oil and gas are forced through and around the arc by this tremendous pressure, putting out the flame. If the moving contact does not experience the last arc extinction while it is still inside the pot, it does so as soon as it exits. It is because a sudden surge of petrol and oil through the pharynx causes fast extinction as soon as the moving contact emerges from the pot.

The main drawback of this kind of pot is that it can't handle fault currents that are either extremely low or extremely high. Low fault currents result in little pressure being created, which lengthens the arcing period. However, when the fault current is large, the gas is produced so quickly that the explosion pot may burst from the tremendous pressure. Because of this, a simple explosion pot only functions effectively at modest short-circuit currents when the rate of gas evolution is also moderate.

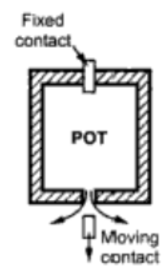

Figure 3: Plain explosion pot

(b) Cross jet explosion pot:

Figure 4 depicts this sort of pot, which is really a basic explosion pot modification. It is comprised of an insulating substance and has arc-splitting grooves on one side. Arc extinction is made easier by the arc splitters' assistance in lengthening the arc. The circuit breaker's movable contact starts to separate when a problem occurs. The arc initially strikes the top of the pot when the moving contact is withdrawn. The oil in the back tube is under pressure from the gas the arc produces. Fresh oil is forced across the arc path as soon as the moving contact exposes the arc splitter ducts. As a result, the arc is forced sideways into the "arc splitters," lengthening it and leading to arc extinction. Heavy fault currents can be effectively interrupted using the cross-jet explosion pot. However, for minor fault currents, the gas pressure is low, which prevents the pot from operating satisfactorily.

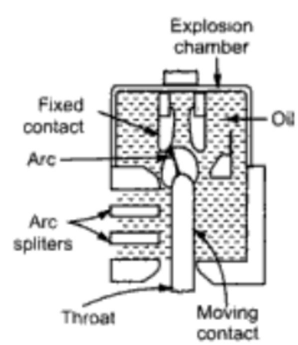

Figure 4: Cross jet explosion pot.

(c) Self-compensated explosion pots:

These pots are essentially a cross between simple and cross jet explosion pots. As a result, it may reasonably interrupt both light and strong short circuit currents. The self-compensated exploding pot's schematic diagram is depicted in Fig. 5. It has two chambers: the cross-jet explosion pot with two arc splitter ducts is in the upper chamber, and the simple explosion pot is in the lower one. When the short-circuit current is large, the device functions like a cross-jet explosion pot and the rate of gas creation is very high. When the moving contact exposes the first or second arc splitter duct, the arc is extinguished. minimal short-circuit currents, however, allow the moving contact's tip to travel to the lower chamber since the rate of gas creation is minimal. Due to the blockage provided by the arc path and right angle bends, very little leakage occurs through arc splitter ducts during this time, allowing the gas to build up adequate pressure. The arc is put out by simple pot action when the moving contact exits the throat. It should be observed that the device operates less and less as a conventional explosion pot and more and more as a cross-jet explosion pot as the severity of the short-circuit current grows. Hence the trend is to enable self-compensation for the control across the entire spectrum of interrupted fault currents.

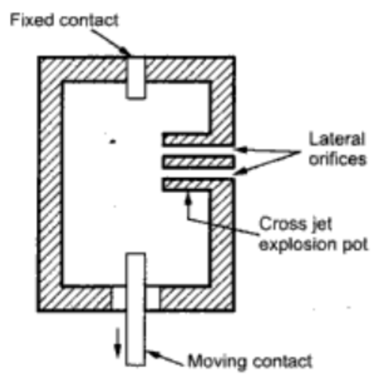

Figure 5: Self-compensated explosion pots.

Low oil Circuit breakers: The oil in the bulk oil circuit breakers that have been previously addressed must serve two purposes. It serves two purposes: first, as an arc quenching medium, and second, by isolating the living components from the soil. It has been discovered that the majority of oil is actually utilised for insulation, while just a little portion is actually used for arc extinction. Because of this, as the system voltage rises, the amount of oil in bulk oil circuit breakers increases to a very high level. This increases the cost, tank size, and weight of the breaker as well as the risk of fire and maintenance issues. Since only a small portion of the oil in the bulk oil circuit breaker—roughly 10% of the total—is actually used to extinguish arcs, it begs the question of why the remaining oil, which is not immediately surrounding the device, shouldn't be removed to reduce bulk, weight, and fire risk. As a result, low-oil circuit breakers were created. A low oil circuit breaker combines solid materials for insulation and a tiny amount of oil that is only enough to extinguish an arc. When it comes to quenching the arc, bulk oil and low oil circuit breakers both behave identically. The arc extinction in a low oil circuit breaker can be made easier by utilising adequate arc control devices [4]–[6].

Construction:

The cross section of a single-phase low oil circuit breaker is shown in Figure 6. Two compartments, which are apart from one another yet both filled with oil, are present. While the lower chamber serves as support, the top chamber acts as a circuit breaker. Oil from one chamber cannot mix with oil from the other chamber because a partition separates the two compartments. Two benefits are possible under this setup. The circuit breaking chamber first needs a small amount of oil, just enough to extinguish the arc. Second, because the oil in the supporting chamber is not tainted by the arc, less oil needs to be changed. The moving contact is hollow and has a cylinder that descends over a piston that stays in place. As an arc control device, the turbulator features both axial and radial vents. Axial venting makes sure that low currents are interrupted, whilst radial venting assists in stopping strong currents.

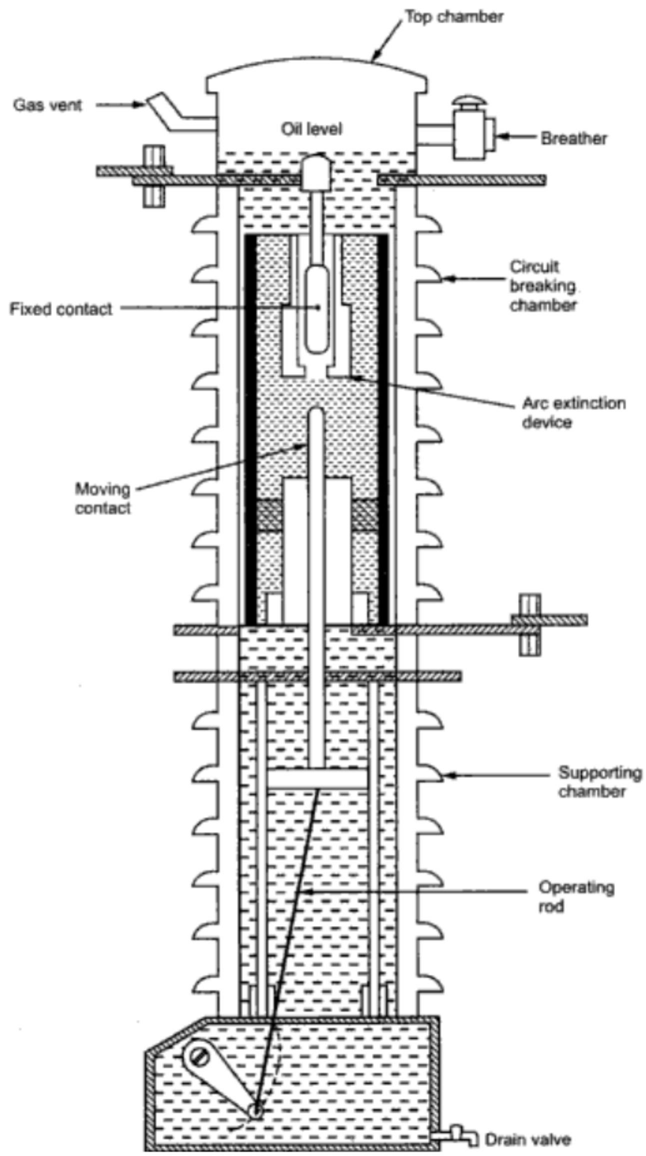

Figure 6: Low oil Circuit breakers.

Top chamber: It is mounted on the circuit-breaker chamber and is made of metal. It gives the oil in the circuit breaker box room to expand. Additionally, a separator is included in the top chamber to stop any oil loss due to centrifugal action brought on by a circuit breaker operating under faulty conditions.

Operation: The moving contact and top fixed contact are still in touch under normal operating circumstances. When a fault develops, the tripping springs pull down the moving contact, which causes an arc to be struck. Oil is vaporised by the arc energy, which also creates gases with a high pressure. This forces a succession of oil through the various channels of the turbulator and forces the oil to pass through a central hole in the moving contact. The arc's parts are sequentially quenched by the effect of different streams of oil running through each section in turn and carrying away its gases during the orderly process of turbulence.

Advantages: The following benefits of a low oil circuit breaker versus a bulk oil circuit breaker:

1. It uses less oil.
2. It takes up less room.
3. Fire risk is diminished.
4. Maintenance issues are diminished.

Disadvantages: The following drawbacks of low oil circuit breakers: compared to a circuit breaker for bulk oil:

(i) Because there is less oil, the degree of carbonization is higher.

(ii) It is challenging to quickly remove the gases from the contact space.

(iii) A significant degree of carbonization causes the oil's dielectric strength to rapidly decrease.

Maintenance of Oil circuit breaker: The general focus of oil circuit breaker maintenance is on the contacts and oil's dielectric strength. A circuit breaker's contacts may become burned by arcing and the oil may lose some of its dielectric strength owing to carbonization after it has repeatedly halted fault currents or load currents. The breaker's ability to rupture is therefore lessened as a result. As a result, it is a good habit to inspect the circuit breaker every three to six months. The following considerations must to be kept in mind when inspecting the breaker:

1. Inspect the arcing contacts and current-carrying components. The contacts should be changed if the burning is bad.
2. Examine the oil's dielectric strength. It should be replaced or reconditioned if the oil is severely discoloured. A conventional oil testing cup with a 4 mm gap between the electrodes and 30 kV applied for one minute should be able to withstand the oil in good condition.
3. Check the insulation for any potential damage.
4. Use a sturdy, dry cloth to clean the surface and eliminate carbon build up.
5. Check the oil level (optional).
6. (v) Inspect the tripping and closing mechanisms.

Applications of oil circuit breaker: The use of oil circuit breakers (OCBs) in electrical systems and diverse sectors is widespread. Here are a few important uses for OCBs: Oil circuit breakers (OCBs), which have many advantages over other types of circuit breakers, have been utilised extensively in a variety of applications, particularly high-voltage electrical systems. We will go into the uses of OCBs in power production, transmission, and distribution networks, as well as in industrial settings, in more detail in this section.

Power producing facilities are one of OCBs' main applications. These plants frequently run at high voltages, and OCBs can handle the high currents and effectively interrupt fault currents. Generator circuit breakers (GCBs) frequently employ OCBs to safeguard generators from over currents and short circuits. The isolation of defective generators without disrupting the rest of the power system is made possible by GCBs with OCBs, which offer dependable protection.

1. Power Generation: In power generation facilities, OCBs are utilised to safeguard generators from overcurrent's and short circuits. In order to isolate defective generators and guarantee the security of the power generating process, generator circuit breakers (GCBs) with OCBs are used.
2. Power Transmission: OCBs are essential components of systems for power transmission. They serve as a defence against faults and abnormalities for high-voltage transmission lines at substations. OCBs offer dependable interruption capabilities that enable the isolation of defective areas and stop lengthy power outages.
3. Power Distribution: To safeguard distribution transformers and feeders, OCBs are frequently employed in distribution substations. They prevent against overloads and faults while ensuring the safe and dependable distribution of energy to residential, commercial, and industrial regions.
4. Applications in Industry: OCBs are widely used in industries where reliable circuit protection is necessary. They are used to safeguard against short circuits and overloads in motor control centres (MCCs), switchboards, and other equipment, assuring the continuity of industrial processes.
5. Railway Systems: To safeguard the power supply to electric locomotives and trains, OCBs are used in railway traction substations. The challenging conditions of railway electrification are a good fit for OCBs due to their high breaking capacity and dependable performance.
6. Switching Capacitive Loads: For switching capacitive loads, OCBs are preferred. In order to increase power factor and regulate voltage, capacitors are employed in power systems. The high inrush current that can happen while switching capacitive loads can be safely and reliably handled by OCBs.
7. High-Voltage Applications: Because OCBs can tolerate large currents and effectively interrupt fault currents, they are especially well suited for high-voltage applications. They are utilised in high-voltage systems including extra-high-voltage (EHV) and ultra-high-voltage (UHV) networks.
8. Specialised Industries: Where high currents and fault levels are common, specialised industries such as mining, petrochemicals, and heavy manufacturing find use for OCBs. They support maintaining the safety and dependability of important equipment and offer strong circuit protection.

Although OCBs were frequently employed in the past, newer technologies like vacuum and SF6 circuit breakers have become more popular because of their enhanced performance and attention to the environment. However, OCBs continue to be used in many current installations and in particular applications where their special qualities and benefits are desired. OCBs are ideal for such environments since industrial settings frequently call for strong and dependable circuit protection solutions. They are employed in fields where large currents and fault levels are typical, including as manufacturing, mining, and petrochemicals. In order to protect against short circuits and overloads and maintain the efficiency of industrial operations, OCBs are used in motor control centres (MCCs), switchboards, and other crucial equipment. In specialised fields like railway systems, OCBs are also used. OCBs are used in railway traction substations to safeguard the electricity supply to electric locomotives and trains. The challenging conditions of railway electrification are a good fit for OCBs due to their high breaking capacity and dependable performance. Capacitive load switching is an important use for OCBs. Power systems frequently employ capacitors to enhance power factor and voltage regulation. The significant inrush current that might happen while switching capacitive loads can strain other kinds of circuit breakers. Because they can take high currents, OCBs are used for secure and trustworthy switching of capacitive loads. There are numerous and varied uses for oil circuit breakers. They are widely utilised in capacitive load switching, industrial settings, railway systems, power generation facilities, transmission substations, and distribution systems. Overcurrent and short circuit protection is effectively provided by OCBs, providing the secure and dependable operation of electrical systems. While more recent innovations like vacuum and SF6 circuit breakers have become more popular, OCBs are still used in some applications, especially where large currents, high voltages, and reliable performance are needed. Because of their adaptability and dependability, OCBs are a popular option in many electrical applications [7]–[9].

Air blast circuit breaker:

An air blast circuit breaker is a particular kind of circuit breaker that uses a high-pressure air blast to put out the arc that forms when electrical current is interrupted. Particularly in high-voltage applications, it is one of the earliest and most commonly utilized circuit breaker technologies. A circuit breaker's main job is to safeguard electrical devices and the power grid against defects like overloads and short circuits. The circuit breaker stops the flow of current when a fault develops by allowing a space between its contacts, extinguishing the arc and stopping additional damage. Air blast circuit breakers use a special method to stop the current. A blast valve is opened when the fault is discovered, letting high-pressure compressed air or gas to flow through a nozzle pointed at the arc. This speedy cooling and extinction of the arc by the high-velocity air blast makes it easier to stop the current.

The air blast circuit breaker has a number of benefits. It first quickly and effectively interrupts excessive currents, protecting both equipment and workers. Second, no additional insulating or arc-quenching materials are required when compressed air is used as the arc-quenching medium. As a result, the design is reasonably straightforward and economical. Air blast circuit breakers are renowned for their dependability and longevity as well. Air blast circuit breakers do have some restrictions, though. The high-pressure air blast system needs routine upkeep and frequent compressed air or gas refills. Additionally, when operating, the air blast mechanism may make noise. The overall complexity and cost may increase in some circumstances due to the need for additional equipment like air compressors and storage tanks. Air blast circuit breakers are still frequently utilized in high-voltage applications where quick stoppage of strong currents is essential despite these drawbacks. The performance, safety, and efficiency of circuit breakers are continually being improved via research and technological breakthroughs, assuring the dependable operation of electrical power systems.

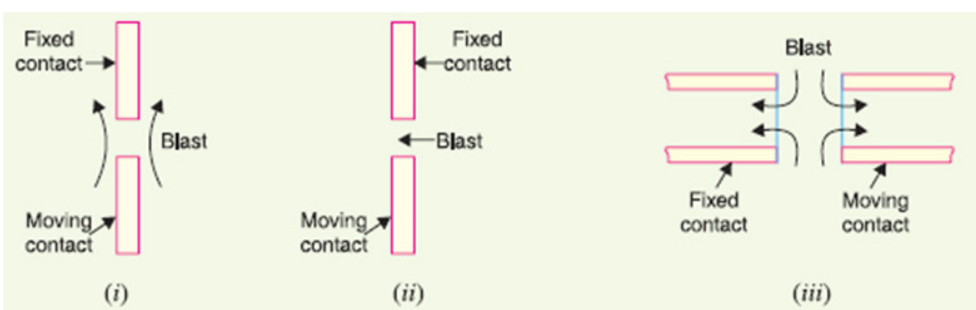

Figure 7: Types of Air blast Circuit breaker

High pressure air blast is used by these breakers as the arc quenching medium. When the blast valve is opened, an airflow is created that opens the contacts. The air-blast sweeps the arcing byproducts to the atmosphere and cools the arc. As a result, the medium between the contacts' dielectric strength grows quickly and the arc cannot be established again. As a result, the arc is put out and the current flow is stopped.

ii) Cross-blast type, as indicated in Figure 7 (ii), in which the air blast is conducted perpendicular to the arc route.

(iii) Radial-blast type, in which the air blast is radially oriented.

Axial-blast air circuit breaker:

An example of an axial-blast air circuit breaker is shown in Fig. 8, along with its key parts. Under typical circumstances, spring pressure maintains the closed position of the fixed and moving contacts. Through an air valve, the air reservoir is connected to the arcing chamber. When a system malfunction occurs, this valve automatically opens by the tripping impulse while remaining closed under normal circumstances. The air valve that connects the circuit breaker reservoir to the arcing chamber opens when a fault arises as a result of the tripping impulse. High-pressure air is introduced into the arcing chamber opposes the force of the spring and pushes the moving contact away. Upon separating the moving contact, an arc is struck. In parallel, a high-pressure air blast passes along the arc and removes the ionised gases in addition. As a result, the arc is put out and the current flow is stopped. It should be noted that the contact separation necessary for interruption in such circuit breakers is typically minimal (1.75 cm or so). A gap this tiny might not provide enough space for the standard service voltage. Therefore, this kind of circuit breaker has an isolating switch as part of its design. This switch opens as soon as the fault is interrupted, giving the insulator the clearance it needs.

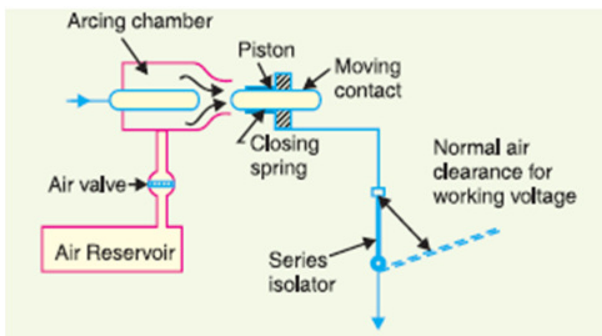

Figure 8: Axial-blast air circuit breaker.

Cross-blast air breaker:

An air blast is sent at an angle to the arc in this kind of circuit breaker. A proper chute for arc extinction is forced into the arc by the cross-blast, which lengthens it. The key components of a typical cross-blast air circuit breaker are shown in Figure 9.

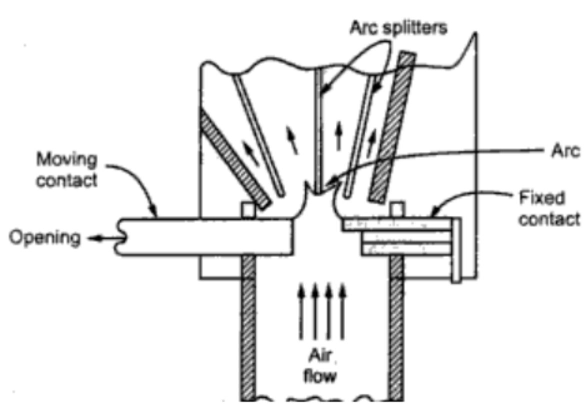

Figure 9: Cross-blast air breaker.

An arc forms between the fixed and moving contacts when the moving contact is removed. Arc splitters and baffles make up the chute into which the arc is forced by the high pressure cross-blast. In addition to providing better cooling, splitters lengthen the arc. As a result, the arc is put out and the current flow is stopped. The inefficiency at low currents is eliminated because blast pressure is the same for all currents. The last gap for interruption is wide enough to allow for typical insulating clearance, negating the need for a series isolating switch.

Sulphur Hexafluoride (SF6) Circuit Breakers:

Sulphur hexafluoride (SF6) gas is employed as the arc quenching medium in these circuit breakers. As an electro-negative gas with a high propensity to absorb free electrons, SF6. A high pressure SF6 gas flow opens the breaker's contacts, causing an arc to form between them. The gas quickly absorbs the conducting free electrons in the arc to produce comparatively stationary negative ions. The arc quickly develops sufficient insulation strength as a result of this loss of conducting electrons to put out the flames. It has been discovered that the SF6 circuit breakers are particularly efficient for high power and high voltage service.

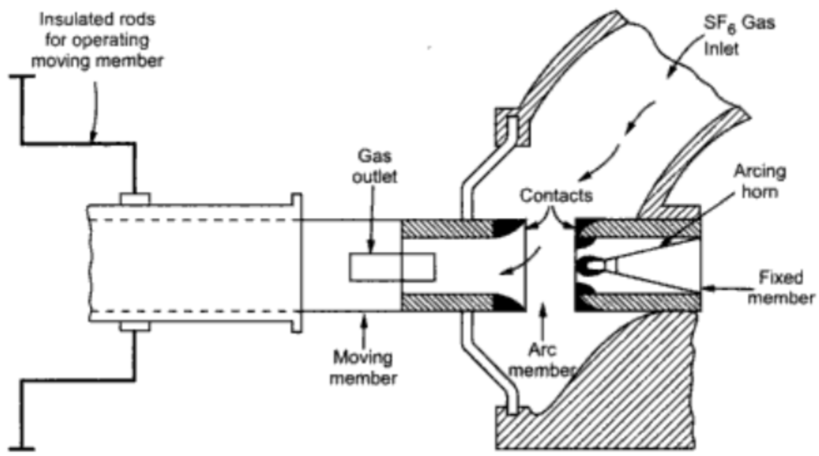

Figure 10: Sulphur Hexafluoride (SF6) Circuit Breakers.

Construction:

The components of a typical SF6 circuit breaker are shown in Figure 10. It consists of stationary and movable contacts surrounded in an arc interruption chamber filled with SF6 gas. The SF6 gas reserve is connected to this chamber. The valve mechanism enables a high pressure SF6 gas to flow from the reservoir towards the arc interruption chamber when the contacts of the breaker are activated. The fixed contact is an arc horn-equipped hollow cylindrical current carrying contact. To allow the SF6 gas to escape after flowing along and across the arc, the moving contact is also a hollow cylinder with rectangular holes in the sides. Copper-tungsten arc resistant material is applied to the tips of the fixed contact, moving contact, and arcing horn. Since SF6 gas is expensive, it is repaired and recovered by an appropriate auxiliary system following each use of the breaker.

Working:

When the breaker is in the closed position, SF6 gas still surrounds the contacts at a pressure of roughly 28 kg/cm2. The movable contact is pulled apart and an arc is created between the contacts when the breaker activates. The opening of a valve that allows SF6 gas at a pressure of 14 kg/cm2 to flow from the reservoir to the arc interruption chamber coincides with the movement of the moving contact. The free electrons in the arc path are quickly absorbed by the high-pressure flow of SF6 to produce stationary negative ions, which are useless as charge carriers. As a result, the arc is extinguished by a rapid buildup of high dielectric strength in the medium between the contacts. A series of springs works to seal the valve after the breaker operation, or after the extinction of the arc.

Vacuum Circuit Breakers (VCB): These breakers use vacuum as the arc quenching medium, with a vacuum level between 10−7 to 10−5 torr. Vacuum has the best arc quenching capabilities of any medium since it has the highest insulating strength. For instance, when a circuit breaker's contacts are opened in a vacuum, the interruption happens at initial current zero and the buildup of dielectric strength between the contacts is thousands of times faster than with other circuit breakers.

Principle: The following explanation explains how an arc forms in a vacuum circuit breaker and disappears: The ionisation of the contacts' metal vapours results in the formation of an arc between the contacts when the breaker's contacts are opened in vacuum (10^{-7} to 10^{-5} torr). The metallic vapours, electrons, and ions generated during the arc, however, immediately condense on the surfaces of the circuit breaker contacts, leading to a rapid recovery of dielectric strength, which causes the arc to be quickly extinguished. The reader may notice vacuum's noteworthy property as an arc quenching medium. Due to the swift rate of dielectric strength recovery in vacuum, once the arc is created, it is quickly put out.

Construction:

The components of a conventional vacuum circuit breaker are shown in Figure 11. It consists of a vacuum chamber-mounted arc shield, moving contact, and fixed contact. Stainless steel bellows link the moving member to the control mechanism. This makes it possible to permanently seal the vacuum chamber, so removing any chance of a leak. The exterior insulating body is a glass or ceramic vase. By preventing metallic vapours from falling on the inner surface of the outer insulating cover, the arc shield stops the loss of the internal dielectric strength.

Working:

When the breaker is in operation, an arc is created between the contacts when the moving contact separates from the fixed contact. Arc formation results from the ionisation of metal ions and heavily depends on the contacts' substance.

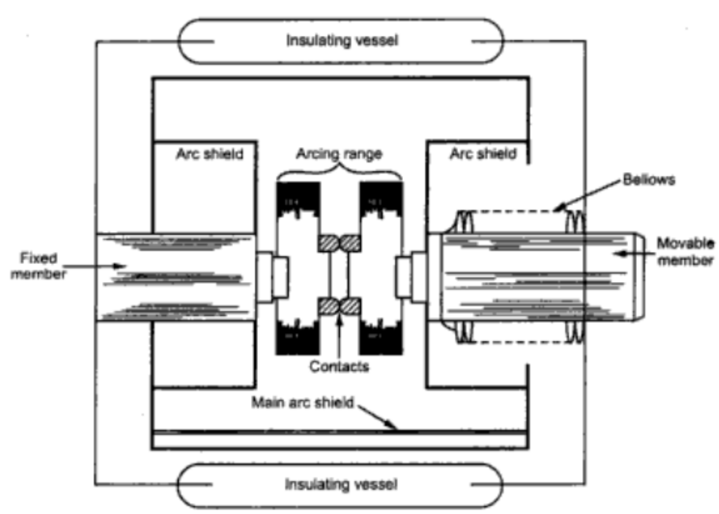

Figure 11: Vacuum Circuit Breakers (VCB).

Because the metallic vapours, electrons, and ions generated by the arc are swiftly diffused and absorbed by the surfaces of moving and permanent parts, as well as shields, the arc is quickly put out. Due to vacuum's incredibly quick rate of dielectric strength recovery, the arc extinction in a vacuum breaker happens with only a little contact separation (let's say 0–625 cm).

Applications: The installation of such outdoor, maintenance-free circuit breakers should show to be a major advantage for a country like India where distances are fairly great and accessibility to remote places difficult. Vacuum circuit breakers are used for outdoor applications with voltages between 22 and 66 kV. They are ideal for the majority of applications in rural locations even with a limited rating, such as 60 to 100 MVA.

Applications of Air blast circuit breaker:

1. **High-Voltage Substations:** Air blast circuit breakers, which normally operate at voltages above 66 kV, are frequently used in high-voltage substations. These circuit breakers can successfully interrupt high fault currents, protecting pricey machinery like transformers, generators and transmission lines.
2. **Power Generation Plants:** Air blast circuit breakers are used in power producing facilities such as thermal power plants, nuclear power plants, and hydroelectric power plants. They guarantee continuous power generation by shielding crucial machinery from failures and overloads, including generators, transformers, and switchgear.
3. **Industrial Facilities:** Air blast circuit breakers are frequently used in industrial facilities that need high-voltage power distribution systems. These circuit breakers are crucial to the stability of power supplies and the protection of equipment in sectors including steel, oil & gas, chemical and manufacturing.
4. **Railways:** Air blast circuit breakers are used in railway systems, particularly in electrified rail networks and high-speed trains. These circuit breakers guard against damage to traction motors, overhead catenaries, and other vital parts while ensuring the safe and dependable operation of the electrical systems on trains.
5. **Mining Operations:** Air blast circuit breakers are used in mining operations to protect the equipment from electrical failures where heavy machinery and electrical equipment are widely utilised. They minimise downtime and ensure worker safety by offering dependable protection against short circuits and overloads.

Air blast circuit breakers are used in a variety of industries that depend on high-voltage electrical systems. These devices are excellent for critical applications where equipment safety and power system dependability are crucial due to their capacity to interrupt high currents quickly and effectively.

Factors affecting Air blast, SF6, and Vacuum circuit breaker: Circuit breakers are essential parts of electrical power networks, and a number of things can affect how well they work. Circuit breakers of the three most used types air blast, SF6, and vacuum each have unique properties and operational issues. We shall discuss the variables that affect the performance and choice of different circuit breaker technologies in this discussion.

1. **Voltage Level:** Choosing the right type of circuit breaker requires consideration of the voltage level. Air blast circuit breakers are frequently used in high-voltage applications, frequently above 66 kV, because of their effectiveness in interrupting high currents. On the other hand, SF6 and vacuum circuit breakers have uses in systems that operate at higher voltages, such as medium-voltage and high-voltage systems.
2. **Current Magnitude:** The choice of circuit breaker technology is also influenced by the fault current's magnitude. Air blast circuit breakers are perfect for substations and industrial sites where big currents are anticipated since they can interrupt high fault

currents. Circuit breakers made of SF6 and vacuum can tolerate a variety of fault currents, but SF6 circuit breakers are best suited for medium- and high-voltage applications [10].

3. **Interrupting Time**: The interrupting time, or the amount of time it takes the circuit breaker to put out the arc and stop the current, is a crucial consideration. The rapid interruption capabilities of air blast circuit breakers makes them ideal for applications where prompt fault clearing is required. Vacuum and SF6 circuit breakers both have quick interruption times, although SF6 circuit breakers have a tiny speed edge.
4. **Environmental Impact:** Environmental factors now play a bigger role in choosing circuit breakers. Sulphur hexafluoride gas, which is used in SF6 circuit breakers, has a high GWP. A considerable amount of attention is being paid to reducing the usage of SF6 and investigating different gases or technologies in response to environmental concerns. Since they don't use SF6 gas, air blast and vacuum circuit breakers are more environmentally friendly alternatives.

CONCLUSION

In summary, circuit breakers are essential in guaranteeing the dependability and safety of electrical systems. By stopping the flow of current when it exceeds safe thresholds or when there is a short circuit, they act as safety devices. This categorization has explored the workings of many kinds of circuit breakers, including thermal, magnetic, and hybrid circuit breakers. Additionally, it has emphasized the value of circuit breakers in a variety of scenarios, including industrial settings as well as residential and commercial facilities. Engineers and electricians can take appropriate action to protect electrical systems and avert dangers by having a thorough understanding of the categorization and features of circuit breakers. A variety of parameters, including voltage level, fault current magnitude, interrupting time requirements, environmental impact, maintenance demands, dependability, size and space requirements, and cost considerations, influence the choice of circuit breaker technology. To select the most appropriate circuit breaker for a given application, careful consideration of the benefits and drawbacks of air blast, SF6, and vacuum circuit breakers is required. Research and development efforts are still being driven towards more effective, dependable, and environmentally friendly circuit breaker solutions by ongoing technological breakthroughs and environmental concerns.

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CHAPTER 8

AN OVERVIEW ON POWER SYSTEM EARTHING

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ABSTRACT:

In a power system, "grounding" or "earthing" refers to connecting an electrical component, such as a neutral point in a star-connected system, a secondary conductor of a transformer, or some other electrical component, to the earth, or dirt. Electrical installations must include power system earthing in order to protect people and machinery. The ideas, varieties, and importance of power system earthing are examined in this classification. It discusses the various earthing techniques, such as solid earthing, resistance earthing, and reactance earthing, as well as its benefits and drawbacks. The essential ideas covered in the classification are briefly summarized in this study. Depending on the circumstances, this connection to earth might be made by a conductor or another circuit component (such as a resistor, a circuit breaker, etc.). No matter how you connect to the earth, there are two main benefits to grounding or earthing. It first safeguards the electrical system.

KEYWORDS:

Equipment Grounding, Neutral Grounding, Resistance Grounding, System Grounding, Solid Grounding.

INTRODUCTION

A substantial fault current will flow via the circuit breaker, for instance, if the neutral point of a star-connected system is grounded through a circuit breaker and a phase to earth fault develops on any one line. To isolate the defective line, the circuit breaker will trip. By doing this, the electricity system is shielded from the fault's negative repercussions. Second, earthing electrical devices (such as home appliances and handheld). The safety of the individuals using the equipment is ensured by the use of tools, industrial motors, etc. For instance, if insulation fails, the live conductor will come into direct contact with the metallic component (i.e., frame) of the apparatus. Anybody who comes into contact with the metallic component of this apparatus will experience a deadly electrical shock. The significance of earthing, or earthing, in the line of power system will be covered in this chapter, with a focus on neutral earthing.

Underground and isolated neutral system: An electrical power distribution system with an underground neutral conductor that is purposefully isolated from the earth is known as an underground and isolated neutral system. The neutral conductor is typically linked to the ground in a power distribution system to serve as a reference point for voltage levels and to maintain system stability. The neutral conductor is maintained electrically separate from the earth in an underground and isolated neutral system, though [1]. Here are some essential components of a hidden, segregated neutral system:

Isolated Neutral: In this system, there is no connection between the neutral conductor and the earth or ground. This indicates that, unlike in a traditional grounded system, there is no electrical or physical link between the neutral conductor and the earth. The neutral conductor in the distribution system transports the imbalanced current but does not give it a way to reach the earth.

Underground Installation: In an underground and isolated neutral system, the power cables and distribution lines are put underground, usually in trenches or conduits. This technique of installation has a number of advantages, including greater aesthetics, decreased sensitivity to weather changes, and reduced possibility of unintentional human or animal interaction.

Insulation Requirements: The neutral conductor must have the proper insulation to prevent accidental electrical contact with the ground because it is isolated from the ground. To ensure electrical safety and to maintain the integrity of the isolated neutral system, high dielectric strength insulation materials and other protective measures are used.

Voltage control: In an underground and isolated neutral system, voltage control is accomplished using a variety of techniques, including the use of voltage regulators, capacitors, and monitoring devices. These gadgets aid in preserving a constant voltage level within allowable bounds and make up for any variations in voltage or reactive power imbalances in the distribution network.

Ground Fault Detection: Ground faults can happen in an underground, isolated neutral system, creating a possible safety issue. To protect people and equipment, specialized ground fault detection tools like ground fault circuit interrupters (GFCIs) or ground fault relays are employed to quickly identify and isolate any ground faults.

Protection and Fault Clearing: In an underground and separated neutral system, protective devices like fuses, circuit breakers, and relays are still used to find and fix problems. When overcurrent, short circuits, and other fault conditions occur, these devices react by isolating the afflicted area of the distribution network in order to limit additional damage and resume normal functioning [2]. Urban locations, residential projects, and sensitive environments where aesthetics, dependability, and safety considerations are vital frequently use underground and separated neutral systems. They have benefits such a less visual impact, increased dependability, and a decreased sensitivity to outside disruptions. To ensure optimum operation and electrical safety, they need careful design, insulation, and maintenance.

Earthed neutral system: An electrical power distribution system that has a neutral conductor connected to the earth or ground is called an earthed neutral system, often referred to as a grounded neutral system. The neutral conductor in this arrangement offers a conduit for unbalanced currents to return to the distribution network as well as a reference point for voltage levels. The most widely utilized system for distributing electrical power throughout the world is the earthed neutral system. An earthed neutral system has the following essential features:

Neutral-Ground Connection: An earthed neutral system has a bond or connection between the neutral conductor and the ground, or the earth. Usually, the main transformer or generator where the power is first produced is where this connection is made. A grounding electrode, such as a ground rod or grounding grid, is physically attached to the neutral conductor, providing a low-impedance route for fault currents to travel to the ground.

Voltage Reference: The earthed neutral acts as a benchmark for the distribution system's voltage levels. Line-to-neutral voltages, also known as phase voltages, can be stable and consistent since the neutral is typically kept at or near the earth potential. The safe and dependable operation of electrical equipment connected to the system is facilitated by this reference point.

Fault Current Path: In a system with an earthed neutral conductor, the neutral conductor acts as a conduit for imbalanced currents to return. The neutral conductor's currents are often balanced when the system is running normally. The imbalanced current, however, passes via the neutral to the grounding electrode during a fault, such as a short circuit or ground fault, ensuring that fault currents are cleared and safeguarding the system and equipment.

Fault Detection and Protection: Ground faults and short circuits can happen in electrical power systems; hence fault detection and protection are important. Fuse, circuit breakers, and ground fault relays are examples of protective devices that are used in an earthed neutral system to find and fix defects. By promptly interrupting the circuit to isolate the faulty segment after sensing aberrant current flow, these devices minimize damage while ensuring the safety of people and equipment.

Considerations for Grounding: For electrical safety in an earthed neutral system, good grounding techniques are crucial. To offer a low-impedance channel for fault currents, the grounding electrode system must be designed and installed in accordance with the pertinent standards and codes. The efficiency of the grounding system also depends on routine testing and maintenance.

Residual Current Devices (RCDs): For improved protection against electric shocks, earthed neutral systems frequently include residual current devices, commonly referred to as ground fault circuit interrupters (GFCIs) or residual current circuit breakers (RCCBs). By rapidly cutting off the circuit if an imbalance is found and detecting minor leakage currents to the ground, these devices guard against electric shocks and ensure human safety [3].

Grounding or Earthing:

It is known as grounding or earthing to link the metallic frame, or non-current carrying component, of electrical equipment, or some electrical component of the system, such as the neutral point in a star-connected system, one conductor of the secondary of a transformer, etc., to earth (soil). The less understood part of the power system is electrical system grounding, which is weird yet accurate. However, it is a highly significant topic. We can effectively prevent accidents and damage to the equipment of the power system and preserve supply continuity if grounding is done methodically in the lines of the power system. There are two types of grounding or earthing: system grounding and equipment grounding. Equipment grounding involves connecting the metal components of electrical equipment that do not transport current to the earth. System grounding, on the other hand, entails earthing a portion of the electrical system, such as the neutral point of a system connected to a star in generating stations and sub-stations.

Equipment grounding: Equipment grounding is the practice of connecting non-current-carrying metal components of electrical equipment (such as the metallic enclosure) to earth (such as soil) so that, in the event of insulation failure, the enclosure effectively remains at earth potential. Electrical devices of various kinds, from home appliances and handheld tools to industrial motors, are something we constantly interact with. By taking into consideration a single-phase circuit made up of a 230 V source linked to a motor, we will demonstrate the necessity of appropriate equipment grounding. At the service door, you'll see that neutral is firmly grounded. For the sake of clarity, we will break up the topic into three sections, namely. (i) An ungrounding enclosure (ii) A connection to the neutral wire (iii) A connection to the ground wire.

(i) **Ungrounded enclosure:** An ungrounded enclosure is depicted in Fig. 1 in this situation. If the device is working properly, nothing will happen if a person touches the metal cage. The resistance Re between the motor and enclosure, however, lowers to a low value (a few hundred ohms or less) if the winding insulation develops a defect. The current journey as depicted in Figure 1 would be completed by a person with a body resistance Rb. The leakage current IL through the person's body could be extremely high if re is low, which is typically the case when insulation failure of the winding occurs. The consequence would be a significant electric shock that might be lethal. This system is dangerous as a result.

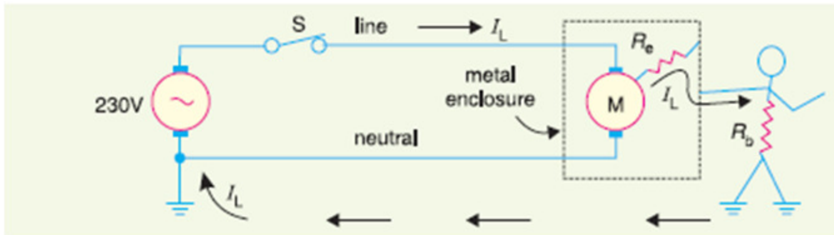

Figure 1: Equipment Grounding Through Ungrounded Enclosure

(ii) Enclosure connected to neutral wire: Connecting the enclosure to the grounded neutral wire as illustrated in Figure 2 may seem to be the solution to the aforementioned issue. The leakage current IL now travels directly from the motor to the neutral wire after passing through the enclosure. The enclosure therefore continues to have an earth potential. As a result, the operator wouldn't get shocked by electricity [4].

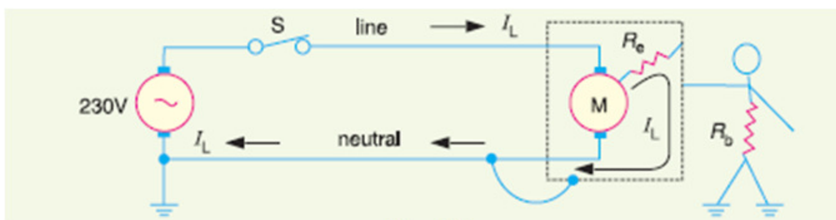

Figure 2: Equipment grounding through Enclosure connected to neutral wire

(iii) Ground wire connected to enclosure: As illustrated in Figure 3, we place a third wire, known as a ground wire, between the enclosure and the system ground to solve this issue. The ground wire could be insulated or left bare. Green indicates that it is insulated.

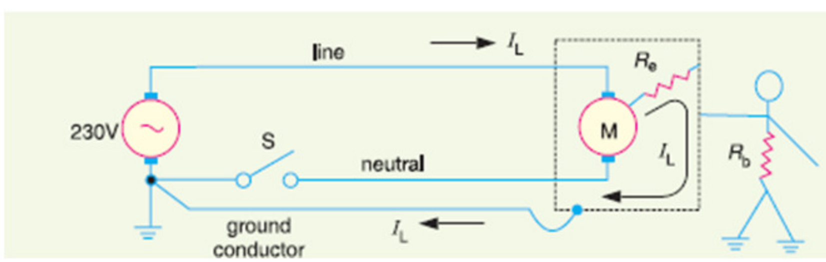

Figure 3: Equipment grounding through Ground wire connected to enclosure

DISCUSSION

System grounding:

System grounding is the process of connecting a certain electrical component of the power system to earth (soil), such as the neutral point of a star connected system, a secondary conductor of a transformer, etc. In the rapidly developing power system, the relevance of system grounding has increased significantly. We can obtain various benefits, including protection, dependability, and safety to the power system network, by adopting correct system grounding schemes. But in order to understand the significance of system grounding, it is preferable to provide two examples before going over the many facets of neutral grounding.

(i) The primary winding of a distribution transformer is shown connected between an 11 kV line's line and neutral. (i). It would seem that a person could touch either secondary conductor without getting hurt if they were grounded, as there is no ground return. This is untrue, though. The capacitance C1 between the primary and secondary, as well as the capacitance C2 between the secondary and ground, are shown in Figure 4. A significant voltage difference between the secondary lines and the ground may result from this capacitance coupling. It might be as high as 20% to 40% of the primary voltage, depending on the relative sizes of C1 and C2. Even with small transformers, the capacitive current (IC) that results from touching any of the secondary wires and flows through the body could be harmful. For instance, if IC is just 20 mA, the individual could receive a lethal electric shock [5]. The capacitive coupling and capacitive current IC virtually reach zero if one of the secondary conductors is grounded. The person won't get an electric shock as a result. This clarifies why system grounding is crucial.

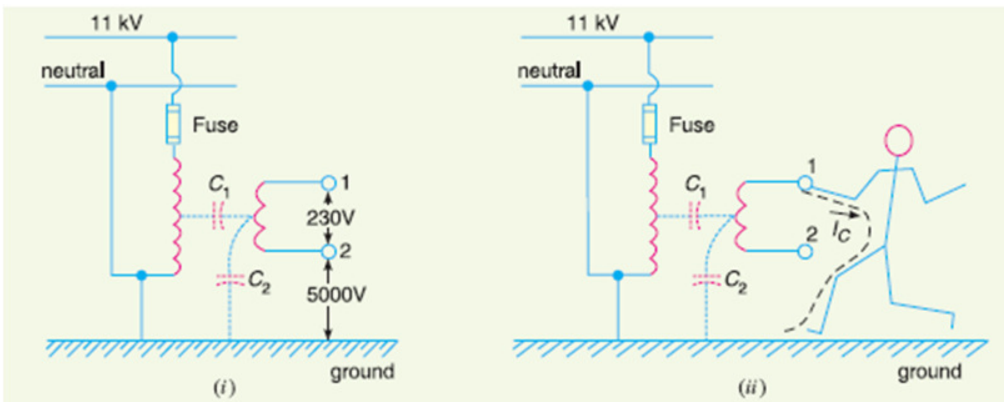

Figure 4: Illustrate the System grounding.

(ii) Let's move on to a more dire scenario. The primary winding of a distribution transformer positioned between an 11 kV line's line and neutral. Ungrounded secondary conductors are used. Assume that the 230 V conductor is touched by the high voltage line (11 kV in this instance). A branch or tree falling across the 11 kV and 230 V cables or an internal failure in the transformer are both potential causes of this. A very high voltage is applied between the secondary conductors and ground in these conditions. The 230 V insulation would be rapidly damaged, leading to a significant flashover. Anywhere on the secondary network, even perhaps inside a house or factory, could experience this flashover. Because of this, ungrounded secondary in this situation poses a risk of fire and may result in serious accidents under unusual circumstances.

Underground Neutral system: The neutral in an ungrounded neutral system is isolated from the ground since it is not connected to the ground. Because of this, this system is also known as a free neutral system or an isolated neutral system. Ungrounded neutral system is seen in Figure 5. There are capacitances between the line conductors and to ground. The former are connected via delta, whilst the latter are connected via stars. The delta-connected capacitances can be disregarded because they have no impact on the system's grounding characteristics (i.e., they have little impact on the earth circuit) [6].

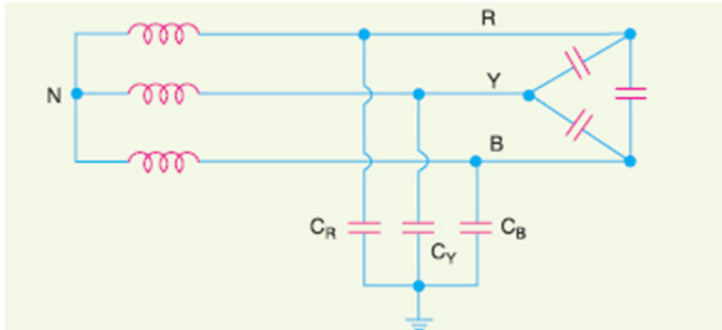

Figure 5: Underground Neutral system.

Neutral grounding: Neutral grounding is the technique of connecting the neutral point of a three-phase system to the earth (soil), either directly or through a circuit component (such as resistance, reactance, etc.). Personal and equipment are protected by neutral grounding. This is so that the protective devices (such as a fuse, etc.) can function to isolate the faulty conductor from the rest of the system when an earth fault occurs and the current route is completed through the earthed neutral. An illustration of this point. A 3-phase, star-connected system with an earthed neutral point (neutral point is connected to ground). This will result in the current flowing through the ground path. Keep in mind that current travels from R phase to earth, then to neutral point N and finally back to R phase. A significant current flow through this path due to the low impedance. This substantial current will isolate the problematic line R and explode the fuse in R-phase. This will shield the system from the fault's negative repercussions, such as equipment damage and employee electric shock. The potential difference between the live conductor and ground will not exceed the phase voltage of the system, which means it will remain almost constant. This is a crucial characteristic of grounded neutral.

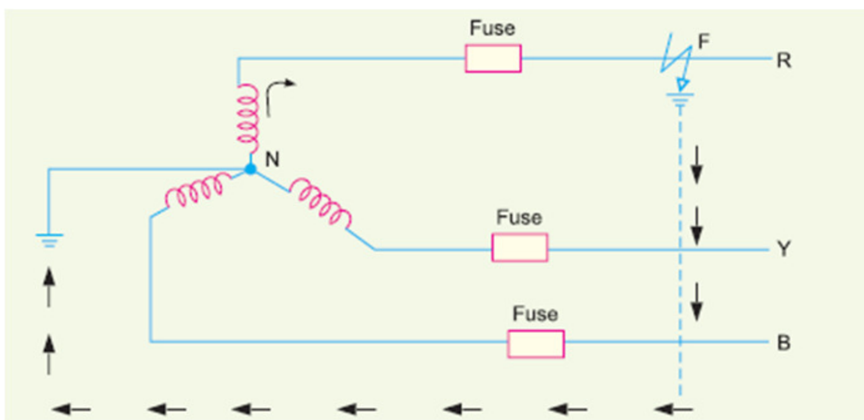

Figure 6: Illustrate the Neutral grounding.

Advantage of Neutral grounding: The benefits of neutral grounding are as follows:

(i) The voltages of the healthy phases are almost constant and do not exceed the voltages from the line to ground [7].

(ii) Arcing grounds' high voltages are eliminated.

(iii) Earth fault protection can be offered using the protective relays. The protective relay will activate in the event of an earth fault on any line to isolate the problematic line.

(iv) Lightning-related over voltages are dumped to earth.

(v) It increases the safety of the workers and the machinery.

(vi) It offers enhanced service dependability.

(vii) Operating and upkeep costs are decreased.

The capacitive current IC that results from an earth fault on any phase is in phase opposition present fault IF. Both currents totally cancel one another out. As a result, neither an arcing ground nor an over-voltage situation may exist. Take a line-to-ground problem for example B. The capacitive currents IR and IY, respectively, are flowing in the healthy phases R and Y. The phasor sum of IR and IY yields the capacitive current IC. The power supply also provides the fault current, abbreviated IF, in addition to these capacitive currents. This fault current will travel through the faulty phase and from the fault point to earth, neutral point N, and back to the fault point. The IC's path is capacitive, while the IF's path is inductive. The two currents entirely cancel each other out since they are in phase opposition. As a result, neither the arcing ground phenomenon nor over-voltage situations are possible.

The phase to earth voltage of the faulty phase drops to zero when an earth fault occurs on any phase of the system. However, because the neutral's potential is set at earth potential, the phase to earth voltages of the other two healthy phases continue to be at normal phase voltage. This enables the device to be phase voltage insulated. As a result, the cost of equipment is reduced. It becomes simpler to defend the system against the regular earth faults that affect it. A significant fault current flows between the fault site and the grounded neutral whenever an earth fault occurs on any phase of the system. This makes it possible for earth fault relays to operate simply [8].

Resistance grounding:

Resistance grounding is a technique used in electrical power systems to control the flow of fault currents and limit the size of the fault current. It entails using a grounding resistor to link a power system's neutral point to the ground. This resistor restricts the current flow during a malfunction, reducing excessive equipment damage and potential worker dangers. The resistance grounding technique has a number of benefits. By causing a voltage drop across the grounding resistor, it first enables the identification of ground defects. This voltage may be tracked, and if it rises beyond a certain threshold, a problem is present. This makes it easier to quickly identify faults and to schedule maintenance and repairs. Second, resistance grounding reduces the possibility for thermal and mechanical pressures on system components by limiting the ground fault current magnitude.

System reliability is increased as a result of reducing equipment damage and extending the life of electrical equipment. Resistance grounding also reduces the possibility of transient over voltages. It prevents equipment from being damaged by voltage surges that can lead to insulation breakage and other electrical problems by giving fault currents a controlled path. Resistance grounding does have some drawbacks, though. In contrast to solid grounding techniques, it does not offer full fault current clearing. A voltage will also be present between the neutral and ground during a ground fault, raising the risk of electric shock dangers. To summarize, resistance grounding is a useful technique for reducing the size of a fault current and enhancing the security and dependability of electrical power systems. It is a popular grounding technique used in many industrial and commercial applications because it finds a compromise between minimizing equipment damage and protecting against fault currents.

Benefits and drawbacks of Resistance grounding: Resistance grounding has several benefits.

1. **Fault Current Limitation:** Resistance grounding's capacity to restrict fault currents is one of its key benefits. The neutral path grounding resistor is used to reduce the fault current's overall strength. This lessens heat and mechanical strains, prevents excessive equipment damage, and improves system reliability all around.
2. **Fault Detection:** Resistance grounding makes it possible to discover ground defects. A voltage drop is produced across the grounding resistor when a fault occurs. Operators can detect the presence of a malfunction and act quickly to perform maintenance and repairs by monitoring this voltage. Early defect detection reduces downtime and raises the power system's overall effectiveness.
3. **Transient Overvoltage Mitigation:** Resistance grounding reduces the likelihood of transient over voltages during a fault by preventing them. It controls the growth in voltage by giving fault currents a controlled path, shielding equipment from voltage spikes that could lead to insulation breakdown and other electrical problems.
4. **Selective Ground Fault Protection:** Resistance grounding makes it possible to defend against certain ground faults. Operators can pinpoint the exact position of the defect by measuring the voltage across the grounding resistor. This makes it simpler to isolate and fix the affected area while causing the least amount of inconvenience to the rest of the system [9].

Applications of Resistance grounding: In many different sectors and electrical power systems, where controlled fault current and fault detection are crucial, resistance grounding is used. Here are a few typical examples:

Industrial and Commercial Facilities: Resistance grounding is frequently employed in industrial and commercial settings, including manufacturing plants, refineries, and data centres. It aids in preventing damage from fault currents in sensitive equipment including motors, transformers, and generators. Controlled fault current also helps find ground problems, enabling quick maintenance and reducing downtime.

Hospitals and Healthcare Facilities: Resistance grounding is used in healthcare facilities where electrical systems must perform consistently to support vital medical equipment. This lowers the danger of equipment damage and limit's fault currents. It improves patient safety and assists in ensuring an uninterrupted power supply.

Water and Wastewater Treatment Plants: Resistance grounding is frequently used in water and wastewater treatment plants to shield electrical components like pumps and motors from fault currents. It assists in preserving the plants' operating effectiveness and guards against potential harm to vital systems [10]. These are only a few instances of the numerous uses for resistance grounding. The design and execution of the resistance grounding system will depend on the particular needs of each application, including fault current levels, system size, and safety considerations.

Reactance grounding: A reactance is introduced between the neutral and ground in this setup. Reactance is used to restrict the earth fault current. The earth fault current can be altered to create conditions akin to solid grounding by altering the earthing reactance. The following drawbacks prevent this strategy from being employed today:

(i) For the identical fault conditions in this system, the fault current needed to activate the protective device is larger than it would be for resistance grounding.

(ii) High transient voltages manifest themselves when there is a fault.

Voltage transformer Earthing: The main of a single-phase voltage transformer is connected between the neutral and the earth in this manner of neutral earthing, as depicted in Figure 7. The secondary of the voltage transformer is linked to a low resistor in series with a relay. The voltage transformer effectively functions as an ungrounded neutral system by offering a high reactance in the neutral earthing circuit. Any phase that has an earth fault results in a voltage across the relay. This results in the protection gadget functioning.

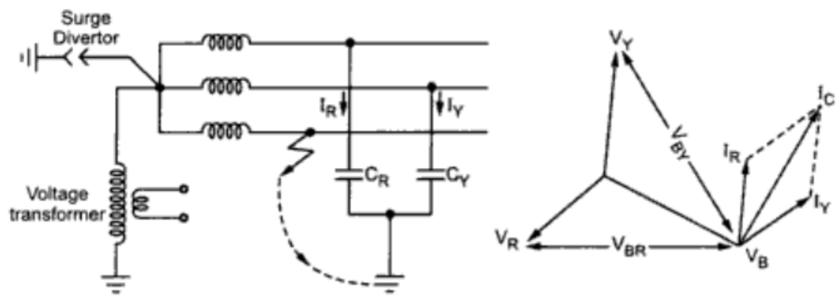

Figure 7: Voltage transformer Earthing.

CONCLUSION

In summary, power system earthing is an essential part of electrical installations that protects against electrical problems and guarantees the security of people and machinery. The principles and various power system earthing configurations, including solid, resistance, and reactance earthing, have been reviewed in this classification. It has emphasized the significance of creating low impedance fault current routes to guarantee proper fault clearance and reduce the possibility of electric shock. The classification has also included the benefits and drawbacks of various earthing techniques, assisting engineers and electricians in making judgements based on particular needs and restrictions. Electrical systems can be protected, reducing the possibility of electrical risks, and preserving a dependable and safe working environment by putting appropriate power system earthing practices into place.

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CHAPTER 9

INVESTIGATING THE PROTECTION METHODS AGAINST OVERVOLTAGE

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ABSTRACT:

The components of a power system, such as generators, transformers, gearbox lines, insulators, etc., are frequently exposed to overvoltages, or voltages higher than the typical value. These power system overvoltages can occur for a variety of reasons, including lightning, the tripping of a circuit breaker, the grounding of a conductor, etc. The majority of overvoltages have small magnitudes, yet they could nevertheless be significant due to their impact on the effectiveness of circuit interrupting machinery and protective devices. Overvoltage is a serious problem that can seriously harm electronic devices and systems. This chapter investigates numerous approaches and strategies for overvoltage protection. It offers an overview of the various protection systems and talks about the significance of overvoltage protection. The chapter also identifies important factors to take into account when deciding on the best protection method for various applications. For engineers, designers, and researchers working in the subject of electrical system protection, the study's findings offer useful insights.

KEYWORDS:

Lightning, Switching Surge, Over Voltages, Voltage Surge.

INTRODUCTION

A sizable portion of these overvoltage’s are severe enough to destroy the insulation of the power system's equipment. As a result, power system experts constantly devise strategies to reduce the severity of produced overvoltages and to manage their impact on the operational equipment. We will focus on the numerous power system overvoltage reasons in this chapter, paying particular attention to the protective equipment that is employed to address these issues[1]–[3]. Although they can be induced by switching or other factors, lightning strikes to transmission lines are by far the most significant source of transients. Similar to how a flow of water rushes along a small valley when the retaining wall of a reservoir at its head suddenly breaks way, when lightning strikes a line, the surge rushes along the line.

Voltage surge:

A voltage surge or transient voltage is a sudden increase in voltage that lasts just a very brief time on the power system. Although transients and surges are momentary in nature and last only a few hundred nanoseconds, they generate overvoltages in the power system. In the majority of situations, such surges can destroy surrounding transformers, generators, or other connected equipment if they are not adequately protected, as well as the line insulators (near the spot where lightning has struck). A typical lightning surge's waveform is depicted in Figure1. The time is measured along the x-axis and the voltage buildup along the y-axis. It is evident that lightning creates waves with a steep front. At any point in the network, voltage builds up more quickly the steeper the wave front. The majority of the time, this build-up is relatively quick, taking between 1 and 5 seconds. Voltage surges are typically described in terms of the time it takes for them to rise (t1) and for them to reach half their peak value (t2). A 1/50-s surge, for instance, achieves its peak value in 1 s and declines to 50% of that value in 50 s.

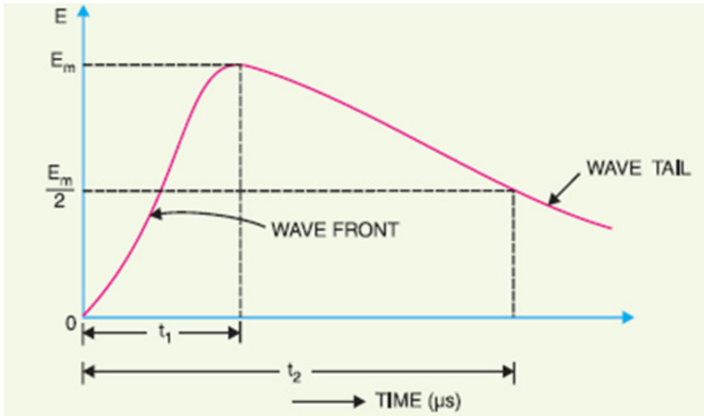

Figure 1: voltage surge graph.

Cause of overvoltage:

A power system's overvoltages can be roughly classified into two categories:

1. Internal causes, which include switching surges, insulation failure, arcing ground, and failure of other components, Resonance.
2. Outside factors, such as lightning

Large-scale surges are not caused by internal factors. Experience has shown that surges resulting from internal causes hardly ever double the system voltage. Surges caused by internal factors are often addressed by giving the equipment in the power system the appropriate insulation. Lightning-related surges, on the other hand, can significantly boost system voltage to levels many times higher than average. The equipment in the power system may sustain significant damage from lightning surges if it is not shielded from them. In actuality, lightning surges are primarily handled by the protection mechanisms against overvoltages provided in a power system.

Internal cause of Overvoltage: The oscillations caused by the abrupt changes in the circuit conditions are the main internal sources of overvoltages on the power system. This circuit shift could be caused by a fault event, such as the grounding of a line conductor, or it could be a regular switching procedure like opening a circuit breaker. The typical system insulation is effectively built to tolerate such surges in practice. We'll talk briefly about what causes internal overvoltages.

1. Switching Surges: Switching surges are overvoltages that are caused by switching processes on the electrical grid. The following cases will be used as examples:

(i) **Case of an open line:** Travelling waves are created during switching operations on an unloaded line, causing overvoltages on the line. Consider, as an example, the connection of an unloaded line to a voltage source in Figure 2.

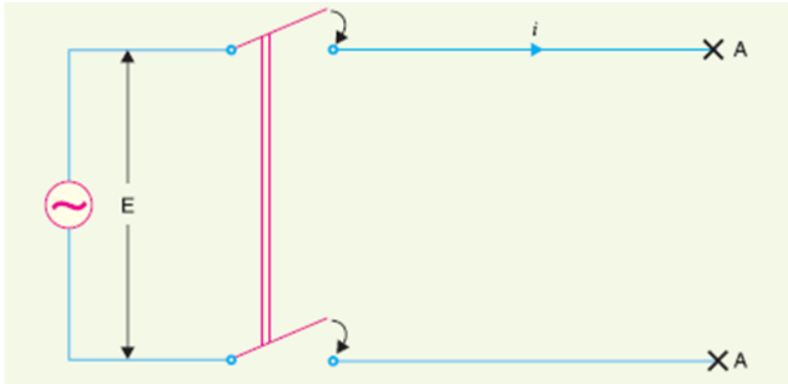

Figure 2: Switching surges.

A voltage wave is created and propagates along the line after the unloaded line is connected to the voltage source. It is unaltered when it returns to the supply end after passing the terminal point A. This results in voltage doubling, when the voltage on the line doubles from its initial value. The instantaneous voltage that the line must tolerate is 2√2 E if Er.m.s. is the supply voltage. This overvoltage is only transient. It happens because line losses reduce the wave's intensity, and the line quickly returns to its typical supply voltage E. Similar to this, when an unloaded line is turned off, it briefly reaches a voltage of 2√2 E before returning to its normal value.

(ii) **A loaded line case:** Additionally, when a loaded line is switched, overvoltages will be generated. Let's say a loaded queue is abruptly terminated. This will create a voltage of 2 Zn i across the break (or switch), where i is the current at that precise moment the line was opened, and Zn is the line's natural impedance. Consider a scenario in which the break occurs while the current is at its peak and the line with Zn = 1000 carries a current of 100 A (r.m.s.). The voltage across the switch, or breaker, is equal to 2√ 2 x 100 x 1000/1000, or 282.8 kV. The highest voltage that a line can withstand is equal to (Vm + 282.8) kV if Vm is the voltage's peak value in kV.

(iii) **Current chopping:** Current chopping causes the air blast circuit breaker to produce high voltage transients across its contacts. Here, it is briefly discussed. Air-blast circuit breakers keep the same extinguishing strength regardless of the magnitude of the current being interrupted, in contrast to oil circuit breakers, which depend on the magnitude of the current being interrupted for their effectiveness. When using an air-blast breaker to break low currents (such as transformer magnetizing current), the current falls sharply to zero much before the natural current zero is reached due to the air-blast's potent de-ionizing impact. Current chopping is the name of the phenomena, which results in high transient voltage across the breaker contacts. Resistance switching prevents overvoltages brought on by current hopping.

2. Insulation failure: The grounding of conductor, or the failure of the insulation between the line and the earth, is the most typical instance of insulation failure in a power system and may result in over voltages. Consider earthing a line at potential E at point X. Two equal voltages of E, carrying currents of E/Zn and +E/Zn, respectively, travel down XQ and XP as a result of the line being grounded. Both of these currents go via X to the earth, resulting in a current of 2E/Zn.

3. Arcing ground: To achieve two benefits, the neutral of three phase lines was not earthed in the early days of transmission. First off, a line-to-ground fault does not render the line inoperable. The interference with communication lines is reduced as a result of the second elimination of zero sequence currents. With short lines and relatively low voltages, insulated neutrals provide no issues. However, a major issue known as arcing ground is frequently observed when the lines are long and run at high voltages. Three to four times the usual voltage oscillations are produced by the arcing ground. Arcing ground is a word used to describe the intermittent arc that occurs in a line-to-ground fault of a three-phase system and the transients that are produced as a result. The cumulative transients caused by an arcing ground can seriously harm the power system's equipment by causing insulation to fail. Earthing the neutral will stop arcing ground.

4. Resonance: In an electrical system, resonance happens when the circuit's inductive reactance and capacitive reactance are equal. Under resonance, the circuit's impedance and resistance are equal, and the p.f. is one. High voltages in the electrical system are a result of resonance. Because the capacitance in typical transmission lines is so low, resonance at the fundamental supply frequency doesn't happen very often. However, if the generator e.m.f. wave is warped, underground cables may also have resonance issues caused by 5th or higher harmonics.

DISCUSSION

Lightning:

Lightning is an electric discharge between a cloud and the earth, another cloud, or the charge centres of the same cloud. When clouds are charged to such a high potential (+ve or -ve) with regard to earth or a neighboring cloud that the dielectric strength of the surrounding medium (air) is broken, lightning, which is a massive spark, occurs. To explain how the clouds gain charge, there are many hypotheses in existence. The most widely recognized theory holds that when warm, humid air rises from the earth, friction between the air and the minuscule water particles causes charges to build up. In the formation of water drops, the larger drops acquire a positive charge while the smaller drops acquire a negative charge. Depending on the charge of the water drops they contain, the accumulated water drops give rise to clouds, which can have either a positive or negative charge. When a cloud's charge builds up enough, it may release onto another cloud or the earth, and we refer to this as lightning. Thunder occurs when lightning strikes because the air is instantly heated and expands, resulting in thunder. The expanding air is pushed back and forth by the surrounding air, creating the air wave motion that we associate with thunder.

Mechanism of lightning discharge:

Now let's talk about how a lightning discharge happens. The ground below receives an equal and opposite charge when a charged cloud passes over it. In Figure 3, a negatively charged cloud causes the soil beneath it to become positively charged. As a cloud's charge rises, the potential between it and the earth rises as well, increasing the gradient in the air. The lightning stroke begins when the potential gradient is high enough (5 kV/cm to 10 kV/cm) to destroy the surrounding air. The following is the stroke mechanism:

(i) As soon as the air in the vicinity of the cloud collapses, a leader streamer, also known as a pilot streamer, shoots out of the cloud towards the earth while carrying charge, as seen in Fig. 3 (i). As long as the cloud from which it emanates feeds it with enough charge to keep the gradient at the tip of the leader streamer above the force of air, the leader streamer will continue on its course towards the ground. The leader streamer ends and the charge dissipates without forming a full stroke if this gradient is not maintained. To put it another way, the leader streamer won't touch down on the planet. The leader streamer is shown to be unable to reach the earth in Fig. 3 (i) because the gradient at its end cannot be maintained above the strength of the air.

It should be noted that the leader streamer's current is low (less than 100 A), and its propagation speed is only slightly faster than that of light. Additionally, the leader's brightness is likewise relatively low.

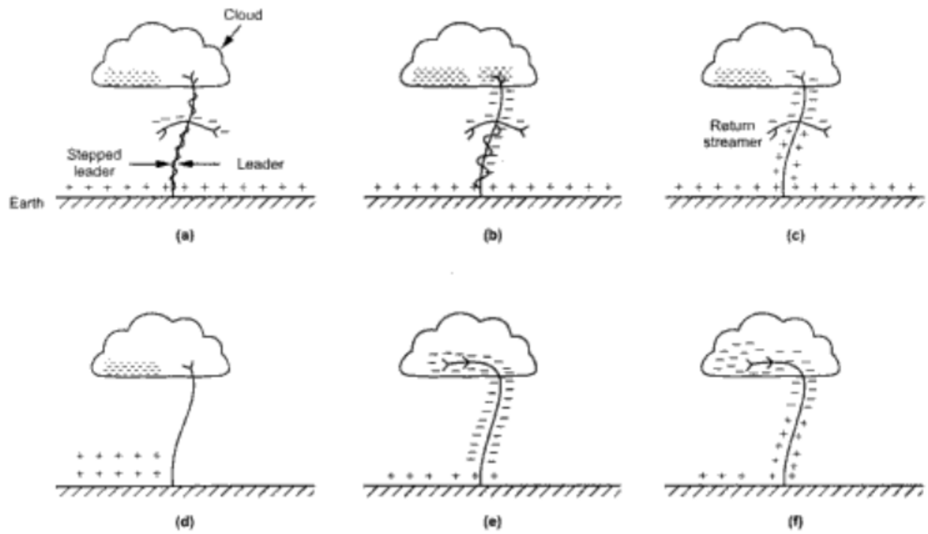

Figure 3: Mechanism of lightning discharge.

(ii) The leader streamer frequently travels further towards the earth until it comes into contact with the earth or an object on the earth. Stepped leaders are created as the leader streamer approaches the earth and is accompanied by points of luminescence that move in jumps. Stepped leaders travel at speeds greater than one-sixth the speed of light and cover around 50 m in each stride. There is a possibility that stepped leaders have sufficient luminance and cause the first visual discharge occurrence.

(iii) The leader streamer's route is one of ionization and, as a result, of total insulation breakdown. A return streamer emerges from the earth to the cloud when the leader streamer approaches the earth and travels along the same direction as the main channel of the downward leader. The downward leader has a negative charge and the return streamer has a positive charge, therefore the action can be equated to closing a switch between the positive and negative terminals. A sudden spark caused by this event is what we refer to as lightning. Any additional discharge from the cloud may need to come from another area of it because a large percentage of the negative charge on the cloud has been neutralized as a result.

The following details of lightning discharge may be noted:

(a) Although a lightning discharge normally appears to the eye as a single flash, it is actually composed of several distinct strokes that follow the same path. The time difference between them ranges from 0 to 5 seconds. Each individual stroke begins with a leader that descends from the cloud.

(b) It has been discovered that just 13% of all lightning strikes come from positively charged clouds, while 87% of all lightning strikes are caused by negatively charged clouds.

(c) It has been calculated that there are roughly 100 lightning strikes every second worldwide.

(d) Currents in a lightning discharge can range from 10 kA to 90 kA.

Types of Lightning strokes: There are two primary methods that lightning can strike the electrical grid, including overhead lines, towers, substations, etc.

1. Direct stroke: In a direct stroke, lightning discharge (i.e., current path) travels straight from the cloud to the target equipment, such as an overhead line. The current path from the line may travel over the insulators, down the pole, and then to the ground. The stroke-induced overvoltages may be significant enough to cause a flashover along this channel straight to the ground. There are two different sorts of direct strokes: strokes A and B [4]–[6].

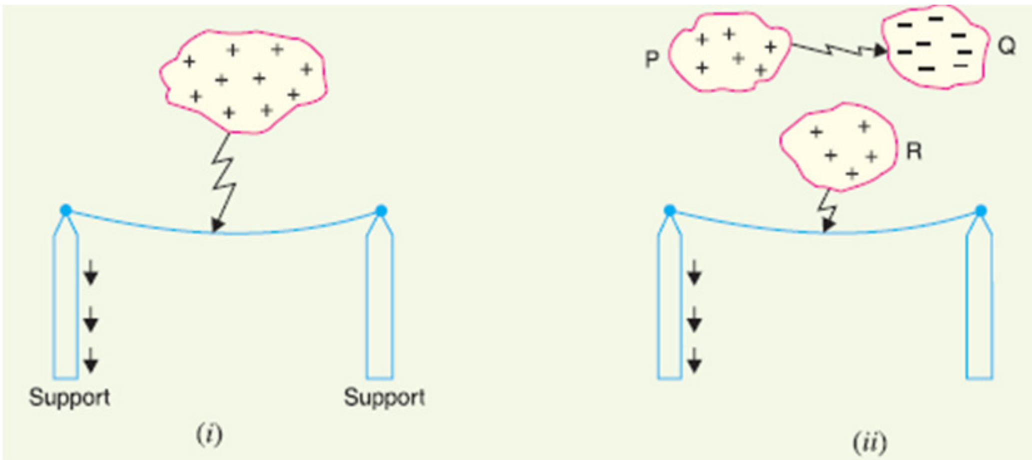

Figure 4: Direct stroke Lightning.

(i) As seen in Figure 4, the lightning discharge in stroke A is from the cloud to the apparatus in question, in this case an overhead line. The tall item, in this case an overhead line, will experience an opposite sign charge as a result of the cloud. Lightning discharges happen between clouds and lines when the potential between them is greater than the breakdown value of air.

(ii) Stroke A between the clouds results in stroke B, which is when discharges on the overhead wire lightning. There are three clouds with positive, negative, and positive charges, referred to as P, Q, and R, respectively. The cloud R is responsible for tying the charge to the cloud Q. Lightning discharge will occur between the clouds P and Q if the cloud P moves too close to them, and charges on both of these clouds will vanish swiftly. As a result, the charge on cloud R abruptly breaks free, discharging quickly to earth while oblivious to tall objects. Regarding direct strikes, there are two things to consider. First off, direct hits to the power system are quite uncommon. Second, since towering objects will always be the site of stroke A, protection can be offered. Stroke B, however, fully disregards the object's height and has the potential to even hit the ground. As a result, there is no way to offer protection against stroke B.

2. **Indirect stroke:** Because charged clouds are present, indirect strokes are caused by electrostatically generated charges on the conductors. Figure 5 is an illustration of this. Electrostatic induction causes a positively charged cloud above the line to induce a negatively charged line. However, this negative charge will only apply to the section of the line directly beneath the cloud; the rest of the line will be positively charged. Through the insulators, the induced positive charge progressively escapes to earth. The negative charge on the wire is isolated when the cloud discharges to earth or to another cloud because it can't travel quickly to earth across the insulators. As a result, negative charge rushes in both directions along the line as travelling waves. It might be important to note that the majority of transmission line surges are produced by indirect lightning strikes.

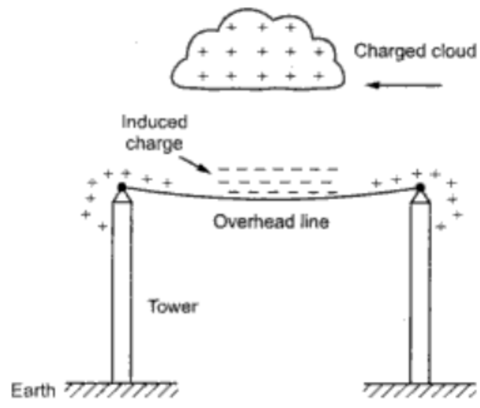

Figure 5: Indirect Stroke Lightning.

Harmful effects of Lightning: A steep-fronted voltage wave is created on a transmission line by a direct or indirect lightning strike. This wave's voltage may increase from zero to its peak value (perhaps 2000 kV) in approximately one second and then decline to half its peak value in about five seconds. A voltage wave with such a steep front will start travelling waves along the line in both directions, with the velocity depending on the line's Land C characteristics.

(i) The travelling waves caused by lightning surges will damage poles and break insulators.

(ii) A transformer or generator's windings may sustain significant damage if the travelling waves caused by lightning strike them. Any quick passage of electric charge is resisted by the windings' inductance. Electric charges "pile up" against the transformer (or generator) as a result. This creates a pressure between the windings that is so high that insulation may fail, causing an arc to form. When insulation has failed and an arc has been generated by a brief overvoltage, the normal voltage between the turns is never enough to start an arc; nevertheless, the line voltage is typically adequate to maintain the arc long enough to seriously harm the machine.

(iii) If a lightning strike initiates an arc in any area of the power system, this arc will cause extremely unsettling oscillations in the line. This could harm other linked equipment a queue.

Systems for lightning protection: Several safety precautions can be taken in order to reduce the risks of lightning strikes:

1. **Lightning Rods (Air Terminals):** Air terminals, commonly referred to as lightning rods, are a crucial component of lightning protection systems. They are made to give lightning a preferred route to go, rerouting the electrical discharge away from buildings. Buildings, towers, and other structures frequently have lightning rods put on their highest points. The lightning rod gathers the electrical charge as a lightning strike approach and securely transfers it to the ground through a system of conductors.
2. **Surge Protectors (Transient Voltage Surge Suppressors):** Surge protectors are tools used to guard against voltage surges brought on by lightning in electrical and electronic equipment. Power lines may experience high voltage surges caused by lightning strikes, which could harm or even destroy delicate equipment. To reduce voltage spikes and safely redirect surplus energy to the earth, surge protectors are installed at the locations where electrical systems enter the building. They serve as a barrier, protecting the equipment by preventing the surge from getting to it.
3. **Grounding systems:** Effective lightning protection depends on proper grounding. Lightning currents can safely flow into the ground using grounding systems' low

resistance channel. Deeply buried conductive elements, like copper or aluminium, make up the grounding system. To ensure the dissipation of electrical energy, it connects numerous lightning protection system elements such surge protectors, equipment grounding, and lightning rods. The potential for damage to structures, the risk of electrical shock, and the protection of equipment are all reduced by adequate grounding.

4. **Lightning Arresters:** Lightning arresters, often referred to as surge arresters, are devices fitted at electrical entry points to prevent surges caused by lightning. They recognize voltage spikes and safely direct extra electrical energy to the earth. Surge arresters serve as a barrier, keeping the surge from destroying equipment and entering the electrical system. They give an extra degree of security, especially for delicate and important equipment.
5. **Installation and Upkeep:** For lightning protection systems to work effectively, proper installation and frequent upkeep are required. Here are some crucial things to remember:
6. **Professional Installation:** Lightning protection systems should only be installed by trained experts who are familiar with the regulations and criteria for lightning protection. Installation must follow accepted industry norms, such as International Electro technical Commission (IEC) Standard IEC 62305 or National Fire Protection Association (NFPA) Standard NFPA 780.
7. **Lightning Risk Assessment:** A complete evaluation of the lightning risk should be done prior to implementing a lightning protection system. It is important to consider elements such the geographic location, building height, environment, and electrical systems. The proper design and elements of the lightning protection system will be determined with the aid of this assessment.
8. **Regular Inspections:** To make sure lightning protection systems are still in good working order, they should be examined on a regular basis. Corrosion, damage, loose connections, and any other indicators of wear should all be looked for during inspections. Immediately fix or replace any deteriorating components that are visible.
9. **Upkeep and Maintenance:** In order to retain the efficiency of lightning protection devices, they need be regularly maintained. This include keeping grounding systems clean of debris or obstructions, ensuring clear paths for lightning rods, and routinely testing surge protection equipment.

Lightning protection is essential to protect human life and limit damage to infrastructure. An efficient lightning protection system must include surge arresters, surge protectors, grounding systems, and lightning rods. The dependability and efficiency of these protective measures are largely dependent on proper installation, adherence to regulations, and routine maintenance. Individuals and organizations can reduce hazards, improve safety, and save priceless assets by putting in place complete lightning protection systems. Our capacity to protect infrastructure and human life from the deadly effects of lightning strikes will be improved through ongoing research and technical advancements in lightning protection.

Protection against lightning:

Switching and other factors can create transients or surges on the power grid, but lightning-related surges are the most significant and destructive. The expensive equipment in the power system (such as generators, transformers, etc.) may sustain catastrophic damage as a result of lightning surges, either directly striking the equipment or striking transmission lines that send waves to the equipment. Protection against both types of surges must be provided. The three most popular lightning surge prevention tools are:

(i) Earthing screens (ii) Overhead ground cables (iii) Lightning arresters or surge diverters.

While overhead ground wires shield transmission lines from direct lightning strikes, earthing screens protect power plants and sub-stations from such strikes. However, lightning arresters or surge diverters shield the station's equipment from both direct strikes and waves that enter the equipment indirectly. We'll talk briefly about various defense strategies.

The Earthing screen:

Usually, expensive equipment is housed in the power stations and sub-stations. By installing an earthing screen, these stations can be shielded from direct lightning strikes. It is made up of a network of copper conductors, commonly referred to as shield or screen, installed on every piece of electrical machinery in the sub-station or power plant. Through a low impedance, the shield is appropriately connected to earth at least twice. When a direct strike occurs on the station, the screen offers a low resistance channel for conducting lightning surges to the ground. The station's equipment is shielded from harm in this way. This method's drawback is that it offers no defence against travelling waves that might get to the station's equipment.

Overhead ground wires: The use of overhead ground wires, as depicted in Figure 6, is the most efficient way to shield transmission lines from direct lightning strikes. One ground wire and one line conductor are presented for simplicity's sake. The ground wires (also known as ground wires) are positioned above the line conductors in such a way that they practically catch every lightning strike. At every tower or pole, the ground wires are grounded with the least amount of resistance. The ground wires will absorb all lightning strikes because of their strategic placement, preventing them from striking line conductors.

The ground wires will absorb the direct lightning strike that strikes the transmission line. The ground wire's significant lightning current (10 kA to 50 kA) flows to the ground, shielding the line from the destructive effects of lightning. It should be noted that the ground wires' level of protection is influenced by the tower's footing resistance. Assume, for instance, that the lightning current from the tower to the ground is I amperes and the tower-footing resistance is R1 ohms. The tower then rises to a potential Vt determined by, where Vt = I1R1. This is also the voltage that will be visible across the string of insulators because Vt (= I1R1) is about the voltage between the tower and line conductor. If Vt's value falls short of what's needed to generate an insulator flashover with no consequences. On the other hand, insulator flashover could happen if Vt is too high. Since the tower-footing resistance R1 determines the value of Vt, it is imperative to keep this resistance as low as possible to prevent insulator flashover.

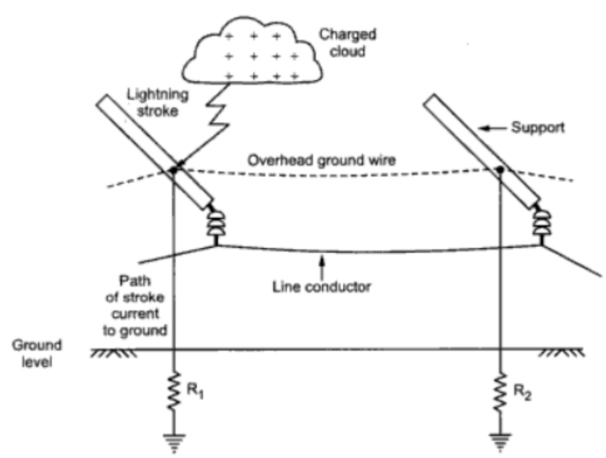

Figure 6: Overhead ground wires

Lightning arresters: The earthing screen and ground wires can effectively shield the electrical system from direct lightning strikes, but they are ineffective against waves that could travel and strike the terminal device. Surge diverters or lightning arresters offer defence against these surges. A surge diverter, also known as a lightning arrester, is a safety measure that transmits high voltage surges on the electrical system to the ground.

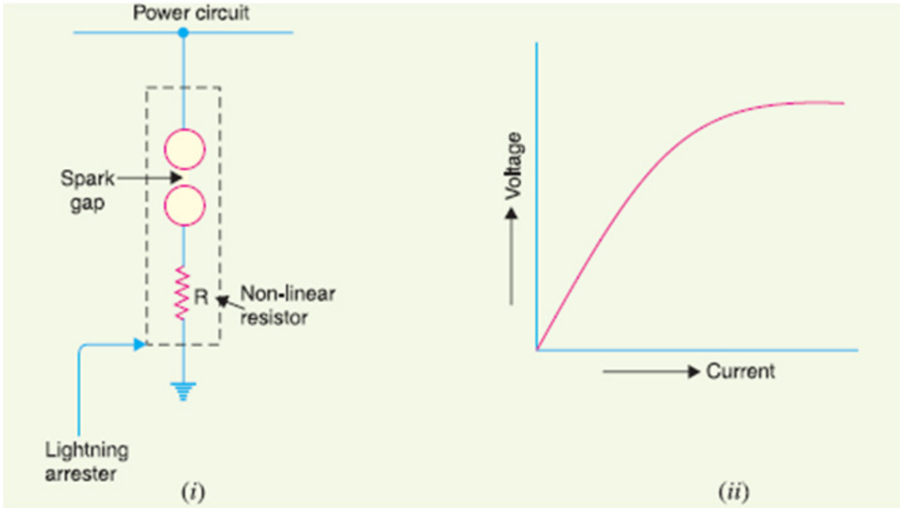

Figure 7: Lightning arrester

The fundamental design of a surge diverter is depicted in Figure 7 (i). It consists of a non-linear resistor in series with a spark gap. The equipment to be protected's terminal is attached to one end of the diverter, while the other end is effectively grounded. Due to the predetermined length of the gap, a standard line voltage will not be adequate to break down the air insulation and create an arc across the gap, but a dangerously high voltage will. The non-linear resistance has the property that when the voltage (or current) rises, so does its resistance, and the opposite is also true. This is evident from the resistor's volt/amp.

The arc would be a short-circuit on the power system and might result in power-follow current in the arrester as the gap sparks over as a result of overvoltage. A short-circuit is avoided because of the resistor's ability to provide high resistance to high voltage (or current). Following the surge, the resistor provides a high resistance to stop the gap from conducting. A lightning arrester's design must take into account two factors. First, the arc in the gap should stop once the surge is over. The resistor and gap may both be destroyed if the arc does not end. This is because electricity would keep flowing through the resistor if it did not. Second, the I R drop over the arrester, where I is the surge current, should not be greater than the breakdown strength of the insulation of the apparatus to be protected [7]–[9].

1. Rod Gap Arrester: This diverter is made up of two 1.5 cm rods that are bent at a right angle and separated by a gap, as shown in Figure 8. The line circuit is connected to one rod, while earth is connected to the other rod. In order to prevent the arc from damaging the insulator, the distance between the gap and the insulator (i.e., distance P) cannot be less than one-third of the gap's length. In order to prevent the cascading of extremely steep wave fronts through the insulators, the gap length is often chosen such that breakdown should occur at 80% of spark-over voltage. There is frequently a rod gap across the string of insulators for an overhead line on the transformer bushing. The rod gap across a transformer's bushing. The gap is still non-conducting in normal operating conditions. When a high voltage surge occurs on the wire, the gap ignites and conducts the surge current to ground. In this manner, any extra charge left over after a surge is safely transported to earth.

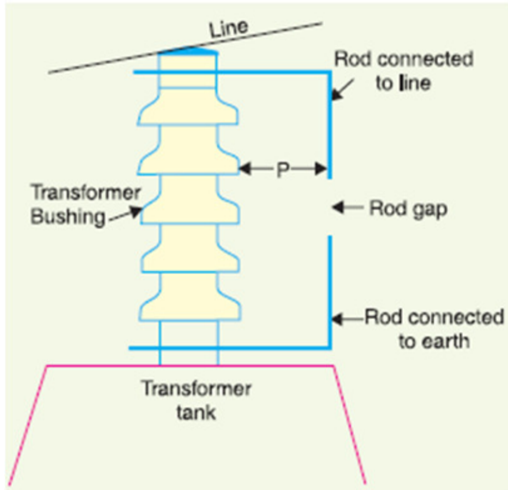

Figure 8: Rod Gap Arrester.

2. Horn Gap Arrester: The horn gap arrester is depicted in Figure 9. It is made up of two horn-shaped metal rods A and B that are spaced apart by a tiny air gap. The horns are designed so that, as depicted, the space between them gradually widens as they approach the summit. On porcelain insulators, the horns are mounted. The line is connected to one end of the horn through a choke coil L and resistance R, while the other end is essentially grounded. The resistance R contributes to keeping the follow current at a low level. Because of how it is constructed, the choke coil has a low reactance at power frequency but a very high reactance at transient frequency. As a result, the choke prevents transients from entering the protective device. Because of the way the spacing between the horns is controlled, a standard supply voltage cannot create an arc across the gap.

The gap is not conducting under normal circumstances, meaning that the supply voltage is inadequate to start an arc between the gaps. When an overvoltage occurs, spark-over occurs across the small gap G. The arc moves up the gap as a result of the magnetic pull of the arc and the hot air surrounding it. Gradually, the arc enters places 1, 2, and 3. At a certain point along the arc the distance might be too great for the voltage to keep the arc going. As a result, the arc is put out. Thus, the extra charge on the line is transferred to the battery through the arrester ground.

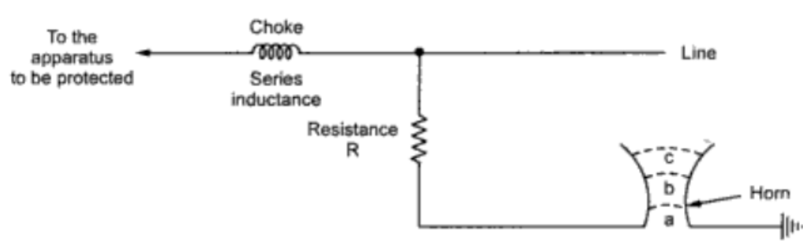

Figure 9: Horn Gap Arrester.

3. Multigap arrester: The multigap arrester is depicted in Figure 10. It is made up of a number of metallic (often zinc alloy) cylinders that are spaced apart from one another and separated by brief air gaps. Through a series resistance, the line is connected to the series' first cylinder (cylinder A), and the ground is connected to the other cylinder. The power arc is restricted by the series resistance. Series resistance is added, which lessens the level of protection from travelling waves. Some of the gaps are redirected by a resistance to get around this challenge.

Point B is at earth potential in typical circumstances, hence the standard supply voltage cannot close the series gaps. The breakdown of series gaps A to B takes place when an overvoltage occurs. After breakdown, the heavy current will select the direct route to the earth via the shunted gaps B and C over the alternate route through the shunt resistance. The arcs B through C go out after the surge, and any power current that occurs afterward is restricted by the two resistances (shunt resistance and series resistance), which are now connected in series. The arcs in the gaps A to B cannot be maintained by the current, and normal conditions return. Such arresters can be used in situations where the system voltage is less than 33 kV.

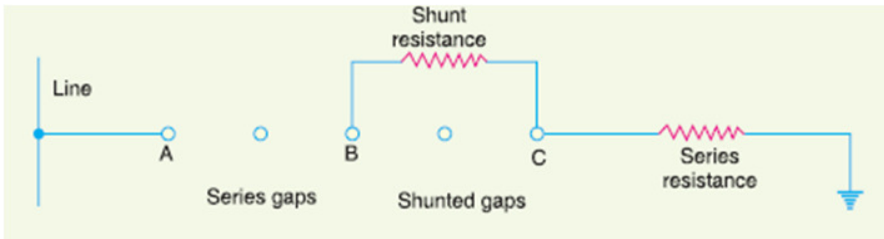

Figure 10: Multigap arrester.

3. **Expulsion-type arresters:**

These arresters, also known as "protector tubes," are frequently utilized on systems that operate at voltages up to 33 kV. The main components of an expulsion type lightning arrester. (i). Basically, it is made up of a rod gap A A′ in sequence with a second gap encased in a fibre tube. Two electrodes create the gap in the fibre tube. The lower electrode is connected to the ground, while the higher electrode is connected to the rod gap. Each line conductor is given its own ejection arrester. The installation of an ejection arrester on an overhead line. (ii). The series gap A A′ is spanned and an arc is produced between the electrodes in the tube when there is an overvoltage on the line. A neutral gas is created when the heat from the arc vaporizes some of the fibre in the tube walls. The gas builds up high pressure in a very brief period of time and is released through the hollow lower electrode. Ionized air from the arc is carried away by the gas as it forcefully exits the tube. Usally, the de-ionizing impact is so severe that the arc terminates at a current zero and cannot be restarted.

4. **Valve type arrester:**

Valve type arresters frequently employed in systems running at high voltages and incorporate non-linear resistors. The various components of a valve-type arrester are depicted in Figure 11 (i). It is made up of two assemblies: series spark gaps in assembly 1 and non-linear resistor discs in assembly 2 made of materials like thyrite or metrosil. The spark gaps are coupled in series with the non-linear components. Both assemblies fit snugly into a porcelain container.

(i) The spark gap is an assemblage of many spark gaps that are identical and are connected in series. Two electrodes with a predetermined gap separation make up each gap. By adding extra resistance components (referred to as grading resistors) across the gaps, the voltage distribution across them is linearized. The series gaps are spaced apart enough to sustain the typical circuit voltage. But an excessive voltage will force the gap to collapse, sending the surge current through the non-linear resistors to the ground.

(ii) The non-linear resistor discs are constructed from an inorganic substance like metrosil or thyrite. The CDs are linked together in a series. When the usual system voltage is applied, the non-linear resistors have the property of providing a high resistance to current flow, but a low resistance to the passage of high-surge currents. In other words, as current through these non-linear parts increases, their resistance falls, and vice versa.

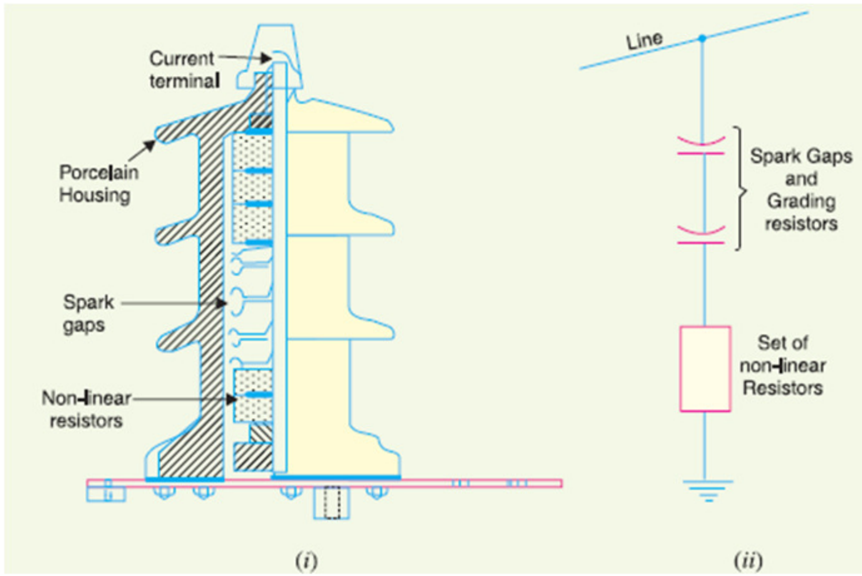

Figure 11: Valve type arrester.

Surge absorber:

The surges' travelling waves that they create on the gearbox lines may harm the terminals' equipment. The severity of the damage relies on both the surge's amplitude and the steepness of its wave front. The equipment was damaged more severely the steeper the wave front of the surge was. Surge absorbers are typically used to lessen the steepness of a surge's wave front. A surge absorber is a safety measure that, by absorbing surge energy, lessens the steepness of a surge's wave front. Although the surge is eliminated by both the surge diverter and the surge absorber, how it is done varies between the two devices. Surge energy is absorbed by the surge absorber while the surge diverter diverts the surge to earth. Here are a few examples of surge absorption:

(i) The line and earth can be linked to a condenser, which can serve as a surge absorber. The transformer winding is protected by a capacitor, which functions as a surge absorber. (i). A condenser's reactance will be low at high frequency and high at low frequency since it is inversely proportional to frequency. The capacitor functions as a short circuit and transmits the high frequency surges directly to ground. However, at power frequencies, the capacitor's reactance is extremely high and essentially no current travels to the ground [10].

(ii) Another type of surge absorber combines resistance and choke in parallel attached in series. The choke (XL = 2 f L) provides a high reactance to surge frequencies. Consequently, the surges are forced. so that they might get past the resistance R and be released there.

(iii). Ferranti surge absorber is its name. It comprises of a line connected in series with an air cored inductor. A dissipator, or earthed metallic sheet, surrounds and insulates the inductor. This configuration is comparable to a transformer with a shorted secondary.

CONCLUSION

In order to prevent potential harm to electrical systems and equipment, protection against overvoltage is crucial. Voltage surges and transients, which are overvoltage occurrences, can cause system failure, component failure, and data loss. The usage of transient voltage suppressors, voltage regulators, and surge protectors are a few of the efficient techniques for overvoltage protection that have been covered in this work. By restraining the voltage at a safe level, transient voltage suppressors can deflect excessive voltage away from delicate components, preventing damage. On the other hand, voltage regulators maintain the input voltage and deliver a constant output, protecting the system against voltage changes. Surge protectors combine numerous protection strategies, including as clamping and filtering, to provide thorough protection.

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CHAPTER 10

POWER SYSTEM AND RELAYING CONSIDERATION: A REVIEW STUDY

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ABSTRACT:

Electrical power systems' stability and dependability can be significantly impacted by power system phenomena such faults, disturbances, and transients. In order to detect and address these events and ensure the safety of the machinery, people, and the entire power system, proper relaying considerations are essential. This chapter examines the major elements to take into account when designing relay protection schemes and provides an overview of significant power system phenomena. The objective is to improve comprehension and judgement when constructing efficient relaying systems. Relays have traditionally been used to safeguard particular machinery, such as motors, generators, lines, and so forth. By doing this, the system gains from the targeted devices being removed when they malfunction, relieving the system of stress and preventing further equipment damage and any subsequent pricey and time-consuming repairs. The system gains from not being compelled into a brief abnormal condition as well.

KEYWORDS:

Islanding, Independent Power Producers, Steady State Stability, Voltage Stability, Transient Stability.

INTRODUCTION

Systems must, of course, be strong enough to resist the removal of any component, but protection settings can only go so far in foreseeing the severity of the stress. Systems can operate past their regularly anticipated limits due to factors including larger than anticipated loads, unusual weather, scheduled or unanticipated equipment breakdowns, or human mistake. Wide-area blackouts caused by these impacts may have negative technical, economic, and social implications. The system phenomena that can cause such disturbances are examined in this chapter [1]–[3]. As was stated in the introduction, the main concern in power system operation is stability, or the loss of it. All (synchronous) spinning machines linked to the power system run at the same average speed and in sync with one another, and the system maintains a frequency that is close to its nominal value at all times. The network is continually experiencing tiny disruptions due to unpredictable variations in load and network setup, but the generator speed governors keep the average machine speed near to its nominal value. Large-scale disruptions, such as extreme oscillations in machine rotor angles and subsequent large swings in power flows, might come from defects on big transmission lines or transformers. Due to the complexity of the machines' behavior in this dynamic domain, it is impractical to apply a single definition of power system stability to all possible power system configurations. It has been discovered that a power system can be classified into three different stability classes. The following are the three definitions of stability.

1. **Steady-State Stability:** A power system has this quality, which allows it to continue running in its current state and means that minor, gradual changes in system loading will result in small changes in the operating point. When subjected to a slow, minor increase in load, a steady-state unstable system will drift away from its operating point and into unsynchronized operation.

2. **Dynamic Stability:** By virtue of this quality, a slight disturbance in the power system results in oscillations that eventually dissipate and allow the system to resume operating as it did before the disruption. An unstable dynamical system generates oscillations that amplify over time and either last indefinitely or result in a continuous, constrained oscillation.

3. **Transient Stability:** With the help of this characteristic, the power system can resume synchronous operation after a significant disturbance, like the one caused by a sustained failure. The failure will cause a transitory unstable system to lose synchronism, with groups of machines accelerating or decelerating in opposition to the synchronous speed. The steady-state stability and transient stability of these three stability concepts are of direct interest in the design of protection systems. The gain and time constant settings of the many controllable devices on the power system, primarily the excitation systems of big generators, have a significant impact on dynamic stability. Only steady-state and transient instabilities and their effects on relaying are covered in this chapter.

Steady state stability: A power system's capacity to keep its equilibrium and function within reasonable bounds under typical operating circumstances is referred to as steady state stability. Given that it guarantees the system's dependability and security, it is a crucial component of power system study and operation. In-depth knowledge of steady state stability, factors impacting it, and techniques for evaluating and improving it are all provided in this article. The capacity of the power system to sustain stable voltages, frequencies, and power flows under typical operating conditions and minor disturbances is the main focus of steady state stability. Changes in load demand, generator output, or transmission line conditions are a few examples of these minor disturbances. Preventing voltage collapse, frequency variations, or cascading failures that could cause extensive blackouts or equipment damage is the goal. A power system's generation capacity, transmission network, load characteristics, and control methods are only a few of the variables that affect the stability of the system. Significant elements influencing steady state stability include:

Power Flow: The harmony between the system's power production and consumption determines its steady state stability. Stable voltages and power flows must be maintained through effective power flow management, which includes load shedding, reactive power control, and voltage regulation.

Generator Capability: For steady state stability, generators must be able to maintain constant voltage and frequency despite changes in load. Automatic voltage regulators (AVRs) and governor controls, among other generator control systems, are crucial for ensuring steady operation.

Transmission System: For steady state stability, the transmission system's ability to manage power flows and maintain acceptable voltage levels is essential. The ability of the system to maintain stable operation can be impacted by transmission line losses, voltage drop, and line impedance.

Load characteristics: Stable steady states can be impacted by the behavior of loads, such as how they respond to changes in voltage and frequency. Certain loads, like motors or powerful industrial machinery, might change the voltage and affect how stable the system is. Numerous analysis techniques and mitigation tactics are used to evaluate and improve steady state stability. Several typical strategies include:

Load flow analysis: Under typical operating conditions, load flow analysis determines the steady state power flows and voltage profiles in a power system. It aids in the detection of potential overloads, voltage irregularities, and areas of concern that might compromise steady state stability.

Stability Limits: Assessing the maximum power transfer capacity of transmission lines, voltage stability margins, and system stability limits are necessary to determine stability limits. This information directs system operation and control within secure operating parameters.

Control of Reactive Power: Maintaining stable voltages and enhancing steady state stability are achieved by effectively managing reactive power through the use of capacitors, voltage regulators, and other reactive power devices. Voltage control, reactive power compensation, and voltage stability analysis are examples of reactive power control approaches.

Generator Control and Coordination: To maintain stable operation and to respond to variations in load demand, generator control systems, including excitation control and governor control, must be coordinated. Stable frequency and voltage profiles are maintained with the help of effective generator coordination.

Continuous monitoring, system planning, and control techniques are necessary to improve steady state stability. Wide-area monitoring systems (WAMS) and sophisticated control algorithms are examples of technological advances that offer additional instruments for enhancing steady state stability. Real-time monitoring, quicker system responses, and improved situational awareness are all made possible by these technologies. Steady state stability is essential for power systems' dependable and secure operation. It guarantees that the system can continue to operate with steady voltages, frequencies, and power flows even when there are minor disruptions and regular operating conditions. Stable state stability is influenced by variables such power flow, generator capability, gearbox system, and load characteristics. Analytical techniques aid in evaluating and enhancing steady state stability, such as load flow analysis and stability limit assessment. System operators can guarantee steady state stability and avoid potential instability or cascading failures in the power system by utilizing efficient control strategies, reactive power management, and coordinated generator control. Technology is always developing, making it easier to monitor and manage the system, increasing steady state stability and the overall dependability of power systems.

DISCUSSION

Transient stability:

The ability of a power system to retain synchronism and recover from significant disruptions, such as faults or abrupt changes in operating circumstances, is referred to as transient stability and is a crucial component of power system analysis and operation. Making sure the system settles into a stable operational condition entails analyzing the dynamic behaviour of the system after a disturbance. This page gives a thorough explanation of transient stability, including its significance, factors that affect it, and techniques for evaluating and improving it. The behaviour of the power system in the few seconds immediately following a disturbance is the focus of transient stability analysis. The system suffers large variations in voltages, currents, and power flows during this period as it responds dynamically to the disturbance. Determine if the system can tolerate these disruptions and retain synchronism, avoiding instability or cascading failures, is the goal of transient stability analysis. A power system's transient stability is influenced by a number of variables. These elements consist of:

Generator and Load Characteristics: A power system's transient stability is influenced by the traits of the generators and loads that are connected to it. Large inertia generators offer stability by absorbing and supplying energy during transient events. Rapid load shifts or loads with high motor starting currents can have an impact on transient stability by bringing about abrupt changes in system dynamics.

Disturbances and Faults: Faults are frequent disturbances that have a major impact on transient stability. Examples of faults include short circuits and line outages. These disruptions produce sharp changes in power flows and have the potential to induce voltage collapses or generator trips. The system's transient stability is significantly influenced by the size and position of the fault.

Control Systems: Transient stability is influenced by the efficiency of control systems, including automated voltage regulators (AVRs) and power system stabilisers (PSS). By altering generator voltages and dampening system oscillations, these control systems react to changes in system circumstances and aid in maintaining stable operation [4]–[6].

System configuration and network topology: The power system network's configuration and topology have an impact on transient stability. By offering additional pathways for power transfer during disturbances, the presence of numerous avenues for power flow, sufficient transmission capacity, and suitable network reconfiguration can improve transient stability.Numerous analysis techniques and mitigation tactics are used in evaluating and improving transient stability. Several typical strategies include:

Transient Stability Analysis: Simulating the power system's dynamic response to a disturbance is known as transient stability analysis. This analysis aids in identifying crucial fault clearance intervals, calculating stability margins, and evaluating the system's resilience to disturbances. These evaluations make use of computer-based simulation tools such transient stability programmes.

Generator and Excitation Control: Maintaining transient stability requires effective generator control, including excitation control and governor reaction. Governors manage the mechanical power input to the generator, whereas excitation systems control the generator's terminal voltage. Coordinated control strategies guarantee that generators react to disturbances appropriately and aid in restoring system stability.

A thorough comprehension of the power system's dynamic behavior, coordinated control methods, and suitable system design are necessary for improving transient stability. Wide-area monitoring systems (WAMS) and real-time control systems are examples of cutting-edge technology that offer useful tools for maintaining transient stability in massive, interconnected power systems. Transient stability is crucial for the dependable and secure functioning of power systems, to sum up. It entails monitoring the system's transition into a stable operational state and analyzing the dynamic reaction of the system to disturbances. Operators can evaluate and improve transient stability by taking into account elements including generator and load characteristics, faults and disturbances, control systems, and system configuration. The power system can absorb disturbances and continue to run steadily, avoiding potential instability or cascading failures, thanks to transient stability analysis, efficient generator management, fault clearing, dynamic reactive power regulation, and power system stabilisers. The overall dependability and resilience of power systems are being improved by ongoing improvements in simulation tools and monitoring technologies, which further improve the capability to detect and manage transient stability.

Voltage stability: The capacity of a power system to sustain acceptable voltage levels under typical operating settings and changing system conditions is known as voltage stability, and it is a crucial component of power system analysis and operation. It is necessary to guarantee the efficient and dependable distribution of electricity to consumers. This page offers a thorough explanation of voltage stability, including its significance, factors that affect it, and techniques for evaluating and improving it. Maintaining appropriate voltage magnitudes and minimizing voltage fluctuations within acceptable bounds are the major goals of voltage stability. Voltage magnitudes can drastically diverge from the desired values when voltage stability is lost, which can cause a number of operational problems, equipment damage, and even a system-wide voltage collapse. There are several analysis techniques and mitigation tactics that go into evaluating and improving voltage stability. Several typical strategies include:

Voltage Stability Analysis: Under various operating situations, the system's ability to sustain appropriate voltage levels is assessed using voltage stability analysis. To pinpoint crucial voltage levels and potential voltage collapse scenarios, it also contains load flow analysis, voltage stability margin calculations, and sensitivity analysis.

Control of Reactive Power: For voltage stability, reactive power must be managed properly. Voltage control, reactive power compensation, and capacitor banks are examples of reactive power control systems that assist in regulating voltage levels and enhancing voltage stability.

Devices for Voltage Regulation: Voltage regulators, tap changers, and other voltage control devices help maintain stability and control voltage levels. To keep appropriate voltage profiles, these devices modify the taps on the transformer windings or inject reactive power.

Load Shedding: As a last resort, load shedding can be used to restore system stability when voltage stability is seriously threatened. In order to balance generation and demand and prevent a voltage breakdown throughout the whole system, load shedding entails deliberately disconnecting some loads.

A thorough understanding of the features, load needs, and control mechanisms of the power system is necessary to improve voltage stability. Wide-area monitoring systems (WAMS) and real-time voltage control systems are examples of cutting-edge technology that offer useful tools for maintaining voltage stability in massive, interconnected power systems. Power systems' ability to operate dependably and effectively depends on voltage stability. Maintaining appropriate voltage magnitudes and reducing voltage fluctuations are required. Operators can evaluate and improve voltage stability by taking into account elements including load characteristics, reactive power management, transmission and distribution network impedance, and generator capability. Power systems can maintain stable voltage levels, avoid voltage collapse, and guarantee dependable power delivery to consumers using voltage stability analysis, reactive power control, voltage regulation devices, and load shedding techniques. The ability to measure and regulate voltage stability is continually improved by improvements in simulation tools and monitoring technologies, which also boost the overall dependability and resilience of power systems.

Dynamics of system frequency: When referring to fluctuations in a power system's total frequency brought on by imbalances between generation and load, we use the term "system frequency dynamics." Since it directly impacts the functionality of electric appliances and machinery connected to the power grid, maintaining a constant frequency is crucial. The dynamics of system frequency, the causes of frequency deviations, and the controls used to preserve frequency stability are all covered in this article. The equilibrium between generation and load in a power system affects the system frequency. A steady-state frequency is produced when the total generation and total load are equal during normal operation. However, frequency variations can result from any mismatch between generation and load.

Governor Controls: Each generator in a power system has a governor control system, which modifies the mechanical power input to the generator in response to frequency variations. In response to frequency variations, governor controls automatically adjust the generator's output in order to bring the frequency back within acceptable bounds [7]–[9].

Automatic Generation Control (AGC): In reaction to frequency variations, AGC is a centralized control technique that coordinates the output of several generators. To maintain frequency stability, it continuously checks the system frequency and modifies the generating set points of individual units.

Load Shedding: As a last option, load shedding may be used when frequency irregularities cannot be remedied by generation management. In order to balance the generation and load again and bring the frequency back within tolerable bounds, load shedding entails selectively disconnecting some loads.

Interconnection and Grid Support: Support from Neighbouring Grids during Frequency Deviations, Power Systems Connected to Neighbouring Systems can benefit from Neighbouring Grid Support. Frequency stability can be restored through interconnection, which allows surplus generation from one system to be transported to support the weaker system.

Modern control and monitoring systems are used to monitor and control the dynamics of system frequency in real-time. Wide-area monitoring systems (WAMS) and phasor measurement units (PMUs) provide real-time data on system frequency and enable quicker response and control actions. In a power system, the balance between generation and load has an impact on the dynamics of system frequency. Frequency variances are influenced by load changes, generation capacity, loss of generation, and frequency control methods. Operators make sure that the balance of generation and load is maintained in order to preserve frequency stability using governor controls, AGC, load shedding, and grid assistance. In order to ensure the dependable and stable functioning of power systems, advanced control and monitoring systems are essential for real-time monitoring and control of system frequency.

Independent power producers: Independent Power Producers (IPPs) are unaffiliated businesses or organizations that produce power and sell it to end users, businesses, or utilities. IPPs only concentrate on power generating, in contrast to traditional utility companies that own and manage infrastructure for power generation, transmission, and distribution. IPPs contribute significantly to the power sector by fostering private sector involvement, boosting competition, and varying the sources of electricity generation. By utilizing a variety of technologies, including thermal power plants, renewable energy projects (solar, wind, hydro, etc.), and combined heat and power (CHP) facilities, they contribute to the overall energy mix [10].

Independent Power Producers (IPPs) are private organizations that concentrate on producing electricity and help to diversify the energy mix. They encourage competition, draw in funding, use cutting-edge technology, and assist regional growth. But for IPPs to operate successfully and reap their benefits in the power industry, a supportive regulatory climate, addressing grid integration issues, and managing financial and environmental risks are crucial.

Islanding: When the primary power grid experiences an outage or is purposefully removed, a distributed power generating source, such as a solar photovoltaic (PV) system or a wind turbine, continues to provide electricity to a local area. This circumstance is referred to as islanding. To put it another way, it happens when a section of the electrical system functions as an island by itself while still receiving power from a nearby distributed generation source. The distributed generating source synchronizes its output with the grid voltage and frequency during typical grid-connected operation. It serves as an additional power source and depends on the reliability of the grid. Traditional grid-tied systems, on the other hand, are made to cut off from the grid in the case of an outage or other grid disturbance in order to protect utility personnel and stop electricity from being fed back into a possibly damaged grid. Islanding can happen accidentally or on purpose. Unintentional islanding happens when the local area is still powered up and receiving power from the distributed generation system despite the main grid's interruption. The risks to utility personnel trying to repair the grid and the potential for electrical safety problems make this situation potentially perilous. Grid-tied inverters used in distributed generation systems have anti-islanding protection features to overcome this problem. The voltage and frequency of the grid are continuously monitored by these devices. The inverter will cut off from the grid if a problem is found, such as a loss of grid power or frequency deviation, to avoid unintended islanding. In order to guarantee the secure and dependable operation of distributed generation systems, this safety element is mandated by grid interconnection requirements.

Blackouts and restoration: Blackouts are the total loss of electrical power in a specific location or throughout a power system. They can happen as a result of a variety of things, such as defective equipment, harsh weather, natural disasters, human error, or deliberate activities. Power restoration becomes a major priority after a blackout to lessen disruption and inconvenience for customers, companies, and critical services. An overview of blackouts and the recovery procedure is given in this article. A blackout results in the loss of energy because the power supply to residences, businesses, and infrastructure is disrupted. Blackouts can be short-lived interruptions or long-lasting outages that linger for hours or even days. The size of the affected area, the reason for the outage, and the accessibility of backup power sources all affect how severe and disruptive a blackout is. Blackouts are interruptions in the provision of electrical power that can happen for a variety of reasons. In order to restore service, a problem must be located, damaged equipment must be repaired, restoration efforts must be prioritized, efforts must be coordinated, the restored system must be tested, and the reason of the blackout must be determined. Investing in infrastructure, taking redundancy precautions, utilizing smart grid technology, and being prepared for emergencies all play crucial roles in reducing the effects of blackouts and speeding up the restoration of power.

CONCLUSION

Phenomena in the power system can come from a number of things, such as faults, disturbances, and transients. Designing effective and dependable relay protection strategies requires a thorough understanding of these phenomena and their properties. Relaying engineers can create efficient protection plans by taking into account elements including fault types, fault locations, fault currents, system stability, and equipment protection needs. In order to provide quick and accurate problem detection, isolation, and system restoration, this also entails choosing the proper relay devices, configuring relay parameters, and coordinating relays. Additionally, there are chances to improve the performance and adaptability of relaying systems thanks to ongoing developments in relay technology, such as microprocessor-based relays and intelligent algorithms. Maintaining current with the most recent relaying techniques and standards is essential for assuring the safety, stability, and effectiveness of electrical power systems as they develop and face new difficulties. Power system operators and protection engineers can reduce risks, increase system reliability, and effectively address power system phenomena by focusing on suitable relaying considerations.

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CHAPTER 11

PROTECTING THE COMPONENTS OF THE POWER SYSTEM: A COMPREHENSIVE REVIEW

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ABSTRACT:

Protecting the components of the power system is the typical objective of protective devices. This is accomplished by identifying a problem or unsatisfactory behaviour and taking corrective action, which typically entails tripping the relevant circuit breakers. Therefore, it is possible to argue that relays' main function is to separate equipment or subsystems from the main power supply. Relaying is essential for maintaining the efficiency and dependability of electricity systems. It entails fault isolation and detection, equipment protection, and system operation coordination. This chapter addresses various relaying strategies and technologies as well as the significance of relaying for system performance. It also talks about the difficulties and potential developments in relaying for system performance improvement.

KEYWORDS:

Adaptive Relaying, Loss of Field Relaying, Out of Step Relaying, Under Voltage Load Shedding.

INTRODUCTION

Usually, this is the right course of action. Systems are made to be strong, so that they can survive the removal of one or more components without putting the system as a whole under undue stress. Recognizing that the power system's built-in intrinsic strength serves as the best barrier against catastrophic breakdowns is a good idea. However, this corrective approach may compound the problem and lead to widespread outages if the system is already under stress for any cause, such as equipment failures, larger than usual loads, extreme weather, etc. goes into great length about the situation that would lead to a stressed system that may eventually have a blackout. In this chapter, we'll talk about the precise relay operations that are intended to prevent or reduce these disruptions [1]–[3]. The reader should be aware that these schemes are active, practical, and worth studying, but it is outside the scope of this book to go into detail about each one. The following, however, discusses some of the more well-known designs.

Under frequency load shedding:

During a considerable reduction in system frequency, under frequency load shedding is a control mechanism used in power systems to preserve stability and avert collapse. To match the decreased generation and restore the balance between supply and demand, a portion of the load must be shed. Under frequency load shedding will be explained in general, along with its goals, methods, and issues. An interconnected power system's frequency normally fluctuates around a nominal value, which is commonly 50 or 60 Hz depending on the location, during normal operation. The equilibrium between the overall system load and the generation capacity directly affects frequency. The frequency may fluctuate from its nominal value if there is a supply and demand imbalance. The balance is upset and the system frequency decreases when there is a sudden loss of generation capacity or a sharp rise in load. This decrease in frequency has an impact on how well electrical devices work, can cause voltage instability, and, if it is not corrected right away, may cause an extensive blackout.

Under-frequency load shedding has the following goals:

System Stability: Upholding the stability of the power system is the major goal of under frequency load shedding. The supply-demand balance is restored by reducing some of the load, and the frequency can return to a stable range, preventing the system from collapsing.

Voltage Stability: It's essential to keep the system's frequency within reasonable bounds in order to maintain voltage stability. A considerable decrease in frequency might result in under-voltage situations, which can harm equipment and impair the performance of associated loads.

System Reliability: By eliminating cascading failures and lowering the possibility of a total blackout, under frequency load shedding contributes to the overall reliability of the power system. Essential services can be given higher priority by shedding non-critical loads, reducing the strain on key infrastructure and preserving the availability of such services. There are numerous processes involved in the execution of under frequency load shedding:

System monitoring: To identify a large decline below the predetermined threshold, real-time system frequency monitoring is crucial. System frequency is continuously measured and monitored by frequency monitoring devices, such as frequency relays and phasor measurement units (PMUs).

Setting of Frequency Threshold: Based on the operating needs of the system and the capacity of the generation and load-shedding resources, a fixed frequency threshold is set. The threshold is often set a little bit above the point at which the system begins to exhibit stability problems.

Design of a Load Shedding Scheme: Load shedding schemes are created to shed non-critical loads in a planned and organized way. These plans are created based on system characteristics, load prioritization, and the resources that can be used for load shedding. Load shedding can be implemented using either automatic or manual processes.

Sequence of Load Shedding: To ensure a systematic load reduction, load shedding operations are carried out in a set order. Normally, non-essential loads are first removed, then lower priority loads, with vital loads and essential services being given priority.

Load Restoration: Load restoration is started in a regulated manner after the frequency has recovered and stabilized. Following a predetermined order, the load is gradually restored during the restoration procedure in order to prevent unexpected frequency disruptions.

In order to keep power systems stable during severe frequency drops, under frequency load shedding is a crucial control measure. By reducing non-essential loads, the supply-demand equation is once again balanced, preventing system failure and maintaining voltage and stability. Effective load shedding and restoration depend on proper system monitoring, threshold setting, load shedding scheme design, prioritization, and coordination. Implementing under frequency load shedding reduces the possibility of extensive blackouts and maintains the provision of vital services while also ensuring the stability and dependability of power systems.

DISCUSSION

Under voltage load shedding:

A safeguard used in power systems to preserve voltage stability during times of low voltage is known as under voltage load shedding. In order to lower the total demand and balance it with the available supply, it entails strategically shedding loads. Under voltage load shedding is described in this article along with its goals, methods, and issues. Voltage levels in a power system are kept within predetermined bounds to guarantee the proper operation of electrical equipment. Voltage is comparatively steady when working normally. A major reduction in voltage, however, might result from situations like a generator trip, transmission line defects, or an unexpected surge in demand. There are a number of problems that can arise when the system voltage drops below a set threshold, including a lack of voltage for optimal equipment functioning, an increase in the demand for reactive power, and voltage instability. For the purpose of reducing these issues and preserving voltage stability, load shedding is used under voltage. The following are the goals of under voltage load shedding:

Voltage Stability: Keeping voltage stability within allowable bounds is the major goal. By reducing demand by shedding a portion of the load, the system voltage can be more closely matched by the available generation capacity.

Protection of Equipment: Low voltage can cause voltage-dependent equipment to malfunction, overheat, and perhaps be damaged. Load shedding shields delicate electronics from working under unfavorable voltage settings and helps prevent equipment breakdowns.

System Reliability: Under voltage load shedding contributes to maintaining the dependability of the power system by shedding non-critical loads. It lessens the possibility of a widespread voltage collapse or blackout by preventing voltage instability from spreading to other system components.

The following actions are required to implement under voltage load shedding:

Voltage Monitoring: To identify a large drop below the predetermined threshold, real-time system voltage monitoring is crucial. System voltage is continuously measured and monitored by voltage monitoring devices like Phasor Measurement Units (PMUs) or voltage relays.

Voltage Threshold Setting: Based on system needs, equipment limitations, and the resources that can be used for load shedding, a fixed voltage threshold is set. The threshold is often set a little bit above the point at which voltage-sensitive equipment begins to exhibit stability problems.

Design of a Load Shedding Scheme: Load shedding schemes are created to shed loads in a planned and orderly fashion. While keeping critical loads and important services operational, these plans give the shedding of non-critical loads priority. The scheme's design takes into account system stability, available shedding resources, and load prioritization [4]–[6].

Schedule of Load Shedding: To achieve a balanced load reduction and lessen the impact on essential loads, a predetermined schedule of load shedding is used. The shedding sequence could take system needs, load characteristics, and load priority into account.

Load restoration: Load restoration is started as soon as the voltage has returned and stabilized. Following a predetermined order, the load is progressively added back during the restoration process in order to prevent unexpected voltage fluctuations and preserve system stability.

To sum up, under voltage load shedding is a safeguard used in power systems to keep voltage stability during low voltage times. Under voltage conditions can be reduced by selectively shedding loads, assuring the proper operation of machinery and reducing the chance of voltage collapse. Effective load shedding and restoration depend on accurate voltage monitoring, threshold setting, load shedding scheme design, prioritization, and coordination. By protecting equipment and preserving voltage stability for the efficient functioning of electrical systems, under voltage load shedding is implemented to help assure the reliability and stability of power systems.

Out of step relaying: A protective method used in power systems to identify and reduce the occurrence of out-of-step circumstances is called out-of-step relaying. When there is a loss of synchronism between various components of the power system, usually brought on by disturbances such unexpected changes in load, faults, or generator tripping, an out-of-step state develops. Out-of-step relaying is discussed in this article along with its goals, methods, and issues. Out-of-step relaying's major goal is to identify synchronization loss and implement the necessary corrective actions to preserve the stability and integrity of the power system. The relaying technique aids in preventing additional disturbances like cascade failures, voltage collapse, or system-wide blackouts by identifying and isolating out-of-step occurrences. The following essential components are necessary for out-of-step relaying to be implemented:

Synchronism Monitoring: To identify the occurrence of out-of-synch circumstances, real-time monitoring of the system's synchronous operation is crucial. To evaluate the synchronism of various system components, variables such generator rotor angles, frequency deviations, and voltage phasors are continuously measured and monitored.

Algorithms for Detecting Out-of-Step: Out-of-step detection algorithms examine the monitored parameters to find departures from synchronous operation as a whole. These algorithms use a variety of methods to identify the loss of synchronism, including rate-of-change-of-frequency (ROCOF), vector analysis, and impedance-based approaches.

Relay Operation and Trip Signals: The relay activates and sends a trip signal to the connected circuit breaker or protection device when an out-of-phase condition is detected. The trip signal starts isolating the afflicted area of the power system, which lowers the danger of future damage and stops disturbances from spreading. Following are some factors to take into account when relaying out of step:

Coordination and Settings: Out-of-step relays must be properly coordinated with other protective relays and system components. Coordination and settings. The coordination makes sure the out-of-synch relays work selectively and in concert with other protection methods to reduce unwanted tripping and guarantee the effective restoration of the system.

System Modeling and Parameters: Effective out-of-step relaying depends on accurate modelling of the power system, which includes generators, transmission lines, and loads. To achieve dependable and accurate detection, relay settings and thresholds must be properly calibrated depending on system characteristics and factors.

Communication and Data flow: Communication systems and protocols are essential for simplifying information flow among various relays, command centres, and security measures. The effectiveness of out-of-step protection is increased by timely and precise data interchange, which enables coordinated measures.

Dynamic Stability Assessment: Out-of-step relaying and the power system's dynamic stability are intimately related, according to the dynamic stability assessment. Effective out-of-step protection requires ongoing monitoring and evaluation of the system's dynamic stability, including generator rotor angles, power flows, and transient responses. In order to identify and reduce the incidence of out-of-step circumstances, out-of-step relaying is a crucial protective mechanism used in power systems. Out-of-step relays give accurate and selective tripping signals to isolate problematic parts and stop future disruptions by monitoring system synchronism and using the right detection algorithms. Effective out-of-step relaying and the overall stability and reliability of the power system depend on proper coordination, system modelling, communication, and dynamic stability evaluation.

Loss of field relaying:

A specialized protection method used in electrical power systems to identify and react to a loss of excitation in a synchronous generator is known as loss of field relaying, also known as field failure protection. A voltage regulator problem, a field winding breakdown, or severe system disturbances are only a few causes of excitation loss. This page gives a general overview of loss of field relaying, including its goals, methods, and issues to take into account. The basic goal of loss of field relaying is to identify when a synchronous generator loses excitation and to start protective measures to stop damage to the generator and maintain system stability. Loss of excitation can cause the power system to become potentially unstable, significantly lower generator output voltage, and loss of synchronization. The goal of the loss of field relaying technique is to quickly identify this situation and isolate the troubled generator from the rest of the system. The following essential components are necessary for loss of field relaying implementation:

Excitation Monitoring: To identify any abnormal situations, it is essential to continuously monitor the excitation system and generator field current. Field current is continuously measured and monitored by excitation monitoring devices, such as voltage regulators or field current relays, to determine the amount of excitation.

Algorithms for Detecting Field Loss: Field current measurements are analyzed by loss of field detection algorithms, who then compare them to reference or threshold values that have been set in advance. In order to recognize a considerable decrease in the field current suggestive of a loss of excitation condition, these algorithms may combine techniques like rate-of-change-of-field current (ROCOF) or voltage/frequency deviation analysis.

Relay Operation and preventive Actions: The loss of field relay activates and starts taking preventive measures when a loss of field condition is identified. In order to stop further damage and ensure system stability, these procedures often involve tripping the generator breaker to isolate the damaged generator from the system.

The following factors in loss of field relaying include:

Coordination and Settings: To ensure effective operation and prevent unneeded tripping, loss of field relays should be properly coordinated with other protective relays and system components. To ensure dependable and selective protection, relay settings, such as thresholds and time delays, need to be properly calibrated based on the generator and system parameters.

System Response and Stability: Loss of field conditions can have a significant impact on the functioning and response of the system. To minimize the influence on the overall system stability, the loss of field relaying scheme response should be quick and coordinated with other protective devices. The effect of losing field protection on voltage stability and the capacity to synchronize the generator back into the system after restoration should be taken into account.

Excitation System Monitoring and Maintenance: It is essential to regularly monitor and maintain the excitation system, which includes the voltage regulator, field winding, and related hardware, in order to avoid or quickly identify any potential problems that could result in excitation loss. The reliability and effectiveness of the loss of field relaying scheme are ensured through proper maintenance procedures and routine testing of the excitation system's components [7]–[9].

Loss of field relaying is a specialized protection method created to identify and react to a synchronous generator's loss of excitation state. Loss of field relays offer quick and selective tripping signals to disconnect the damaged generator from the system, preventing additional damage and maintaining system stability. They do this by monitoring the field current and using detecting algorithms. For loss of field relaying to work well and to guarantee the steady operation of power systems, good coordination, system monitoring, and maintenance procedures are essential.

Adaptive relaying:

An advanced power system safety concept called adaptive relaying uses clever algorithms and methodologies to dynamically change the settings and parameters of protective relays in response to actual system conditions. By adjusting to shifting system dynamics, varying operating conditions, and various disturbance kinds, adaptive relaying aims to improve the performance, dependability, and selectivity of protection schemes. Traditional protective relays are frequently built with predefined operating parameters. These settings may not always be ideal, despite being carefully selected based on system factors and anticipated operating conditions. This constraint is overcome by adaptive relaying, which adjusts relay settings after continuously monitoring and analyzing system parameters. Adaptive relaying's primary goal is to increase the precision and efficiency of fault detection, discrimination, and fault clearing. Adaptive relaying techniques successfully handle shifting system conditions, such as fluctuating fault impedance, shifting system topology, and various failure kinds, by adjusting the relay parameters in real-time. As a result, the power system becomes more reliable overall thanks to improved problem identification, decreased disoperation rates, increased system stability, and quicker fault clearance. Adaptive relaying implementation comprises a number of crucial components. First and foremost, it is crucial to gather real-time data from multiple sources within the power system. This comprises readings from current and voltage sensors, PMUs, digital relays, and other monitoring tools.

The availability of synchronized, high-quality data is essential for precise analysis and decision-making. Furthermore, adaptive relaying algorithms use sophisticated estimating methods to continuously evaluate crucial system parameters. These metrics include fault location, fault kind, system impedance, fault impedance, and other pertinent data. These estimates are utilized to adjust relay settings and decision criteria and are updated in real-time based on the data obtained. Thirdly, adaptive relaying algorithms analyses the obtained data, estimate system characteristics, and reach the best relay operation options by utilizing advanced decision-making processes. In order to adaptively modify relay settings based on historical data, system models, and real-time measurements, these algorithms frequently combine machine learning, artificial intelligence, and statistical methodologies. Adaptive relaying implementation involves a number of factors. First, the effectiveness of the relaying system is significantly influenced by the choice and creation of adaptive algorithms. To guarantee reliable and precise performance under a variety of system settings, the algorithms must be thoroughly created and evaluated. Second, coordination and communication among relays, command centres, and other safety measures are crucial. To adaptively update relay settings and provide proper system-wide protection, coordination and timely information sharing between various relays are required. Adaptive relaying's cybersecurity implications should also be taken into account. To safeguard the relaying system from potential cyber threats and attacks, it is necessary to implement strong security measures due to the increased reliance on data collecting, communication, and computing algorithms. Adaptive relaying, a cutting-edge idea in power system safety, aims to improve the effectiveness and dependability of protective relays by constantly modifying their settings in response to real-time system conditions.

Adaptive relaying schemes can adaptively alter relay settings by continuously monitoring and analyzing system data. As a result, fault detection is improved, disoperation rates are decreased, system stability is increased, and fault clearance is completed more quickly. Advanced algorithms, real-time data collecting, estimating methods, and decision-making algorithms are all used in the implementation of adaptive relaying, in addition to factors like communication, coordination, and cybersecurity. In the face of dynamic and shifting operational conditions, adaptive relaying has the potential to significantly improve the dependability and effectiveness of power system protection [10].

CONCLUSION

Maintaining the efficiency and dependability of power systems requires relaying. Relaying safeguards equipment, minimizes damage, and lessens the effects of disruptions on the system and its users by quickly recognizing and isolating errors. In order to improve system performance, numerous relaying methods and technologies, including as distance relays, differential relays, and adaptive relaying systems, have been created. Relay coordination is necessary for the system to operate correctly and remain stable. In order to isolate faults and restore service while minimizing unneeded tripping and disturbances, coordinated relaying schemes allow the selective functioning of relays depending on predetermined parameters and coordination durations. Relaying for system performance will increasingly incorporate cutting-edge technology, such as wide-area monitoring systems (WAMS) and phasor measurement units (PMUs), to enhance fault detection and system monitoring. Another interesting trend is the use of intelligent relays, which can adapt and self-adjust their settings based on fault characteristics and system conditions. Relaying is essential for preserving the efficiency and dependability of electricity systems, to sum up. Relaying ensures the smooth running of the system and the protection of equipment through fault isolation, coordination, and fault detection. The performance and resilience of power systems will be further improved by overcoming the difficulties and adopting upcoming advances in relaying technologies, allowing them to meet the increasing needs of the contemporary energy landscape.

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CHAPTER 12

AN OVERVIEW ON SWITCHING SCHEMES AND PROCEDURES

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ABSTRACT:

The operation and maintenance of power systems include switching schemes and practises. To ensure the safe and dependable operation of power systems, they require the planning, coordinating, and execution of switching operations. An overview of switching procedures and schemes, including their goals, methods, and factors, is given in this article. It discusses several switching techniques, including busbar switching, transformer switching, and line switching, as well as the protocols and safety precautions that go along with each. The necessity of adhering to pertinent rules and norms is stressed, along with the significance of good planning, coordination, and communication in switching operations. The necessity of strong switching schemes and procedures in preserving the integrity and stability of power systems is highlighted in the article's conclusion.

KEYWORDS:

Breaker, Relaying, Computer Programme, Relay Setting, Monitoring, Periodic Test, Reclosing.

INTRODUCTION

We have discussed the interaction between protective relays on both individual pieces of equipment and entire systems so far in this book. We must also talk about the ancillary disciplines related to power system relaying in order to comprehend the whole range of protective devices. The protection-related elements that must be considered when creating or implementing a protective scheme are covered in this chapter. These include topics like testing, computer programmes for configuring relays, and related schemes like breaker failure, reclosing, and single-phase breaker operation that are neither relays or relay applications in and of themselves but are nonetheless important to take into account [1]–[3].

Relay testing: The most crucial characteristic of a protective relay and relay systems is relay reliability, which has the twin features of dependability and security. Relays may hold the rare distinction of being the only piece of equipment in a power system that is constructed and designed with the hopes that it never needs to operate, despite this requirement. In fact, for the course of a given relay's lifespan, which could be 40 or 50 years, it might never be required to respond to the circumstances for which it was installed, or if it does, it might perform flawlessly in a matter of milliseconds. Therefore, it is not surprising that there is ongoing worry that a relay might not be prepared to complete its task at the needed time and with the necessary speed. As a result, it is widely acknowledged that protective relays need to undergo routine testing and maintenance. Ironically, however, testing, calibrating, and other maintenance only serve to demonstrate that the relay would have performed its function up until the time it was tested for practically all of the relays currently in use. Of course, there is no assurance that this situation would persist after the relay is put back in service. In reality, it happens frequently that testing itself can leave the relay in a deteriorated state that is not noticed. It cannot be emphasised enough that excessive testing is just as bad as, if not worse than, insufficient testing.

Therefore, whatever tests are carried out, they must be clearly constrained to what has to be validated.

New relay design: Testing a new design or a prototype of a new relaying concept is not what we are worried with here. Such testing necessitates in-depth research and simulations, frequently involving real short circuits on a functioning power supply. Designing a relay to function under specific circumstances, or proving its dependability, is not too difficult. Designing an is much more challenging. Relay must be secure in order to not function under any of the other circumstances to which it will be subjected while in use. High voltages or high temperatures may typically be replicated in laboratories both currents, but not both at once. The majority of the time, the lab's equipment lacks the required power rating. The typical switching, fault initiation, and clearing transient voltages and currents on the primary system are also so varied and site-specific that it is nearly impossible to duplicate them in a laboratory setting or to model them accurately.

Acceptance and commissioning test during initial installation:

A comprehensive visual check should be part of the initial commissioning tests to ensure that the relay was not physically harmed during transportation. Make primary circuit tests by injecting current into the transducers from a low-voltage source, such as 230V and 30 A, when the relay is connected to its current and/or voltage transformers. This should be a variable source with enough current capacity to verify the connections' polarities but not to imitate a fault current. The relay(s) are then connected in accordance with the designs after thorough secondary wiring tests. The first calibration and configuration should then be finished. Naturally, manufacturers' advisories offer useful information on the individual relays being tested and should be strictly complied with When the relay is received by several utilities, thorough inspections are done before the relay is brought to the station. Regardless of the results of the laboratory examinations, the relay must be installed for the final checks.

Periodic test:

Calibration, general mechanical and electrical characteristics, and the trip circuit's circuit continuity are all periodically tested. Periodic relay testing has traditionally been the outcome of knowledge gained from electromechanical relays. The increasing experience with solid-state and digital relays is gradually changing these test methods and practises. Environmental conditions that may not affect solid-state or digital relays can cause electromechanical relays to fail. Potential defects that can affect a relay's performance include ageing, which changes a component's characteristic or value, wear and binding of bearings due to temperature changes, dirt on discs and cups that affects their operating time, and oxides that form on contacts and increase their resistance and prevent circuit continuity. Due to these failure scenarios and the fact that the majority of these flaws cannot be found when the relay is operating, many test procedures demand that the relay be removed from its container for inspection and that parts of the device may need to be disassembled for cleaning and adjusting. The relay needs to be put back in its case on the switchboard panel for the final calibration and trip tests after the preliminary inspections and bench tests are finished. This is crucial, especially when dealing with electromechanical relays, whose performance is impacted by alignment, balancing, and shielding. All relay manufacturers offer internal test capabilities, such as a movable test block or switches, to aid in testing the relay while it is installed. These distinguish the relay's internal components from its external wire. Then, the tester needs to reattach those elements that need to be tested using jumpers or switches that are already connected. To check settings or directionality, for instance, current and voltage coils can be reconnected, leaving the connections cut off so that the relay won't trigger the circuit breaker when it operates. A three-phase relay can have one of its phases tested in this testing facility while the other two remain in use. The testing requirements have changed dramatically as a result of the increased use of solid-state relays. Physical concerns like alignment and dirt are no longer a concern, but ageing, temperature effects, and electrical degeneration still pose a threat. However, compared to their electromechanical equivalents, solid-state relays provide far more constant monitoring of internal voltages and logic status.

During a defect or test, indicator lights activated by internal relay elements can track the logic flow and give a good indication of potential issues. Additionally, trip cutout switches are offered in functional testing facilities so the relay can be tested in service without triggering the circuit breaker. As a result, the time and effort needed to conduct periodic tests is being considerably decreased while the intervals between tests are being increased. The digital relay introduces an entirely new level of routine calibration and testing. Periodic tests can be all but removed because the digital relay can totally and continuously self-check itself. The digital relay can report if it is (or is not) running correctly because it is constantly performing calculations and making decisions, and typically there is no malfunction and no action is necessary. The relay might then only be maintained when a problem is apparent.

Monitoring:

Automatic oscillography are the method most frequently used to assess the performance of protective relays, especially with electromechanical relays where it is impossible to monitor the internal relay components. It's interesting to note that this monitoring has not decreased despite the growing popularity of solid-state and digital relays. In actuality, the reverse has happened. Oscillography make it possible to monitor a much wider range of the protective system, including the coordination of various relays, communication lines, and circuit breakers [4]–[6].

DISCUSSION

Computer programme for relay setting:

The most important operating factor for any protective system is the relay settings. Every relay has a setting philosophy that is particular to its design and function within a particular protection system, as has been covered throughout this book. Some relays require relatively straightforward calculations for their settings, such as zone 1 of a mho-type relay, which just needs to know the impedance of the line being protected and the values of the potential and current transformers (CTs). Single-input time-delay overcurrent (TDOC) relays, in comparison, require significantly more intricate computations since they must take into account various fault currents, system setups, and the performance of other relays with which they must communicate. This is not a simple task and calls for combining a large number of different research as well as paying close attention to system and load changes. Computers were more accessible to individual engineers as they evolved from mainframe to mini and microcomputers. They were obvious candidates for relay situations because of their capacity for managing a plethora of data, doing calculations, and adhering to limitations and logical directions. The initial computer programmes focused on the issue of coordinating TDOC relays at lower voltage levels, but over time, computer programmes started to address the complete protective system at a given voltage level or in a certain area. The computer's capacity to access multiple independent programmes and aggregate their results in a relay-setting programme is one aspect that contributes to its acceptance as a significant calculating and decision-making tool.

For instance, load flows are created on a regular basis for operational and planning purposes. It is now feasible to prevent relay misoperations when the relay's load ability is exceeded by fusing the findings of those research with a file of relay settings. Similar to this, short-circuit studies that are updated as a result of system modifications can instantly confirm relay settings or recommend adjustments. It is theoretically possible, but not very likely in the near future, for digital relays to have their relay settings automatically updated as load-flow and short-circuit studies are finished. Digital relays also have the capacity to be remotely accessed. The amount of engineering judgement that goes into each relay-setting choice accounts in part for the reluctance to fully accept computer-generated settings without some control by the relay engineer. The worry of malevolent hackers gaining access to relay programmes and causing harm to the power grid is another issue with remote accessibility of computer relays that is being considered by relay engineers. This will undoubtedly be a significant topic for discussion and the creation of defences against hacker attacks in the upcoming years.

Breaker failure relaying:

Circuit breakers that fail to work during disturbances are detected and handled using a protection method called "breaker failure relaying" in electrical power systems. Breaker failure can be caused by a number of things, including mechanical problems, problems with the control circuit, and communication problems. An overview of breaker failure relaying, including its goals, methods, and issues, is given in this article. The main goal of breaker failure relaying is to quickly identify when a circuit breaker has failed to resolve a fault and to start further protective measures to isolate the affected area of the electrical system. The protective relays connected to the damaged circuit should trigger a trip signal to the related circuit breaker when a fault arises in order to fix it. The breaker failure relay recognises this scenario and takes appropriate action to stop a lengthy fault duration and potential equipment damage if the breaker does not operate within a predetermined amount of time. Several essential components are required for the installation of breaker failure relaying:

Circuit breaker status and related protection signals are continuously monitored by breaker failure relays, which also detect breaker failure. They contrast the trip signal sent by the protective relays with the anticipated circuit breaker operation time. The breaker failure relay notices a failure if the circuit breaker does not activate within the allotted period.

Trip Signal Monitoring: Breaker failure relays additionally keep an eye on the trip signals that the protective relays connected to the effected circuit send out. They make that the protection relays are operating properly and that the trip signals are reliable. The breaker failure detection can be triggered by any irregularities in the trip signals, such as absent or delayed signals [7]–[9].

Backup Protection Activation: The breaker failure relay initiates backup protection to isolate the faulty portion when it detects a breaker failure condition. To isolate the malfunctioning portion of the network from the rest of the system, trip commands may be sent to other circuit breakers in the system. Depending on the particular needs of the power system, the backup protection methods may include overcurrent relays, distance relays, or other acceptable protection schemes. The following are factors to take into account while relaying a breaker failure:

Time Coordination: The timing features of the protective relays and the circuit breaker should be correctly coordinated when relaying in the event of a breaker failure. The breaker failure relay's detection time delay should be configured to provide the protection relays enough time to work and the breaker enough time to clear the fault. This cooperation prevents the breaker failure relay from starting erroneous trips.

Communication and monitoring: Relay, control centre, and other device communication may be necessary during breaker failure relaying. To allow for the exchange of trip commands and status information, reliable communication channels must be established. In order to guarantee the proper operation of the relaying system for breaker failure, it is crucial to continuously check the communication channels.

Sensitivity and Selectivity: Breaker failure relays should be selective enough to prevent false tripping during system disruptions or brief delays in breaker operation while being sensitive enough to quickly identify true breaker failures. To achieve the requisite sensitivity and selectivity, proper relay settings and synchronisation with other protective devices are required. Breaker failure relaying is a safety measure created to identify and react to circuit breakers that are unable to operate due to problems. Breaker failure relays assist in preventing prolonged fault duration and equipment damage by monitoring trip signals, identifying breaker failure circumstances, and triggering backup protection. For the effective implementation of breaker failure relaying, proper timing coordination, communication, sensitivity, and selectivity considerations are essential.

Reclosing: When a momentary defect occurs in a power system, power is automatically restored by the protective mechanism known as reclosing. The reclosing scheme starts the automated closing and re-energization of the circuit breaker after a set amount of time when a fault, such as a short circuit or equipment failure, disrupts the power supply. An overview of reclosing, including its goals, methods, and issues, is given in this article. Reclosing's main goal is to shorten the time that power outages last and swiftly restore service to the affected area. Reclosing schemes work to increase system dependability by automatically re-opening the circuit breaker after a transient fault and minimising the effect of transient faults on the power supply. The time delay before reclosing is usually chosen to give the fault time to clear and avoid persistent faults from being reenergized, which could worsen the damage or jeopardise system stability. Reclosing implementation comprises numerous crucial components, including:

Fault Detection: Reclosing schemes depend on protective relays to identify faults and start the circuit breaker trip when there is a problem. The protective relays keep track of the state of the system and compare it to preset thresholds or fault detection formulas. The protective relay trips the circuit breaker when a problem is found, isolating the affected area from the rest of the power system [10].

Time Delay: After the circuit breaker has been opened, there is a delay until it is closed again. The time delay is necessary to allow for fault clearance, which may involve the automatic reclosing of upstream breakers or the arc extinction in the faulty equipment. The type of defect, system characteristics, and coordination requirements are often taken into account when determining the time delay.

Reclosing Attempts: After the time delay has passed, the circuit breaker is automatically closed by the reclosing scheme. If the issue continues, the reclosing method can make several efforts to shut off the circuit breaker. Every effort at reclosing is followed by a brief interval of open circuit time to give the fault a chance to clear or to address any possible problems. The following are factors to take into account when reclosing:

System Stability: When planning a reclosing strategy, take into account how the power system will be stable both during and after the operation. Reclosing attempts should be timed in accordance with system dynamics to prevent instability or additional disturbances. Reclosing on weak systems, during generator synchronisation, or in the presence of sensitive loads is given special concern.

Reclosing Scheme Supervision: During the reclosing process, system conditions are frequently monitored by relays that supervise reclosing schemes. Based on variables like voltage levels, current intensities, or power swings, these relays determine whether or not reclosing attempts were successful. The reclosing relay stops any subsequent attempts to close the circuit breaker and locks it in the open position if a fault persists or the system conditions are outside of the predetermined range.

Coordination with Protection: In order to provide proper fault isolation and detection, reclosing schemes must be coordinated with other protection schemes. Setting suitable time delays, ensuring selective tripping, and preventing cascading failures are all part of coordination. To accomplish successful fault clearing while minimising system disturbances, protective relays and reclosing strategies must be coordinated. To sum up, reclosing is a safety mechanism intended to instantly restore power following a temporary malfunction. Reclosing schemes work to shorten power outages and boost system reliability by starting the automatic closing and re-energizing of the circuit breaker after a time delay. Key factors in the execution of reclosing include proper fault detection, time delay setting, attempts at reclosing, and cooperation with protective methods. Reclosing schemes are essential in reducing the impact of transitory errors on power supply because they provide prompt power restoration while preserving system stability.

CONCLUSION

For electricity systems to run safely and reliably, switching schemes and practices are essential. They guarantee effective switching operations management, minimizing downtime and lowering the possibility of equipment damage or employee injuries. For switching operations to be carried out successfully, proper planning, coordination, and communication are required. In conclusion, switching protocols and schemes are essential components of power system maintenance and operation. They ensure the integrity and stability of power systems by enabling the safe and dependable execution of switching activities. The implementation of switching schemes and procedures requires careful planning, coordination, communication, and safety precautions. To increase the efficiency of switching operations and keep power systems operating reliably, there must be constant evaluation, training, and adherence to standards and regulations.

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