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INSULATION AND CIRCUIT BREAKER

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CHAPTER 1

WORKING PRINCIPLE OF CIRCUIT BREAKER

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An electrical circuit breaker is a switching mechanism for managing as well as safeguarding an electrical power system that may be used both manually and automatically. A circuit breaker should be specially designed to be able to safely stop the arc created during the shutting of a circuit breaker since the contemporary power system deals with very high currents. The fundamental description of a circuit breaker was as follows. The vast power network and many electrical devices it is coupled with make up the contemporary power system. A strong fault current will pass through this equipment as well as the power network during a short circuit fault or any other sort of electrical fault (such as electric cable problems). The networks and equipment may sustain long-term harm from this high current. The fault current has to be eliminated as soon as possible from the system to protect these items of machinery and the power networks. To send dependable, high-quality power to the receiving ends, the system must quickly return to normal operation when the problem has been fixed. In addition, many switching activities must be carried out for the power system to be controlled properly[1], [2].

Therefore, there must be a unique form of switching devices that can be operated securely under enormous current carrying conditions to quickly disconnect and reconnect various elements of the power system network for protection and management. Significant arcing would occur between switching contacts during the cessation of a large current, hence care should be made to safely quench these arcs in circuit breakers. The circuit breaker is a unique device that performs all necessary switching activities while there is electricity flowing. This served as a basic overview of a circuit breaker. Additionally, the circuit breaker may be thought of as a switching mechanism that stops an aberrant or faulty current. It is a mechanical device that switches on and off as well as interrupts the passage of large magnitudecurrent. The circuit breaker's primary purpose is to close or open an electrical circuit, protecting the electrical system in the process.

When abrupt electrical failures occur, whether, at home or work, they often result in substantial damage to the electrical infrastructure of the location if they are not treated swiftly. In some cases, they can result in deadly accidents and fires that may have disastrous implications. The circuit breaker, which is the key element of a well-protected electrical system, is one of the numerous protective devices used in electrical installations to prevent these circumstances, along with the fuse, the surge arrester, and the surge protector[3], [4].

Working Principle of Circuit Breaker

A circuit breaker has two crucial connections, and they are:

1. Fixed contacts
2. Moving contacts

The contacts touch one another and transport the current when the circuit is closed, which is the typical state. Current-carrying contacts in a closed circuit breaker are referred to as electrodes because they make contact with one another under the force of a spring. By either opening or shutting the circuit breaker's arms, the switching and functionality of the facility are handled. By pulling the trigger, the circuit breaker is opened. The trip coil of the breaker becomes electrified and moves away from each other when there is defective electricity flowing through any section of the system, opening the circuit. Essentially, a circuit breaker is made up of movable and stationary contacts. When the circuit is closed, these contacts are contacting each other and conduct current normally. The electrodes the current-carrying contacts engaged with one another when the circuit breaker was closed under the force of a spring[5], [6].

The circuit breaker's arms may be opened or closed during regular operation to switch and maintain the system. Only pressure has to be given to a trigger to release the circuit breaker. The trip coil of the breaker is triggered if a fault develops in any component of the system, and the movable contacts are separated from one another by some mechanism, opening the circuit. Fixed contacts and movable contacts make up the majority of the circuit breaker. These two contacts are physically linked to one another while the circuit breaker is in its typical "ON" state as a result of the mechanical pressure being exerted on the moving contacts. When a switching signal is applied to a circuit breaker, the potential energy that has been accumulated in the working mechanism is released. The potential energy may be stored in the circuit breaker in a variety of methods, including via hydraulic pressure, compressed air, or deforming metal springs. However, potential energy must be released during operation, regardless of the source. The moving contact slides quickly thanks to the release of potential energy.

When a switching pulse energizes the working coils (tripping coils and closure coils) in a circuit breaker and displaces the plunger inside of it, the circuit breaker trips. This operating coil plunger is typically connected to the circuit breaker's operating mechanism. As a result, mechanically stored potential energy in the breaker mechanism is released as kinetic energy, which causes the moving contacts to move because they are mechanically connected to the operating mechanism through a gear lever arrangement. After a circuit breaker cycle, the whole energy saved is released, and potential energy is afterward once again stored in the functioning mechanism of the circuit breaker using a spring charging motor, an air compressor, or any other method. We have so far spoken about the mechanical operation of a circuit breaker. However, while discussing how a circuit breaker operates, it is also important to take into account its electrical properties[7], [8].

The circuit breaker must handle huge rated power or experience a failure. Due to this significant power, the arcing between the circuit breaker's moving and fixed contacts are always at dangerously high levels. As we previously explained, if the dielectric strength between the circuit breaker's current-carrying contacts grows quickly during each alternating current zero crossing, the arc in the circuit breaker may be safely quenched. There are several ways to increase the dielectric strength of the media between contacts, including compressing the ionized arcing media because doing so speeds up the deionization process of the media, cooling the arcing media because doing so increases the resistance of the arcing path, or replacing the ionized arcing media with new gases. Therefore, the functioning of the circuit breaker should include certain arc quenching operations. There are remote control circuit breakers that can be controlled on demand and from a distance, even though circuit breakers typically fulfill their duties autonomously and without supervision.

Types of Circuit Breakers and Their Parts

A circuit breaker is a safety tool that guards against overcurrent or short circuit damage to an electric circuit. This device's main purpose is to stop the flow of electricity so that the equipment is protected and there is no chance of a fire. A switching device known as a circuit breaker protects users by trip-tripping and turning off power to a load in the event of an error. Circuit breakers are mostly employed in industries, buildings, commercial complexes, hotels, and other similar establishments to switch various types of loads. Accidents often occur in the field of electrical and electronics. Buildings, offices, homes, schools, businesses, etc. will sustain significant damage. Even though safety precautions are taken, voltage and current cannot be trusted. Circuit breakers will regulate the fast increase of voltage and current after they are fitted. It will protect against any accidents. Circuit breakers resemble the electrical system's beating heart. Circuit breakers come in a variety of sorts, and they are placed based on the system rating. Distinct types of circuit breakers are utilized in homes, while a different kind is used in enterprises. The arc is the one that must be carefully examined while circuit breakers are in use. Therefore, the arc phenomena in circuit breakers occur in defective circumstances. For instance, if there is a large current flow across the contacts before the defensive approach and contact initiation[9], [10].

When the contacts are in the OPEN state, the contact area rapidly decreases, and the current density increases due to the significant SC current. This event causes an increase in temperature, and indeed the heat that is produced is sufficient to ionize a medium. The conductor functions as the ionized medium, which holds up the arc in the space between the contacts. For the contacts, the arc produces a route with little resistance, and there will always be a large current flowing through it. The circuit breaker's functionality is harmed by this circumstance. Let's examine the factors responsible for the occurrence of the arc before learning about arc termination methods. Reasons include:

1. The possibility of variance between interactions
2. Particles with ions that are present between

Due to the proximity of the contacts, the potential variation between them is sufficient to support the creation of an arc. The ionization medium also can keep the arc intact. The arc is the one that has to be watched while a circuit breaker is in use. As a result, when a circuit breaker malfunctions, the arcing event occurs. Before taking a defensive stance and starting interactions, for instance, wait until there is a large flow of contacts. When the contacts are in the open state, the contact area rapidly shrinks while the high current causes the current density to rise. The temperature increase and heat output required for the ionization interruption medium is determined by this event. The arc between the contacts is received by the ionized medium, which also serves as a conductor. A significant amount of current will flow while the arc is present because it creates a channel with the lowest resistance for the contacts. This circumstance prevented the circuit breaker from operating.

Types of Circuit Breaker

Different kinds of circuit breakers exist based on various parameters. The circuit breaker may be classified into the following groups based on its arc-quenching media:

1. Oil circuit breaker
2. SF6 circuit breaker
3. Vacuum circuit breaker
4. Air circuit breaker

The circuit breaker can be categorized as follows based on their services:

1. Indoor breaker
2. Outdoor circuit breaker

According to the operating mechanism of circuit breakers they can be categorized as:

1. Pneumatic circuit breaker
2. Hydraulic circuit breaker
3. Spring-operated circuit breaker

Different kinds of circuit breakers are referred to as:

1. High voltage circuit breaker
2. Medium voltage circuit breaker
3. Low voltage circuit breaker

Parts of a Circuit Breaker

The frame or outer covering

The frame shields all of the circuit breakers interior parts, as the name implies. Additionally, it offers insulation to keep the arc contained and supports the components. They come in three other forms: molded, insulated, and metal, depending on the current and voltage employed.

Operating System

Every sort of circuit breaker employs a technique to cut off the power supply. Solenoid, hydraulic, pneumatic, and spring-loaded switches are often used in these. Its job is to activate or deactivate the circuit breaker's contacts.

Electronic Connections

When contacts are closed, they serve the purpose of allowing current to flow through the circuit breaker. A circuit breaker typically has two electrical contacts: a temporary contract and a static contract.

Extinguishing arcs

When a fault occurs, this generally puts out the arc. Electricity may jump across the space between the contact's end pieces when the contacts are disengaged. This results in an electrical arc that may produce an extremely hot temperature. To stop the damage and arc from occurring again, a circuit breaker employs an arc suppression device.

Travel Unit

In the case of an overcurrent or short circuit, the trip unit aids in the detection of aberrant current flow. The contacts are opened by the working mechanism as a result. Because the current flow in the loop has been obstructed by the air or another insulator, an open circuit will not conduct electricity.

Oil Circuit Breaker

An oil circuit breaker is a crucial component of the electrical system since it will strengthen it. Based on the medium employed to minimize the arc, they are divided into many categories. One kind of circuit breaker where insulating oil may be utilized as an arc quenching medium is an oil circuit breaker. When a failure in the system manifests itself, the circuit breaker contacts will become separated and an arc will be struck between them. An oil circuit breaker is the earliest kind of circuit breaker. It has distinct contacts, the primary purpose of which is to separate an insulating oil. As opposed to air, it is an excellent insulator. The contacts of the breaker will open below the oil when the fault develops. After the arc forms between the breaker's two contacts, the heat from the arc will dissolve the surrounding oil and split into a sizable amount of gaseous hydrogen under high pressure. This circuit breaker's key advantages are its inexpensive price, dependability, and simplicity. An example of a circuit breaker that uses oil as a dielectric or insulating medium for arc extinction is an oil circuit breaker. The contacts of an oil circuit breaker are constructed to split within an insulating oil. When a malfunction in the system occurs, the circuit breaker contacts are open below the insulating oil, an arc forms connecting them, and the heat from the arc evaporates the oil around it. There are two types of oil circuit breakers:

1. Bulk Oil Circuit Breaker
2. Low Oil Circuit Breaker

Circuit Breakers for Bulk Oil

To destroy an arc, this kind of circuit breaker needs a lot of oil. Another name for it is a dead tank circuit breaker. The tank of this breaker is kept at ground potential, as the name would imply. The voltage of the system mostly determines how much oil is needed in this circuit breaker. For instance, 8 kg to 10,000 kg of oil is used when the system voltage is 110 kV. Similar to how it takes 50,000 Kg of oil for 220 kV. The oil acts as an arc extinguishing medium in this sort of circuit and insulates the existing components from the ground.

Circuit Breaker with the Less Oils

Less oil is used in this kind of circuit breaker. For ground insulation, the oil tank is set atop a porcelain insulator. Included in it is an arc chamber that is covered with bakelite paper. The porcelain top section of this circuit breaker is encased in contacts, while the porcelain bottom portion is sustained via the porcelain. It takes up less room than bulk oil types. Where repeated operations are required, it is not employed. The key advantages of this circuit breaker are that it consumes less oil, takes up less room, is lighter, has a smaller tank, requires less maintenance, etc. Air is not as good of an insulator as mineral oil. The movable contact and fixed contact of an oil circuit breaker are submerged within the insulating oil. When current-carrying contacts in oil separate, an arc in the circuit breaker are initiated at the same time. As a result of this arc, the oil is vaporized and breaks down into mainly hydrogen gas, which eventually forms a hydrogen bubble surrounding the arc. After the current hits the cycle's zero crossing, the arc cannot be struck again because of the tightly compressed gas bubble around it. One of the earliest types of circuit breakers is the oil circuit breaker.

Working of Oil Circuit Breaker

Let's explore how an oil circuit breaker works as it is pretty simple to use. An arc forms between the separated contacts when the current-carrying contacts in the oil are separated.In reality, the distance between the current contacts is tiny when contact separation has barely begun, causing a strong voltage gradient between the contacts. The oil was ionized by the large voltage gradient between the contacts, which then started an arc between the contacts. This arc will generate a lot of heat in the nearby oil, evaporating it, and breaking it down mostly into hydrogen and a little bit of methane, ethylene, and acetylene. The hydrogen gas is broken down into its atomic form, releasing a lot of heat, since it cannot persist in its molecule state. Up to 5000oK may be reached by the arc. This high temperature causes the gas to be released around the arc extremely quickly, creating an abnormally quick-growing gas bubble. It is discovered that the volume of the gas combination is about 1,000 times larger than that of the degraded oil. An oil circuit breaker, also known as an OCB, is a kind of circuit breaker that securely breaks the circuit by quenching the arc using insulating oil as a dielectric medium.

The oil used is insulating oil, which has more dielectric strength than air and is often used in transformer oil. We may infer how quickly the gas bubble surrounding the arc will expand from this illustration. The arc will be extinguished at the zero crossing of the current cycle if the expanding gas bubble around the arc is compressed in any way, as this will cause the deionization process of the ionized gaseous media between the contacts to accelerate and quickly increase the dielectric strength between the contacts. This is how an oil circuit breaker works fundamentally. Additionally, the rapid arc quenching in the oil circuit breaker aids in cooling the hydrogen gas around the arc path.

Maintenance of an Oil Circuit Breaker

It is necessary to do maintenance on all types of circuit breakers. Similar to the oil type, it is important to check and replace contacts as well as oil. A circuit breaker is halted after a short circuit has occurred. Arcing may sometimes cause damage to the contacts. Therefore, if the dielectric oil becomes carbonized near the contacts, its dielectric strength and breaking capacity may both diminish. Therefore, breaker maintenance is required for checking and changing the oil, and contacts. It must first be turned off before being separated from both sides by opening the relevant electrical isolator for circuit breaker repair. The circuit breaker must be actuated for local and distant conditions at this non-isolated condition once a year and as needed. The circuit breaker must first be controlled physically from locally, then electrically from a distance. By eliminating any coating that has formed between sliding surfaces, this sort of procedure increases the breaker's dependability. The following points must be checked before inspecting the circuit breaker

1. Check the arcing connections and internal components. The connections must be replaced if a short circuit occurs.
2. The surface of the breaker has to be cleaned and carbon deposits need to be removed using a firm, dry cloth.
3. Check the coil's dielectric strength.
4. Check the oil level.
5. Both the tripping and shutting mechanisms need to be examined.

Circuit Breaker Bulk Oil Maintenance

We should examine contact burning for the bulk oil circuit breaker. Remove the burn beads and polish the surface of the burning extremely little. Replace the tips and arcing ring with a fresh set if the burning is very intense. Before doing the final tightness, we should loosen and tighten the tips many times.

Oil Circuit Breaker Maintenance at a Minimum

For MOCBs, the breaker's oil level and evidence of leaking should be examined periodically. If an oil leak is discovered, it has to be fixed, and low oil levels need to be topped up. Quarterly visual inspections of the circuit breaker and its workings, as well as checks on the paintwork and gasket on the mechanism kiosk door, should be done. If any damage is discovered, appropriate steps should be taken.

Construction, Working and Advantage of Oil Circuit Breaker

Construction of Oil Circuit Breaker

Construction of an oil circuit breaker is fairly simple. It is made up of current-carrying contacts that are encased in a sturdy, weatherproof earth metal tank. Transformer oil is kept within the tank. Between the live component and the soil, the oil serves as both an arc extinguishing medium and an insulator. Air is pumped into the tank near the top of the oil, acting as a cushion to regulate the displaced oil's impact on the production of gas surrounding the arc and also to soften the mechanical shock of the oil's upward movement. The breaker tank is firmly fastened to withstand the vibration brought on by cutting off a very high current. As illustrated in Figure 1.1, the gas outlet for the oil circuit breaker is installed in the tank lid for the disposal of the gases.

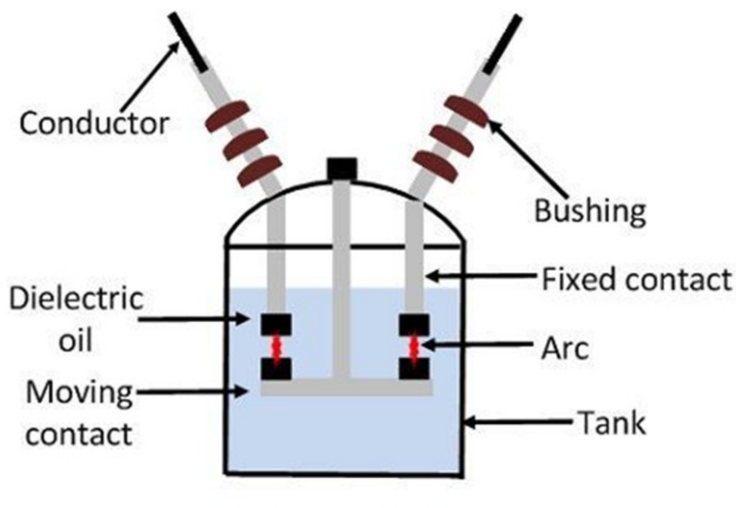

Figure 1.1: Representing the Construction of Oil Circuit Breaker [Circuitglobe].

Working of Oil Circuit Breaker

The oil circuit breaker's contact is closed and carrying current when it is functioning normally. When a failure in the system occurs, an arc is created between the contacts of the breaker as they move apart. A significant quantity of heat is released by this arc, and a very high temperature is attained as a result, vaporising the surrounding oil into gas. The arc is encircled by the gas that has been released, and the oil has been forcibly displaced by the gas' rapid expansion. When the distance here between fixed and moving contact reaches a certain critical value, which is determined by the arc current and recovery voltage, the arc is put out. The oil circuit breaker is relatively affordable and very dependable in use. The fact that no special technologies are used to manage the arc created by moving contact is the most crucial aspect of oil circuit breakers. The oil has certain benefits and drawbacks as an arc quenching medium.

The contact in the circuit breaker will be closed and carrying the current during normal operation. The contacts will move apart once the fault in the system occurs, and an arc will be struck between the contacts. A significant amount of heat will be released by this arc, and a high temperature can be reached to vaporise the nearby oil into gas. As a result, the arc will be formed around this gas, which will cause the oil to be violently moved by its unstable increase. Once the distance between the fixed and moving contacts reaches a specific critical value, the arc will be cut off. It primarily depends on the arc current & recovery voltage. This circuit breaker's operation is very affordable & dependable. The primary characteristic of this circuit breaker is that no special devices are employed when controlling the arc brought on by moving contact.

When a fault occurs, an arc is created between the breaker contacts, which are open in oil. The oil that surrounds the contacts evaporates as a result of the arc's heat, producing high-pressure hydrogen gas. A hydrogen gas bubble envelops the arc region and nearby portion of contacts as the oil is forced away from the arc. An extremely significant and necessary component of the electrical power system is the oil circuit breaker. This tool aids in power system adjustment. Depending on how it is applied to lessen the arc, it is classified into various types. Another type of circuit breaker is an oil circuit breaker, which uses insulating oil for arc quenching. Once a fault occurs in the system, the contacts of the circuit breaker will be disconnected and an arc will strike between the contacts.

Advantages of Oil as an Arc Quenching

1. After the arc has been put out, the oil acts as insulation between the contact points because to its high dielectric strength.
2. A tiny space exists between the conductors and the earth components thanks to the oil used in circuit breakers.
3. The hydrogen gas, which has a high diffusion rate and strong cooling qualities, is created in the tank.
4. It requires less oil, and oil has a high dielectric strength.
5. As oil in the breaker breaks down, it will absorb arc energy.
6. Less area, lower fire risk, and lower maintenance requirements

Disadvantages of Oil as an Arc Quenching

1. Because oil circuit breakers employ flammable oil, there is a risk of fire.
2. The possibility of an explosive combination with air exists.
3. As a result of the oil's arc-induced disintegration, carbon particles are produced, contaminating the oil and lowering its dielectric strength.
4. Because it consumes less oil, the amount of carbonization will rise.
5. The high level of carbonization makes it harder to remove the gases from the contact region, and it also causes a fast fall in the oil's dielectric strength.
6. Arcing time is lengthy; avoid high-speed interruptions.
7. Arc interruption may be controlled dependent on the length of the arc.
8. Through the air, it may create any volatile combination.

Application of the Oil Circuit Breakers (OCB):

Various application of OCB as mention below:

1. Switchyard oil is used as a circuit breaker, an excellent dielectric, and to quench arcs.
2. To safeguard distribution lies, oil circuit breakers are employed in small and medium substations.
3. Since oil is a highly effective insulator, there may be less space between earth components and live conductors.

Introduction to Air Circuit Breakers (ACB)

An automated electrical switch that utilizes air to protect an electrical circuit from damage brought on by too much current from an overload or short circuit is known as an air circuit breaker (sometimes referred to as an air blast circuit breaker or ACB). After a problem is found, its main job is to stop current flow. An arc will then develop between the contacts that have disrupted the circuit when this occurs. Air circuit breakers either employ compressed air to blow out the arc or, alternatively, quickly swing the contacts into a tiny sealed chamber, causing the air that was displaced to escape and blow out the arc. Atmospheric pressure air is used to operate this kind of circuit breaker. The medium voltage air circuit breaker has been mainly replaced with oil circuit breakers around the globe since the invention of the oil circuit breaker. Even yet, up to a voltage of 15 kV, ACBs are still the preferred option in nations like France and Italy. In the event of an oil circuit breaker, ACBs are a viable option for reducing the danger of an oil fire. Up to the invention of modern vacuum circuit breakers and SF6 circuit breakers, ACBs were the only kind of circuit breaker utilised in American systems up to 15 kV. To restart normal functioning, a circuit breaker may be reset (manually or automatically), unlike a fuse, which can only be used once before needing to be replaced. In contrast to fuses, which cannot be controlled remotely, you may also have a remote-controlled circuit breaker.

The Operation of an Air Circuit Breaker

Electric circuits between 800 and 10K Amps may be protected against overcurrent and short circuits using an air Circuit Breaker (ACB). These are often used in low voltage settings with voltages below 450V. These systems are located in distribution panels (below 450V). We will talk about how the air circuit breaker works in this post. When the atmospheric pressure is a certain value, an air circuit breaker uses the air as an arc-extinguishing medium. Today's market offers a variety of Air circuit breakers and switching equipment that is strong, efficient, and simple to install and maintain. Oil circuit breakers were entirely replaced with air circuit breakers. This circuit breaker operates on a somewhat different concept than all other kinds of circuit breakers. All types of circuit breakers are designed with the primary objective of preventing the reestablishment of arcing after the current has decreased to zero by establishing a scenario where the contact gap will survive the system recovery voltage. The air circuit breaker functions similarly, but in a different way. It generates an arc voltage that is greater than the supply voltage for interrupting arcs. The bare minimum voltage necessary to sustain the arc is known as arc voltage. The major three ways that this circuit breaker raises the arc voltage are:

1. By cooling the arc plasma, it might raise the arc voltage. More voltage gradient is needed to keep the arc going as the arc plasma's temperature drops because the arc plasma's particles have less mobility.
2. By lengthening the arc path, it might raise the arc voltage. In order to maintain the same arc current, more voltage must be applied across the arc path as the length of the arc increases due to the path's increased resistance. This indicates an increase in arc voltage.
3. Arc voltage is also raised by dividing the arc into several series arcs.

Air typically, circuit breakers have two sets of contacts. The primary pair of contacts, which are formed of copper metal, is responsible for carrying the current under normal load. The arcing contact is the second pair, which is carbon-based. The primary contacts open first when the circuit breaker is turned on. The arcing contacts were still in contact with one another when the primary contacts opened. The arcing contact becomes a parallel low-resistive channel for the current as it flows. There won't be any arcing in the primary contact throughout the opening process. Only after the arcing contacts have finally been separated does the arcing begin. Each of the arc contacts has an arc runner, which is helpful. As shown in the image, both thermal and electromagnetic factors cause the arc discharge to migrate higher. The arc enters the arc chute, which is made up of splatters, as it is propelled higher. When the air circuit breaker is operating, the arc in the chute will get colder, extend, as well as divide; as a result, the arc voltage will be significantly higher than the system voltage, and the arc will ultimately be extinguished during the current zero.

Characteristics of ACB (Air Circuit Breakers)

Due to its many benefits, including their high sectional capability, flawless operation, compact construction, and great performance, ACBs are employed in power systems, including transformers, power distribution stations, industrial, and mining companies.When a current overload or failure occurs, the ACB will immediately turn off the circuit, operating as a fuse switch and an overheating relay at the same time. Short-circuit and under-voltage protection are efficient in resolving issues with power lines and equipment.

By disconnecting and reconnecting the load circuit, ACBs regulate electrical circuits to run electrical equipment properly. Because they are lightweight and tiny, these gadgets are compact. Due to its compatibility with industry standards and ease of installation, ACBs are utilised in a variety of settings, including industrial, mining, power transformers, distribution centres, and many more.Insulation plates are used in ACBs as a safety precaution on both sides to divide the conductors and provide operational security. To prevent corrosion and increase dependability, the pieces are positioned within the frame. ACBs may execute a variety of tasks thanks to the coordination of its parts, which also includes an electrical switch for reliable performance.When compared to other circuit breakers, the ACB has a greater rated current and shell rating. Additionally, this indicates that the ACB's permissible current value is larger and may be utilised to safeguard the motor.

REFERENCES

[1] S. Liu en M. Popov, "Development of HVDC system-level mechanical circuit breaker model", *Int. J. Electr. Power Energy Syst.*, 2018, doi: 10.1016/j.ijepes.2018.05.017.

[2] A. Mokhberdoran, D. Van Hertem, N. Silva, H. Leite, en A. Carvalho, "Multiport Hybrid HVDC Circuit Breaker", *IEEE Trans. Ind. Electron.*, 2018, doi: 10.1109/TIE.2017.2719608.

[3] X. Pei, O. Cwikowski, A. C. Smith, en M. Barnes, "Design and Experimental Tests of a Superconducting Hybrid DC Circuit Breaker", *IEEE Trans. Appl. Supercond.*, 2018, doi: 10.1109/TASC.2018.2793226.

[4] O. Cwikowski, A. Wood, A. Miller, M. Barnes, en R. Shuttleworth, "Operating DC Circuit Breakers with MMC", *IEEE Trans. Power Deliv.*, 2018, doi: 10.1109/TPWRD.2017.2658540.

[5] A. Mokhberdoran, O. Gomis-Bellmunt, N. Silva, en A. Carvalho, "Current Flow Controlling Hybrid DC Circuit Breaker", *IEEE Trans. Power Electron.*, 2018, doi: 10.1109/TPEL.2017.2688412.

[6] C. Li, J. Liang, en S. Wang, "Interlink hybrid DC circuit breaker", *IEEE Trans. Ind. Electron.*, 2018, doi: 10.1109/TIE.2018.2803778.

[7] R. Sander, M. Suriyah, en T. Leibfried, "Characterization of a Countercurrent Injection-Based HVDC Circuit Breaker", *IEEE Trans. Power Electron.*, 2018, doi: 10.1109/TPEL.2017.2709785.

[8] S. Wang, Z. Song, P. Fu, en H. Li, “Conceptual design of bidirectional hybrid DC circuit breaker for quench protection of the CFETR”, *IEEE Trans. Appl. Supercond.*, 2018, doi: 10.1109/TASC.2018.2841918.

[9] M. T. Kesim, H. Yu, Y. Sun, M. Aindow, en S. P. Alpay, “Corrosion, oxidation, erosion and performance of Ag/W-based circuit breaker contacts: A review”, *Corrosion Science*. 2018. doi: 10.1016/j.corsci.2018.02.010.

[10] T. Cheng, W. Gao, W. Liu, en R. Li, “Evaluation method of contact erosion for high voltage SF6 circuit breakers using dynamic contact resistance measurement”, *Electr. Power Syst. Res.*, 2018, doi: 10.1016/j.epsr.2017.08.030.

CHAPTER 2

AIR CIRCUIT BREAKER CONSTRUCTION

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For the construction of an air circuit breaker, the following list of interior and external parts may be employed. The main elements of the ACB's external parts include LED indicators, the ON/OFF button, an indicator for the energy storage mechanism, indicator for the main contact role, the RST button, the controller, the handle for energy storage, the rated nameplate, the shake, the displays, the fault trip rest button, the rocker repository, etc. The primary internal components of the ACB are the trip unit, the horizontal terminals, the pole group insulating box, the current transformer, the arcing chamber, the closing springs, the trip unit, the terminal box, the plates to move the arcing and main contacts, the CB opening and closing control, as well as the plates for fixed main & arcing contacts[1], [2].

Types and Maintenance of Air Circuit Breakers (ACB)

Types of Air Break Circuit Breaker

For preserving the interior medium voltage as well as switch gear of the house, the air circuit breakers are typically of four sorts.

1. Plain Break Type ACB or Cross-Blast ACB
2. Air Chute Air Break Circuit Breaker
3. Air Blast Circuit Breaker
4. Magnetic Blowout Type ACB

Circuit breaker of the simple break type

The most basic kind of air breakers are simple brake air circuit breakers. The primary points of contact are shaped like two horns. These circuit breakers have an arc that runs from one tip to the other. Cross blast ACB is another name for this particular kind of circuit breaker. This setup is possible via an arc chute, which is a chamber encircled by the contact. The chamber or arc chute, which is constructed of refractory material, aids in cooling. The inside of the arc chute is walled off, and metallic separation plates are used to divide it into discrete sections. These plates are arc splitters, and each section serves as a little arc chute. In order for all arc voltages to rise beyond the system voltage, the initial arc will split into a series of arcs. Low voltage applications employ them[3], [4].

Circuit Breaker with a Magnetic Blowout Type Air Break

Circuit breakers with magnetic blowout air are utilised for voltages up to 11 KV. The magnetic field produced by the current in blowout coils may be used to extend the arc. In order to achieve arc extinction in the devices, this kind of circuit breaker offers magnetic control over the arc moment. As a result, this extinction may be managed using a magnetic field that is generated by the current flowing through blown coils. The circuit that is being disturbed may be used to link blow-out coils in series. These coils are referred to as "blow out the coils" as their name implies. The arc that is created in the circuit breaker is not controlled by the magnetic field; instead, it is sent through arc chutes where it is appropriately cooled and extended. Up to 11kV, these CBs are used.

Circuit Breaker for Air Chute Air Break

The primary contacts in the air chute air break circuit breaker typically consist of copper and conduct electricity when closed. Circuit breakers for air chute air breaks are silver-plated and feature minimal contact resistance. The arcing connections are comprised of a solid, heat-resistant copper alloy. This circuit breaker has main and arcing or auxiliary connections. Copper and silver plates, which have low resistance and conduct current in a tight space, may be used in the design of main contacts. Due to their heat resistance, copper alloy is used to develop other kinds, such as arcing and auxiliary. These are employed to prevent arcing from damaging the primary contacts, and they are easily replaceable when necessary. When using this circuit breaker, both contacts are opened both after and before the main contacts are closed[5], [6].

Circuit Breaker for Air Blast

These circuit breakers are utilised for system voltages of 245 KV and 420 KV and even higher, especially where rapid breaker functioning is required. Below is a summary of this circuit breaker's advantages over oil-type circuit breakers.

1. There is no possibility that oil will start a fire.
2. When an air blast circuit breaker is operating, its breaking speed is much greater.
3. When using an air blast circuit breaker, arc quenching occurs significantly more quickly.
4. For all values of minor as well as large current interruptions, the length of the arc remains constant.
5. As the arc's duration decreases, less heat is transferred from the arc to the current-carrying contacts, extending the contacts' useful lives.
6. The circuit breaker's rate of operation determines how effectively the system's stability can be maintained.
7. Needs a lot less maintenance than an oil circuit breaker.

Air Circuit Breaker Maintenance

With capacities ranging from 400A to 6300A or higher, ACBs function as circuit protection devices for a wide variety of low voltage applications up to 600V AC, including UPS, generators, micro power stations, MCCB distribution boards, etc. Nearly 20percent of power distribution system failures in this circuit breaker are caused by poor maintenance, hard grease, dust, corrosion, and frozen components. Circuit breaker maintenance is thus the best option to guarantee reliable functioning and extend the lifespan. It's crucial to maintain the air circuit breaker. To do so, first switch it off, then open the necessary electrical isolator to isolate it from both sides. Every year, the circuit breaker has to be reset in this common situation for remote and restricted places. The circuit breaker has to be operated physically from restricted after being electrically separated. By removing any external layer that has formed between sliding faces, this operation will increase the consistency of the breaker[7], [8].

Testing of Air Circuit Breakers

Different types of test equipment are used to test circuit breakers in order to determine their condition in any electrical system. Different test methodologies and testing tools may be used to do this testing. The testing equipment includes an analyzer, a micro ohmmeter, a high current main injection tester, etc. The following are some advantages of circuit breaker testing:

1. The circuit breaker's performance may be improved.
2. The circuit may be examined with or without load.
3. Acknowledges the need for maintenance
4. Problems may be prevented
5. Faults' early warning signs may be found

Operation and Application of Air Circuit Breaker

An ACB's operation may be divided into three parts. By bringing the arc into touch with as much insulating stuff as possible, the first goal is often accomplished. There is a chamber around the contact in every air circuit breaker. Arc chute is the name of this chamber. It has an arc drilled into it. The arc chute wall will aid in cooling if the interior of the arc chute is properly designed and if the arc can be made to adhere to the contour. Any form of refractory material should be used to create this kind of arc chute. The best materials to use for creating an arc chute are high-temperature polymers reinforced with glass fiber and ceramics. Together with the first purpose, the second goal, which is to prolong the arc route, is accomplished. If the inner walls of the arc chute are designed in such a manner that the arc is pushed into a serpentine channel that is projected on the arc chute wall in addition to being forced into close contact with it. The arc resistance rises as the arc route lengthens. Utilizing a metal arc slitter within an arc chute is the third method. Using metallic separation plates, the main arc chute is separated into several tiny compartments. Arc splitters are essentially these metallic separating plates, and each of the little compartments functions as a separate mini-arc chute. The first arc in this method is divided into many series arcs, each of which will have its mini-arc chute. As a result of each split arc's tiny arc chute, which has a cooling and extending effect of its own, the voltage of each split arc increases individually. Together, they result in an overall arc voltage that is much greater than the system voltage.

The air circuit breaker doesn't need an arc control device when used at voltage levels up to 1 kV. ABCs with the proper arc control device is an excellent alternative, especially for large fault current on low voltages (low voltage level over 1 kV). Typically, these breakers feature two pairs of connections. At a typical load, the primary pair of contacts, which are constructed of copper, carry the current. The extra pair, which is formed of carbon, is the arcing contact. The primary contacts open first when a circuit breaker is turned on, and while they are opening, the arcing contacts are still in contact with one another. When main contacts are opened, there won't be any arcing in the main contact since the current will take a parallel, low-resistive route via the arcing contact. Only after the arcing contacts have finally been separated does the arcing begin. Each arc contact has an arc runner that aids in the arc discharge's upward motion owing to thermal and electromagnetic causes. The arc enters the splitter-filled arc chute as it is propelled higher. When the air circuit breaker is operating, the arc in the chute will get colder, extend, and divide, causing the arc voltage to exceed the system voltage. As a result, the arc is eventually quenched during the current zero[9], [10].

Air Circuit Breaker Benefits

Compressed air at a pressure of 20–30 kg/cm2 is used as an arc quenching medium in air blast circuit breakers. Circuit breakers with air blasts are appropriate for 132 kV and higher operating voltages. Normally, equalizing capacitors and switching resistors are linked across the interrupters. Switching resistors assist to stop arcs by lowering transient overvoltages. To balance the voltage across the break, capacitors are used. The system voltage affects how often breakdowns occur. Below are some of the benefits and drawbacks of air blast circuit breakers:

1. The interrupting medium's low cost, free availability, chemical stability, and air inertness
2. Air blast circuit breakers benefit from fast functioning.
3. As opposed to oil circuit breakers, air blast breakers have the following advantages: • Short and uniform arcing times result in less contact burning;
4. Less maintenance is required for air blast circuit breakers.
5. They are suitable for regular use and provide the potential for rapid closing.
6. For all current values, the arc's temporal length is constant.
7. They are appropriate for repeated procedures.
8. Because of the lower arc energy, it is employed in situations where frequent operation is necessary.
9. The circuit breaker's default speed is excessively higher.
10. Chemical staleness and inertness of air, as well as the cheapest and free availability of the interrupting medium.
11. As with oil circuit breakers, the fire threat is removed.
12. A high-speed re-closure facility.
13. There is reduced contact time due to short, constant arcing times.

Disadvantages of Air Circuit Breaker

1. Installation and upkeep of an air compressor plant are required.
2. When an arc is interrupted, an air blast circuit breaker discharges air into the open atmosphere, which creates a lot of noise.
3. There is a problem with current hopping in the air blast circuit breaker.
4. The issue of re-striking voltage exists.
5. There is a potential issue with air pressure leakage coming from the air pipe junction side.
6. The possibility of a high rate rise in re-striking current as well as the issue of voltage chopping exists.
7. A powerful air compressor is inside.
8. There is a current chopping issue in the air blast circuit.
9. When air is discharged into the open atmosphere, this air blast circuit breaker makes a lot of noise.

Application of Air Circuit Breaker

A low-voltage circuit is protected by an air circuit breaker, which is primarily used to turn on and off high currents. It serves as the master of a factory, a building, and a ship's main circuit breaker. Depending on the application, various accessories may be attached.

Introduction to SF6 circuit breaker

Circuit breakers are used in electrical systems to prevent against fault current. They quickly interrupt the circuit and securely extinguish the arc. The simple act of separating the contacts is all that is required to break the circuit, but the arc that results, which prevents the circuit from breaking and causes damage, must be quenched as soon as possible. The voltage, the distance between the contacts, the temperature, the pressure, and many other factors all affect how strong the arc is. There are several methods and media that may be used to quench the arc. One of the many different kinds of circuit breakers that employs SF6 gas as the arc quenching medium to safely break the high voltage circuit is the SF6 circuit breaker. A form of circuit breaker known as an SF6 circuit breaker puts pressure on SF6 gas to put out an arc. It is a dielectric gas that is far better than air or oil at insulating and quenching arcs. In power plants, electrical grids, etc., it is utilised for arc quenching in high voltage circuit breakers up to 800 kV. Sulfur hexafluoride gas is used as an arc quenching medium in SF6 circuit breakers. Because of its high dielectric strength, which makes it an effective arc quenching medium, SF6 gas is employed. An electro-negative gas with a significant ability to take in free electrons, SF6. When SF6 gas is flowing at a high pressure, the circuit breakers' contacts open, and an arc forms between them. The arc's free electrons are immediately absorbed by gas to create negative immobile ions, which causes the arc to swiftly cool. The inert, non-toxic, non-flammable gas known as SF6 is used to make circuit breakers with voltage ratings ranging from 6.6 kV to 760 kV. At atmospheric pressure, SF6's dielectric strength is 2.35 times greater than that of air.

The electronegativity of SF6 gas is quite high. It strongly prefers to take up free electrons. The free electrons are absorbed when an arc is created between the contacts. Negative ions are produced as a result, and they are heavier than electrons. Its movement is restricted by its weight. Since the movement of charges is what causes current flow, the limited mobility of the charges in SF6 gas improves the dielectric strength of the medium. The term "SF6 circuit breaker" refers to a device that uses SF6 under pressure gas to put out an arc. Excellent dielectric, arc-quenching, chemical, and other physical characteristics of SF6 (sulphur hexafluoride) gas have shown its superiority over alternative arc-quenching media like oil or air. The three primary varieties of SF6 circuit breakers are:

1. Non-puffer piston circuit breaker
2. Double-puffer piston circuit breaker.
3. Single- puffer piston circuit breaker.

The arc extinguishing force develops up in the circuit breaker that employed air and oil as an insulating medium relatively slowly following the movement of contact separation. With high voltage circuit breakers, rapid arc extinction features are implemented, which take less time and result in faster voltage builds up. Comparing SF6 circuit breakers to oil or air breakers, they have better characteristics in this area. Therefore, SF6 circuit breakers are employed in high voltage systems up to 760 kV.

Properties of Sulphur hexafluoride Circuit Breaker

Sulfur hexafluoride has excellent arc quenching and insulating properties. It is a colourless, odourless, non-toxic, and non-flammable gas, among other qualities.SF6 gas has five times the density of air, is extremely stable and inert, has a higher thermal conductivity than air, which helps it cool current-carrying parts more effectively, and is strongly electronegative, which makes free electrons in discharge easily removed by the formation of negative ions.After the source energising spark is eliminated, it has the unusual property of quick recombination. Its dielectric strength is 2.5 times that of air and 30% less than that of dielectric oil, making it 100 times more effective than arc quenching medium. The gas becomes more dielectrically strong at high pressure.Moisture may seriously damage SF6 circuit breakers. When the arc is broken, SF6 gas and humidity combine to create hydrogen fluoride, which can damage the circuit breakers' internal components.

Construction of SF6 Circuit Breakers

The interrupter unit and the gas system are the two major components of SF6 circuit breakers. Disruptor Unit. This device comprises of a series of current-carrying components, an arcing probe, and movable and stationary contacts. It is linked to the SF6 gas storage facility. Slide vents in the movable contacts of this machine allow high-pressure gas to enter the main tank. SF6 circuit breakers use a closed circuit gas system. Because the SF6 gas is expensive, it is recycled after every procedure. This device has low- and high-pressure chambers as well as warning switches and a low-pressure alarm. This system emits a warning signal when the gas pressure is extremely low, endangering the breakers' capacity to quench arcs and causing a fall in the dielectric strength of gases (Figure 2.1).

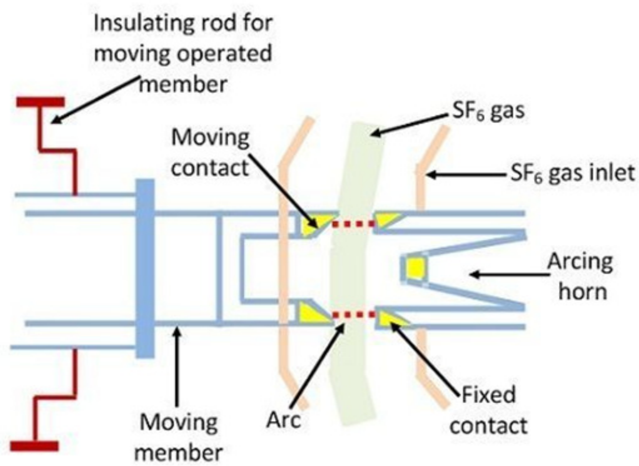

Figure 2.1: Representing the Construction of SF6 Circuit Breakers.

The fixed contact is an arcing 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 likewise a hollow cylinder with rectangular holes on the sides. Copper-tungsten arc-resistant material is applied to the tips of the fixed contact, moving contact, and arcing horn. Because SF6 gas is expensive, it is cleaned and recovered by an appropriate auxiliary system after each breaker action.

Working and Application of SF6 Circuit Breaker

The breaker's contacts are closed when it is working normally. The contacts are pushed apart and an arc is created between them when the system malfunction occurs. The valve that enters the high-pressure SF6 gas in the arc interrupting chamber at a pressure of about 16 kg/cm2 causes the displacement of the moving contacts to be synchronised with that of the valve. By absorbing the free electrons in the arc path, the SF6 gas creates ions that are not charge carriers. These ions make the gas more dielectric, which causes the arc to go out. The SF6 gas is kept in the low-pressure reservoir after this operation lowers its pressure to 3 kg/cm2. To be reused, this low-pressure gas is drawn back to the high-pressure reservoir. These days, arc quenching pressure is produced during an opening operation by use of a piston connected to the moving contacts.

Alternately, we may state that when the SF6 circuit breaker is closed, SF6 gas still surrounds the contacts at a pressure of around 2•8 kg/cm2. The movable contact is pushed 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 consequence, 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.

The first version SF6 CB operated relatively simply and resembled an air blast circuit breaker to some degree. A high-pressure reservoir was used to compress and store SF6 gas in this instance. This highly compressed gas is released during the operation of an SF6 circuit breaker via the arc in the breaker, collected in a comparatively low-pressure reservoir, and then pumped back to the high-pressure reservoir for further use. In the present day, SF6 circuit breakers operate somewhat differently. The SF6 CB is significantly simpler to use thanks to the invention of the puffer type design. In a buffer type design, pressure is created in the arcing chamber for arc quenching by using the arc energy. Here, SF6 gas is pumped into the breaker at the necessary pressure. Two fixed contacts are installed with a certain contact gap. These are connected to permanent contacts via a sliding cylinder. Along the contacts, the cylinder is axially slideable upward and downward. One stationary piston is located within the cylinder and is attached to the other stationary components of the SF6 circuit breaker in such a manner that it cannot move while the cylinder is in motion. The SF6 circuit breakers are used because the cylinder is sliding or moving but the piston is stationary. Applications

A standard SF6 circuit breaker is made up of interrupter units, each of which can handle currents up to 60 kA and voltages between 50 and 80 kVA. The number of units linked in series depends on the voltage of the system.For voltages between 115 kV and 230 kV, power ratings between 10 MVA and 20 MVA, and interrupting times under 3 cycles, SF6 circuit breakers have been designed. The primary purpose of SF6 circuit breakers is to safeguard extremely high voltage circuits up to 800 kV against fault current. A high voltage circuit may be safely broken and depowered for any kind of inspection or maintenance. Each interrupter unit has an 80 kV range handling capacity of 60 kA. According to the system, several interrupter units are linked in series to improve their ability to handle voltage. They are used to safeguard electricity distribution and transmission networks. They are included into power producing facilities and electrical infrastructures. When tripped by a protective relay, sulphur hexafluoride circuit breakers safeguard electrical power plants and distribution networks by halting electric currents. A sulphur hexafluoride circuit breaker uses sulphur hexafluoride (SF6) gas to cool and quench the arc when opening a circuit rather than oil, air, or a vacuum.

SF6 Circuit Breakers Advantages

SF6 circuit breakers are used for high voltage applications and above due to the characteristics of SF6 gas, such as good arc quenching, strong electronegative nature, and great dielectric strength. The following are some benefits of SF6 circuit breakers:

1. Compared to oil or air circuit breakers, SF6 gas has excellent arc quenching capabilities, which gives SF6 circuit breakers significant benefits. Following is a list of some of them:
2. Such circuit breakers have a very low arcing time because of the excellent arc quenching characteristic of SF6.
3. Such breakers may stop substantially bigger currents because SF6 gas has a dielectric strength that is 2 to 3 times greater than that of air.
4. Unlike the air blast circuit breaker, the SF6 circuit breaker operates quietly thanks to its closed gas circuit and lack of emissions to the environment.
5. The inside is kept dry by the closed gas enclosure, eliminating any moisture issues.
6. SF6 gas is not flammable, hence there is no danger of fire in these breakers.
7. Because there are no carbon deposits, tracking and insulating issues are resolved.

8. The SF6 Circuit breakers need less auxiliary equipment, have a light foundation requirement, and have minimal maintenance costs.
9. SF6 breakers are completely contained and isolated from the environment, making them especially ideal for places where there is a risk of explosion, such as coal mines.
10. Pure SF6 gas has no hazardous properties.
11. Since SF6 gas is non-flammable, there is no risk of fires. Additionally, since it runs without a hitch, maintenance is minimal.

Disadvantages of SF6 Circuit Breakers

Somewhat suffocating is SF6 gas. When there is a leak in the breaker tank, SF6 gas, which is heavier than air, settles in the surrounding area and suffocates the operational staff.The SF6 breaker tank is very vulnerable to moisture intrusion, which leads to many failures.The particular facility is necessary for transporting and maintaining the quality of gas. The internal components need cleaning during periodic maintenance in a dry and clean environment.

Introduction to Vacuum Circuit Breaker

In the year 1960, the vacuum interrupter technology was first made available. It is still a developing technology, however. The vacuum interrupter's size has decreased over time from that of the early 1960s as a result of several technological advancements in this area of engineering. A circuit breaker is a device that shuts off an electrical circuit to stop excessive current from flowing as a consequence of a short circuit, which usually happens as a result of an overload. Its fundamental role is to stop current flow when a defect is found. Vacuum circuit breakers are breakers that employ vacuum as an arc extinction medium. The fixed and movable contacts of this circuit breaker are encased in a permanently sealed vacuum interrupter. As the contacts separate in a high vacuum, the arc is extinct. It mostly handles medium voltage systems between 11 KV and 33 KV. Compared to conventional circuit breakers, vacuum circuit breakers have a higher insulating medium for arc extinction. The vacuum interrupter has a pressure of around 10-4 Torr, and there aren't many molecules within the interrupter at this pressure. A circuit breaker that conducts arc quenching in vacuum is known as a vacuum circuit breaker. The technique is mostly appropriate for applications requiring medium voltage. Though developed, higher voltage vacuum technology is not yet economically feasible. The vacuum chamber in the breaker known as the vacuum interrupter is where the opening and shutting of current-carrying contacts and the arc interruption that results from this action happen.

The vacuum interrupter comprises of ceramic insulators that are symmetrically positioned around a steel arc chamber in the centre. A vacuum interrupter typically maintains a vacuum pressure of 10- 6 bar. The vacuum circuit breaker's performance is significantly influenced by the material selected for the current-carrying contacts. The best material to manufacture VCB connections is Cu/Cr. In the year 1960, vacuum interrupter technology was first developed. It is still a developing technology, however. The vacuum interrupter is becoming smaller over time compared to how big it was in the early 1960s because of many technological advancements in this area of engineering. The contact geometry is likewise becoming better with time, going from the early butt contact to spiral, cup, and axial magnetic field contact. For medium voltage switchgear, the vacuum circuit breaker is now acknowledged as the most dependable current interruption device. Comparatively speaking to other circuit breaker systems, it needs the least maintenance. The vacuum circuit breaker primarily has two extraordinary qualities.

Vacuum is a better dielectric medium when compared to other insulating materials used in circuit breakers. With the exception of air and SF6, which are used at high pressure, it is superior to all other media.When contacts are moved apart to open an arc in a vacuum, the initial current zero experiences an interruption. Compared to other breakers, their dielectric strength rises with the arc disruption by a factor of thousands.The breakers are more effective, smaller and less expensive because to the aforementioned two characteristics. They need essentially little maintenance and have a significantly longer service life than any other kind of circuit breaker.

A particular kind of circuit breaker where the arc quenching occurs in a vacuum medium is known as a vacuum circuit breaker. In a vacuum chamber within the breaker called a vacuum interrupter, the action of turning on and off current-carrying contacts as well as associated arc interruption takes place. A vacuum circuit breaker is one that uses vacuum as the arc quenching medium because vacuum has excellent arc quenching properties and provides high insulating strength. The majority of standard voltage applications may utilise this because higher voltage applications can employ developed but not yet commercially viable vacuum technology. The vacuum chamber of the breaker, sometimes referred to as the vacuum interrupter, is where the functioning of the current-carrying contacts and the associated arc interruption take place. In the middle of the symmetrically arranged ceramic insulators in the heart of this interrupter lies a steel arc chamber. Vacuum interrupters may maintain vacuum pressure between 10 and 6 bars. The performance of vacuum circuit breakers is mostly determined by the current-carrying contact material, such as Cu/Cr.

Construction of Vacuum Circuit Breaker

When compared to other circuit breakers, its construction is quite straightforward. Fixed contacts, moving contacts, and an arc shield that is housed within an arc interrupting chamber make up the majority of their structure. Glass makes comprises the vacuum circuit breaker's exterior envelope because it makes it easier to examine the breaker after an operation from the outside. If the glass changes from its initial finish of a gleaming mirror to milk, it means the vacuum in the breaker is depleting. The breaker's fixed and movable contacts are positioned within the arc shield. When a vacuum interrupter seals off, the pressure is maintained at around 10-6 torr. Depending on the operating voltage, the moveable contacts of the circuit breaker may move 5 to 10 mm. The movable contacts are moved by the stainless steel metallic bellows. The life of the vacuum circuit breaker relies on the capacity of the component to execute repeated operations properly, thus the design of the metallic bellows is crucial (Figure 2.2).

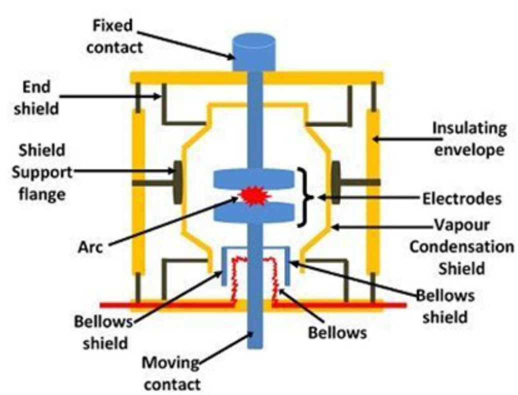

Figure 2.2: Representing the Vacuum Circuit Breaker.

A circuit breaker is a device that shuts off an electrical circuit to stop excessive current from flowing as a consequence of a short circuit, which usually happens as a result of an overload. Its fundamental role is to stop current flow when a defect is found. A particular kind of circuit breaker where the arc quenching occurs in a vacuum medium is known as a vacuum circuit breaker. A vacuum chamber within the breaker known as the vacuum interrupter is where the action of turning on and off current carrying contacts and accompanying arc interruption takes place.

Working and Application of Vacuum circuit breaker

According to the vacuum circuit breaker's operating theory, when the contacts of the circuit breaker are opened in a vacuum, an arc may be produced between the contacts due to the ionization of metal vapors in the contacts. However, the arc is swiftly extinguished because the metallic vapors, electrons, and ions that are produced during the arc quickly condense over the outsides of the CB contacts, allowing the dielectric strength to be quickly restored. The most crucial characteristic of a vacuum is that, once an arc has been created there, it may be swiftly put out thanks to the vacuum's rapid increase in dielectric strength. The contacts of the breaker are pulled apart when a failure in the system occurs, which causes an arc to form between them. Ionization happens as a result of the extremely high temperature created when the current-carrying contacts are forced apart. Ionization causes a vapor of positive ions to be expelled from the contact material, filling the contact area.

The current in the arcing affects the density of the vapor. Their rate of vapor release falls due to the lowering mode of the current wave, and once the current is zero, the medium regains its dielectric strength provided the vapor density near the contacts decreases. As a result of the metal vapour being swiftly evacuated from the contact zone, the arc does not ignite again. The Vacuum Circuit Breaker operates by ionizing the metal vapor in the contact, which causes an arc to form between the contacts once the circuit breaker is activated within the contact vacuum. However, the arc is quickly put out. To rapidly reach dielectric strength, fast electrons, ions, and metallic vapour are produced in the outer region of the circuit breaker contact. The vacuum's ability to rapidly boost its dielectric strength when an arc is formed inside of it makes it the most crucial component of an electrical system.

Properties of Vacuum Circuit Breakers

Compared to other kinds of circuit breakers, the vacuum circuit breaker has a high arc extinction insulating medium. There are extremely few molecules present in the vacuum interrupter, which has a pressure of around 10-4 torr. The majority of this circuit breaker's exceptional qualities are as follows:

1. This circuit breaker is a better dielectric medium when compared to other insulating media used in circuit breakers. Other than SF6 and air, which are employed at high pressure, it is superior to other media.
2. An arc will break at the main current zero after it has been opened independently by moving the contacts in a vacuum. In comparison to other types of breakers, their dielectric strength will improve up to a thousand times by interrupting this arc.
3. The circuit breakers will be more effective, lighter, and less expensive thanks to these qualities. These circuit breakers have a longer lifespan than ordinary circuit breakers and don't need any maintenance.
4. Vacuum interrupter, terminals, flexible connections, support insulators, operating rod, tie bar, common operating shift, operational corn, locking cam, making spring, breaking spring, loading spring, and main link are the components of vacuum circuit breakers.

Different Types of Vacuum Circuit Breakers

Mitsubishi Vacuum Circuit Breaker

Mitsubishi Electric is the manufacturer of these circuit breakers. High levels of safety, dependability and environmental protection are offered. The following characteristics apply to Mitsubishi VCBs.

1. The product selection is extensive.
2. There is no requirement for the six specific hazardous materials.
3. The name of the material is displayed over the major plastic components.
4. The framework can be folded to mount it.

REFERENCES

[1] A. J. Robinson, J. Colenbrander, G. Byrne, P. Burke, J. McEvoy, en R. Kempers, “Passive two-phase cooling of air circuit breakers in data center power distribution systems”, *Int. J. Electr. Power Energy Syst.*, 2020, doi: 10.1016/j.ijepes.2020.106138.

[2] Z. Ma, Z. Peng, C. Zhao, en T. Xu, “Research and Development of 5 kV High-speed Medium-voltage DC Air Circuit Breaker”, *Gaodianya Jishu/High Volt. Eng.*, 2020, doi: 10.13336/j.1003-6520.hve.20190410015.

[3] J. Li en F. Tartarini, “Changes in air quality during the COVID-19 lockdown in singapore and associations with human mobility trends”, *Aerosol Air Qual. Res.*, 2020, doi: 10.4209/aaqr.2020.06.0303.

[4] H. Heiermeier en R. B. Raysaha, “Evolving Fault and Parallel Switching for SF6 Circuit Breakers”, *IEEE Trans. Power Deliv.*, 2020, doi: 10.1109/TPWRD.2019.2922111.

[5] X. Xiong en P. Wang, “Cam Optimization Design of Spring Operating Mechanism of Vacuum Circuit Breaker”, *Gaoya Dianqi/High Volt. Appar.*, 2020, doi: 10.13296/j.1001-1609.hva.2020.11.019.

[6] X. Li, Y. Liu, H. Cao, en P. Xu, “Discussion on Insulation Performance of 40.5 kV Air-insulated Switchgear”, *Gaoya Dianqi/High Volt. Appar.*, 2020, doi: 10.13296/j.1001-1609.hva.2020.10.019.

[7] J. Lou, A. Liu, en S. Yu, “A Reliable and Controllable Motor Actuator without Permanent Magnetic for 40.5 kV Vacuum Circuit Breakers”, *IEEE Trans. Ind. Appl.*, 2020, doi: 10.1109/TIA.2019.2960214.

[8] B. Niu *et al.*, “Fault Analysis of Pre-insertion Resistors for 800 kV Circuit Breakers in AC Filters Field”, *Gaoya Dianqi/High Volt. Appar.*, 2020, doi: 10.13296/j.1001-1609.hva.2020.07.006.

[9] R. Nakayama, C. Ou, S. Zen, en K. Yasuoka, “Dielectric strength of electric contacts after short-duration arc in a hybrid DC circuit breaker”, *IEEJ Trans. Electr. Electron. Eng.*, 2020, doi: 10.1002/tee.23102.

[10] T. Liu *et al.*, “Field-Time Breakdown Characteristics of Air, N2, CO2, and SF6”, *IEEE Trans. Plasma Sci.*, 2020, doi: 10.1109/TPS.2020.2991860.

CHAPTER 3

SIEMENS VACUUM CIRCUIT BREAKER

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The SION 3AE5 Siemens vacuum circuit breakers are employed in all common switching applications, including industrial networks and medium-voltage power distribution, where they can handle short-circuit currents and switching loads up to busbar sections or connecting networks. It will be less necessary to use various panels thanks to their sturdy construction and minimal depth and breadth dimensions. Therefore, these circuit breakers are available via an optional grounding switch for permanent installation and plug-in variants. These are some of this circuit breaker's key attributes.

1. High reliability,
2. Compact design,
3. Remote switching through the remote control unit,
4. Low planning costs, extended service life,
5. Ease of maintenance.
6. Very simple installation inside air-insulated medium voltage switchgear[1], [2].

Vacuum Circuit Breaker Testing

The performance of the various switching mechanisms as well as the timing of the whole tripping system are often tested through circuit breaker testing. After vacuum interrupters are created or put to use in the field, three primary types of tests are employed to verify their functionality: the contact resistance test, the high potential withstand test, and the leak-rate test.

Vacuum Circuit Breaker Benefits

Vacuum circuit breakers don't need to be filled with extra oil or gas. They don't need routine replenishing.After adequate contact separation, there is a quick return of high dielectric strength on current interruptions when arcing lasts just a half cycle or less.Breaker unit is portable and all-in-one. Vacuum circuit breakers are quite popular due to the aforementioned factors as well as the economic benefit they provide. It may be fitted in any needed orientation.

Vacuum Circuit Breaker Drawbacks

Vacuum interrupters must be produced using advanced technology.Additional surge suppressors are required to prevent the interruption of certain low magnetising currents.If the interrupter loses vacuum as a result of transport damage or failure, the whole device is rendered worthless and cannot be fixed on the spot.

Uses for Vacuum Circuit Breakers

Vacuum circuit breakers are very helpful as very high speed making switches in many industrial applications because to their narrow gap and quick recovery.These breakers clearly outperform conventional breakers when the voltage is high and the current to be interrupted is low.In compared to other interrupting devices, the price is reasonable for modest fault interrupting capabilities.These breakers are ideal for systems requiring voltage between 11 and 33 kV because they require little maintenance[3], [4].

Outdoor Circuit Breaker and Indoor Breaker

Protective devices are added to the system to safeguard it from any defective conditions. One of any electricity system's primary protection devices is the circuit breaker. It responds swiftly to anomalous conditions and clears faults extremely quickly. In the fields of electronics and electricity, circuit breakers are crucial. To stop severe damage to buildings, offices, buildings, schools, businesses, etc., circuit breakers are utilised. It is simple to stop the current from overheating once the circuit breaker has been installed. The harm might be avoided. A circuit breaker is a switching mechanism that may be used to govern and safeguard an electrical power system, respectively, both manually and automatically. Based on several classifications, there are many kinds of circuit breakers. Due to the large currents that the contemporary power system handles, extra consideration should be given while designing the circuit breaker to the safe interruption of the arc created during the circuit breaker's operation. It should be mentioned that there are several methods in which we may classify circuit breakers for simpler comprehension and knowledge of the functioning circumstances of the device rather than particular criteria for doing so. These multiple classifications may be made in accordance with the circuit breaker's operating medium, the signal that activates it, various construction and operation principles, etc.

High voltage vacuum indoor and outdoor circuit breakers have a broad range of applications in power plants, substations, and other monitoring and usage. For instance, current indoor and outdoor vacuum circuit breakers are the first domestic indoor and outdoor vacuum circuit breakers to reach maintenance-free concept. Other examples include chemical factories, steel mills, automation facilities, airports, and power supply components of huge structures. The arc-extinguishing system's maintenance-free functioning is guaranteed by the high-life vacuum interrupter, which has a highly dependable working mechanism and is constructed using epoxy-casting and sealing technology. A completely electronic power supply and an intelligent control unit are used in the electronic control section to enable maintenance-free electronic control, replacing the standard auxiliary switch with a photoelectric proximity switch. In the switch cabinet, the interior vacuum circuit breaker is often utilised, mostly to stop the current. Larger than the indoor circuit breaker is the outdoor high voltage vacuum circuit breaker. The distance from the ground to the bare conductor is 0.125 metres, or more than 2.5 metres. Because of its size, the form cannot be placed. Outdoor high-voltage vacuum circuit breakers are often mounted on the column in the switchgear. Because the creepage ratio between indoor and outdoor vacuum circuit breakers differs, indoor vacuum circuit breakers cannot be used outdoors to ensure the charging distance[5], [6]. The remote controller can be realised by the indoor and outdoor circuit breakers, and the current transformer and voltage transformer may be set up, compassion of both circuit breakers as shown in Table 3.1.

Table 3.1: Illustrating the Comparison of Indoor and Outdoor Circuit Breakers.

Content	Indoor Substation	Outdoor Substation
Definition	An interior substation is a substation that is installed for low voltage needs within a building's structure.	An outside substation is a substation that is installed outside a building's structure to meet high voltage requirements.
Construction	The indoor substation's construction is challenging.	The outdoor substation's construction is not more difficult.
Voltage	These substations can supply voltage up to 66kV.	These substations are designed to operate at voltages higher than 66 kV.
Location	The indoor substations are typically located inside the building.	Outside the building are the external substations.
Types of equipment's of Substation	The indoor substation's equipment is difficult to see.	The outdoor substation's equipment is simple to visualize.
Space Required	A small area is necessary.	There is required plenty of space.
Installation	Indoor substation installations are difficult to scale up.	The installation of outdoor substations can be easily expanded.
Cost	The indoor substation is inexpensive.	The outdoor substation is expensive.
Fault Condition	Very simple to fix the problem.	It is very challenging to fix the problem.
Maintenance	High maintenance is needed for indoor substations.	Substations that are outdoors require less upkeep.
Repairing & Replacement	The indoor substation's equipment is difficult to repair and replace.	The outdoor substation's equipment is easily replaceable and repairable.
Additional	It does not need further	Additional defense against things

Protection		like dust and lightning is crucial.
Safety (for the human being)	Substations inside are significantly safer.	Substations that are outside are not much safer.

High-voltage circuit breakers

Circuits with voltage ratings more than 600 volts are serviced by high-voltage circuit breakers, including intermediate voltage breakers. These circuit breakers typically have voltage ratings between 4,160 and 765,000 volts and three-phase interrupting values between 50,000 and 50,000,000 kVA. The majority of high-voltage circuit breakers used in the early phases of electrical system development were oil circuit breakers. Air circuit breakers of the compressed-air and magnetic types, however, have been created and are now in use. At 13,800 volts, the magnetic air circuit breaker has a rating of up to 750,000 kVA. With the help of magnetic blowout coils, this kind of circuit breaker prevents the flow of air between two detachable contacts. During a fault state, the arc is dragged out horizontally and transmitted to a series of arcing contacts as the current-carrying contacts split. The blowout coil also creates a magnetic field that pulls the arc up into the arc chutes simultaneously. The arc speeds upward into the arc chute, where it is lengthened and split into several little segments thanks to the blowout coil's magnetic field and heat processes. This kind of circuit breaker has a similar design to a big air circuit breaker used in low-voltage applications, but they are entirely electrically controlled instead of using air[7]–[9].

A circuit breaker is a kind of electrical switching mechanism that may be used either manually or automatically to safeguard and regulate the electrical system. The majority of high voltage circuit breakers use a spring charge to supply mechanical power. The spring is often charged by a DC motor through a gear system, however it may also include a manual spring charge option. The closing or tripping coils for the corresponding actions drive a mechanism that releases the spring; these coils are a linear solenoid actuator that transmits electrical signals. The coils need to receive a control signal during both manual and automated operations. The breaker is typically closed or opened remotely by a switching device using a manual action. While the tripping circuit, which is activated in the case of a defect brought on by overload, short circuit, etc., performs the automated tripping.

Classification of High Voltage Circuit Breaker

These High Voltage Circuit Breakers can be used for indoor or outdoor applications, and they fall under the following general categories.

1. Oil circuit breakers (OCBs)
2. SF6 Circuit Breakers
3. Air circuit breakers
4. Vacuum circuit breaker (VCB)

Below is a brief description of the aforementioned types. The contacts on circuit breakers are submerged in oil. Current disconnect occurs in oil, which cools the arc that forms and controls it. This oil circuit breaker has three poles and is used to protect three phases. The large high-voltage circuit breakers have each pole in a separate oil tank, whereas the poles of small oil circuit breakers can be combined in a single oil tank. Oil circuit breakers typically have sealed oil tanks. Through porcelain bushings, electrical connections are made between the contacts and external circuits. The following are benefits of using oil as an arc-quenching medium, which we must take into account before using oil.

1. Has a high dielectric strength
2. Cold oil is able to act as an insulator
3. Oil is very good insulator

High Voltage Circuit Breaker Applications

It is used to safeguard modest voltage transformers. In the railway system, it is used.ABC is also utilised in an electrical sharing system and in industrial facilities where there is a significant risk of explosion or fire.They are helpful for maintaining switchgears and interior medium voltage.It is used to safeguard distribution lines in Small and Medium substations.Due to their minimal maintenance needs, they are often utilized for voltage transmission lines in remote locations.VCB is used in substations and generators.Due to their extended lifespan, they are often utilized in trains, highways, subways, and airports.The vacuum circuit breaker is the kind of circuit breaker that is most often used in the construction sector since it requires less maintenance.VCB is widely utilised in data centres; it is employed in the nuclear business.
The primary electrical component used in the building and urban development sectors is vacuum circuit breakers.

How High Voltage Circuit Breakers Work

Electrical power is used to activate the HT circuit breaker. It operates on the idea that, in the event of a failure, magnetic blowout coils intercept the arc between the fixed and moving contacts. The contacts separate from one another during an overload, the arc advances horizontally, and the current is spread within the contacts. It is done to make sure the circuit is not harmed. The coils provide the arc a magnetic field that allows it to extend upward to the arc chute, where it is subsequently broken up into smaller pieces. The current-carrying high voltage lines generate a significant quantity of arcing between the conductor gaps when they are in operation. The HV circuit breakers put an end to this arcing and allow the feeders to run securely and dependably. Electrical switching devices known as circuit breakers are used to control and safeguard electrical systems that are controlled manually or automatically. These tools may be used to stop the flow of electrical current and stop harm caused by a short circuit or an overcurrent. Circuit breakers come in a few distinct varieties and may be utilized in a variety of electrical systems at varied voltages, either medium or high. In this post, we'll examine the various high voltage circuit breakers that could be present in a substation.

Low-Voltage Circuit Breakers

Low-voltage circuit breakers use main contacts that split in the open to stop short- and overload failures. These breakers are also known as air circuit breakers, in contrast to medium-voltage circuit breakers, which often use vacuum interrupters (ACB). Circuit breakers, switching devices, are primarily used to isolate certain parts of an electrical distribution system under abnormal circumstances. System vulnerabilities that might lead to unusual scenarios are often the root cause of dangerous situations for both people and the system. Circuit breakers not only provide system security but also enable the isolation of certain electrical distribution zones for usage and maintenance. In this note, certain circuit breaker concepts are summarised along with how they relate to low voltage power systems. Low-voltage power networks use a kind of electrical distribution apparatus known as a low-voltage circuit breaker (AC distribution equipment with an AC rated voltage of 120 volts or less and a DC distribution equipment with a DC rated voltage of 1200 volts or less). Low-voltage circuit breakers are defined as: Switching devices that connect, carry, and break currents under typical circuit conditions may also be switched on, carrying current for a certain period of time under predetermined abnormal situations, and breaking current under such circumstances (such as overload, short circuit, undervoltage, and single-phase ground fault). It was once known as an air circuit breaker, an air switch, and an automated switch (air switch, air switch).

Classification of Low-voltage Circuit Breakers

Low-voltage circuit breakers may be divided into the following groups based on its application, function, and design: Vacuum and phase selection closed type, universal type (also called frame type), plastic case type, de-excitation type, explosive type, etc. The last four are only used in unusual circumstances, thus they won't be addressed here. There are two main types of circuit breakers: universal type and plastic container (mold compression moulded case). Depending on their use categories, the IEC standard from the International Electrotechnical Commission and the associated standards from my country are further divided into two types: A and B.

Type A: It describes the selective protection of a distinct short-circuit protection device connected in series on the load side by the circuit breaker in the case of a short circuit. This kind of circuit breaker is not required to have a rated short-time withstand current, with the exception of short-circuit circumstances like selective protection. As a class A circuit breaker, it has a short-time withstand current that is equivalent to the usual value (12 in or 5 kA, and 30 kA when in> 250OA is as little as 30 kA). Several miniature circuit breakers, circuit breakers with moulded cases, and a few universal circuit breakers with low current requirements are all included in Class A. Its main feature is that it only executes two protection phases, with significant delays for overload and immediate short circuit.

Type B describes the selective protection of a short-circuit protection device in situations when a short circuit develops and the circuit breaker is visibly coupled in series on the load side. That is, a brief time delay (adjustable) is given for selective protection in the case of a short circuit. The majority of universal circuit breakers are class B devices, which need rated short-time withstand current.The plastic casing type using the intelligent controller is now included in category B. (trip). Its most notable features are the three-stage protection of overload long delay, short circuit transient, and short circuit short delay most effective for focused defence.

Circuit Breaker Maintenance

Circuit breakers that can be accessed for maintenance must be carefully inspected and cleaned often. Before trying to work on circuit breakers, properly read the applicable technical guide. Turn off the circuit breaker before working on it. Mark the switch that shuts off the circuit breaker's power so that it is not used while you are working. Manually flip the circuit breaker on and off many times to ensure sure the mechanism is operating smoothly. Look for corrosion or arcing-related pitting on the contacts. If pitting is obvious, polish the contacts using a fine file or sandpaper with a number 00. Make sure the contacts are making the proper contact before turning the working mechanism to the "on" position. To ensure that the wire and terminals are secure and corrosion-free, check the connections at the terminals. Check the wear and tightness of each piece of mounting hardware. Check each component for wear. Clean the circuit breaker entirely. After completing the circuit breaker, turn on the power again, and then remove the tag from the switch that controls the circuit.

Advantages of Low Voltage Circuit Breakers

This low voltage circuit breaker has to be temperature sensitive. Circuit board temperatures and current may be measured at different levels. The Low Voltage Circuit Breaker has a certain level of technology, so all you need is a piece of equipment that can handle both cold and heat. Even though there is only one main programme implemented, there is always a little improvement here. They see internal defence as their top concern. The internal communication of the gadget is also improving daily.Modern technology states that the LVCB has a long lifespan since it is made of durable materials. Due to its lower voltage and current range than a high voltage circuit breaker, it cannot survive as many breaches. There are a couple more breaks even if there aren't many people tolerating.

For another perfect use, a Low Voltage Circuit Breaker should last for a long period. It features two extraordinary adventures. Those are thermomagnetic and electronic travels. As more cutting-edge technology are incorporated into the circuit breaker, these excursions are increasing its lifespan. All low voltage circuit breakers now come with trip protection as a feature.This device controls a number of unpredictable phenomena, such as phase asymmetry, overcurrent, and overvoltage. It must thus be discernible to the applicant. For prompt emergency response, a power distribution capability that works properly is required.It has both electrical and mechanical components, just as if you focused on the parts. The system uses all updated parts, including spring charge motors, shunt trips, mechanical interlocks, extension busbars, under-voltage release, and others. Initially, there weren't many components needed to make a low voltage circuit breaker. Nevertheless, a range of elements are now used, depending on their applicability and the situation.

This device's fixed and withdrawal settings are right. Since it can withstand just 1000 volts, the device doesn't need a high voltage circuit breaker's design. But it has received the help it needs. The repairs and withdrawals are today built relatively large in order to withstand and exist for a long time, in contrast to how little they were when the LVCB was first established.Installing the low voltage circuit breaker is easy and portable. You just need a working knowledge of wiring and a few simple processes to get by. The most unique aspect of LVCB is that it may be positioned vertically or horizontally, among other directions.A circuit breaker has to be durable since its job is to protect other devices. It must be robust enough to shield any internal parts from damage. Many circuit breakers were originally in use. They were obliterated after receiving one pressure attack. To safeguard the internal components, low voltage circuit breakers, however, are now made of robust materials.A low voltage circuit breaker can easily find the short circuit. A short circuit is one kind of loop that causes high current flow. It might potentially be fatal and ruin all other electrical devices, in general. Therefore, the best way to get rid of it is to install a low voltage circuit breaker. It may detect issues before they become serious thanks to sensitive components that are installed.Last but not least, it needs very minimal maintenance. The device has an open type. The setup may be made and fixed by any electrician with a basic grasp of the subject. Make sure the structure is maintained so that it lasts a long time.

Circuit Breakers and theirs Importance

The circuit breaker will keep an eye on the circuit and will promptly turn it off if there is a problem. When too many high-power tools are hooked into a single circuit or when appliances or equipment malfunction, this is frequently known as "tripping a breaker" or "tripping a breaker." Imagine a household outlet that has a vacuum, a television, and a space heater plugged in. It is virtually guaranteed that this will result in a breaker trip, which will prevent access to and usage of that circuit until the issue is resolved and the breaker is reset and put back in its original location. Circuit breakers are perfect for the majority of ordinary uses. To provide protection, numerous tools, applications, and circumstances call for a separate power supply monitoring system, or a mix of them. This is why it's crucial to constantly read the instructions that come with any new electrical equipment, and it's a good idea to collaborate with licenced electricians when developing emergency power response systems. All electrical systems are required to include circuit breakers by law. Usually, they are all put together in a breaker box. Circuit breakers have a variety of uses, but its main function is to interrupt electricity (hence the name circuit breaker). When your electrical system experiences unusually high temperatures, an imbalanced current, or a short circuit, a breaker identifies the problem. It will trip if any of these unfortunate events occur. By doing so, the circuit is opened, stopping the flow of power.

One of your home's most crucial safety features and a need in the contemporary world is the circuit breaker. These simple devices interrupt electricity until an issue can be fixed if electrical wiring in a structure has too much current running through it. Household power would not be viable without circuit breakers (or the equivalent, fuses) because to the risk of fires and other havoc brought on by simple wiring issues and device failures. The "pressure" that causes an electric charge to move is voltage. The pace at which the charge passes through the conductor, as measured at any given location, is known as the charge's "flow," or current. Depending on the conductor's size and composition, it provides a specific level of resistance to this flow. You cannot adjust one without also affecting the others since voltage, current, and resistance are all interdependent. Voltage divided by resistance is equal to current (usually represented as $I = v / r$). This makes logical sense: Greater charge will flow if you exert more pressure on it or reduce the resistance. Less charge will flow if the pressure is reduced or the resistance is raised. Check out How Electricity Works for more information.

Your home receives energy from a power plant through the power distribution system. The electric current in your home travels via a large circuit that is made up of several smaller circuits. The hot wire at one end of the circuit connects to the power plant. The neutral wire at the other end connects to the ground. There is a voltage across the circuit anytime the circuit is closed because the hot wire is connected to a high energy source and the neutral wire is connected to an electrically neutral source (the earth). Because of its frequent direction shifts, the current is referred to as an alternating current. (For further details, see How Power Distribution Grids Operate. In the United States, the power distribution system provides electricity at a constant voltage of 120 or 240 volts, while resistance (and therefore current) vary inside a residence. A particular amount of resistance, also known as the load, is offered by each kind of light bulb and electrical equipment. The appliance operates because of this resistance.

For instance, the filament inside a light bulb is very resistive to flowing charge. The filament becomes heated as a result of the charge's difficult movement, which makes it glow. In wiring for buildings, the hot and neutral wires never come into direct contact. A device that serves as a resistor always receives the charge travelling through the circuit. This is how electrical resistance in devices restricts the amount of charge that can pass across a circuit (with a constant voltage and a constant resistance, the current must also be constant). For safety reasons, appliances are designed to maintain a relatively low level of current. The appliance's wires and the building's wiring would be heated to unsafe temperatures by too much current flowing through a circuit at one time, possibly igniting a fire. Because of this, the electrical system often functions without any problems. However, on sometimes, something may link the hot wire to the neutral wire or another source of ground directly. For instance, a melted fan motor might fuse the hot and neutral wires together due to overheating and melting. Or perhaps someone will unintentionally prick one of the power lines with a nail while hammering it into the wall. Because there is little resistance in the circuit when the hot wire is connected directly to ground, a lot of charge is forced through the wire by the voltage. If this keeps happening, the wires could overheat and catch fire.

Importance of Circuit Breakers

Fundamental components for a safe and code-compliant electrical installation are circuit breakers. Electrical devices and conductors are susceptible to failure and damage, and there is always a chance that a device may be improperly connected or used. A device may use more current than it is designed to under certain circumstances, and the accompanying circuit breaker may trip to isolate the problem. It is crucial to comprehend the differences between the two primary current situations that cause a circuit breaker to trip before giving an overview of circuit breakers. When a device consumes current that is somewhat over its rated amount but not significantly so, this is known as an overload current. For instance, an overload issue is probably present in a motor that is rated for 60 Amps but is requiring 75 Amps. When a live conductor hits another at a different voltage (a short circuit), or a conductive surface, a fault current that is orders of magnitude larger than the rated current of a circuit occurs (ground fault). In both situations, a low-resistance contact is made over a voltage differential, resulting in a high-magnitude current. A domestic circuit that typically carries 20 Amperes, for instance, may encounter a several thousand Amperes during a failure.

Under both scenarios, a circuit breaker must trip, although the appropriate trip action varies depending on the situation. There should be a delay in the reaction to an overload current. Some kinds of equipment operate normally by temporarily drawing more current than their rated value. Electric motors, for instance, may start up with an inrush current that is up to 8 times their rated current. A fault current should prompt an immediate reaction. Under any operating circumstances, these currents are abnormal, and they need to be eliminated right away. The majority of circuit breakers actually feature two safety mechanisms in a single device due to this mix of performance criteria. A magnetic protection system responds to fault currents, whereas a thermal protection mechanism reacts to overload current.

Circuit breakers have both benefits and downsides

Accidents often occur in the field of electrical and electronics. Buildings, offices, homes, schools, businesses, etc. will sustain significant damage. Despite the fact that safety precautions are taken, voltage and current cannot be trusted. Circuit breakers will regulate the fast increase of voltage and current after they are fitted. It will protect against any accidents. Circuit breakers resemble the electrical system's beating heart. Circuit breakers come in a variety of sorts, and they are placed based on the system rating. Distinct types of circuit breakers are utilised in homes, while a different kind is used in enterprises. Let's go into depth about the many kinds of circuit breakers and why they are important. Although they are often rather complex, electrical systems are something that everyone should have a fundamental grasp of. The main key benefits and drawbacks of the circuit breaker are provided in this article to help you understand this subject if you are unsure whether they are better options for the electrical systems in your home than infuses.

Advantages of circuit breaker:

1. It is more dependable and safeguards against damage brought on by excessive current flow.
2. Because it is operated by a switch, it can be reset.
3. It operates with great sensitivity.

Drawbacks of Circuit breakers

1. They are more expensive to install and maintain than fuses.
2. Compared to C/b, Fuse reacts more quickly.

The cost-effective functioning of contemporary systems depends on maintenance. One recent study found that one minute of downtime in the automobile sector, for instance, costs $22,000 on average. Unplanned downtime in the industrial sector costs as much as $50 billion annually, with 42% of the cost attributable to equipment failure.Additionally, maintenance may be crucial for safety: Without assurance that an aircraft has been adequately maintained, nobody would board it. In fact, the U.S. National Transportation Safety Board has shown that inadequate or inappropriate maintenance contributed to at least 1,503 aircraft incidents between 1988 and 1997, including 504 fatalities. Thus, it is obvious that proper maintenance is necessary for safety-critical equipment.All of this upkeep is quite expensive even though it's necessary. Paying employees, purchasing new components, and shutting down systems for upkeep are all necessary. In Finland, manufacturing enterprises spend up to 25% of their total revenue on maintenance, which equates to around 5.5% of their total revenue. Therefore, it is important to strike a balance between the impact of failures and the expense of maintenance.

This equilibrium is sometimes enforced from without: For instance, the U.S. Federal Aviation Administration establishes guidelines for the routine inspection of aeroplanes. However, asset managers often have the freedom to determine the value of maintenance on their own.A complete knowledge of the impacts of such maintenance is necessary to make an educated choice about when to apply what maintenance. This thesis's subject is as follows: We present techniques for analysing maintenance-required systems in terms of performance, by computing various metrics of the system dependability, such as availability, reliability, and expected number of failures over time, and cost, by calculating the costs of both maintenance and downtime, each of which can be divided into the costs of various maintenance actions and per-component failure costs.This makes it possible to improve the maintenance strategy by concentrating work and resources on the system's most efficient components, which may reduce costs and/or increase dependability.

Reliability Assessment

A basic definition of reliability is the quality of being dependable, or the capacity to rely on something. The capacity of a product or system to execute its intended functions for a certain period of time, under normal life cycle circumstances, is what is meant by reliability, according to a more formal definition. Dependability engineering aims to design and run systems in a manner that satisfies their dependability criteria.

We can see that the discipline of reliability engineering encompasses more important performance indicators for system dependability than just reliability. The so-called RAMS metrics—reliability, availability, maintainability, and safety—are the most crucial. These are described as follows:

1. Reliability is the consistency of quality service.
2. The readiness of the appropriate service.
3. The capacity for modification and repair.
4. Safety is the lack of incidents that might be disastrous for the user and the environment.

Other key performance indicators may be crucial for dependability depending on the system and context. Systems that are vulnerable to malevolent attackers, for instance, should also adhere to integrity standards. The RAMSSHEEP elements, which expand RAMS to encompass security, health, the environment, economics, and politics, are among the other additions.After determining a system's dependability needs, it is vital to determine how to satisfy those criteria. Reliability is first ensured during the design phase, when judicious usage of high-quality components and design patterns like redundancy aid. The design should also take into account how the system will operate, making maintenance easier, choosing components that will need less shipping, etc.

Reliability engineering usually comes to an end after the product has been created for short-lived items. For assets with longer lifespans, more effort is needed: During the system's operational life, one may continue to assure its dependability, for example, by keeping an eye on its performance, making minor design adjustments, and scheduling maintenance as needed. PDCA process. A system normally has to be maintained once it has been created and built. The planning of such maintenance is the focus of this thesis in order to prevent needless maintenance while maintaining high dependability. Long-lasting systems' maintenance procedures often need to change over time when parts begin to deteriorate and new knowledge about the system's behaviour comes to light.

The plan-do-check-act cycle, commonly known as the Deming cycle, is a well-liked framework for continuous improvement in product development and risk management. It is also used to maintain the maintenance policy up to date. The cycle is a method for achieving continual planned improvements for maintenance, to focus on maintenance particularly. There are four stages to it:

Plan: Create a maintenance schedule that will make sure the system satisfies its dependability standards.

Do: Follow the maintenance policy exactly as it is written.

Check: Compile information on the impact of the maintenance that was done. Identify any unforeseen issues or circumstances.

Act: The newly planned policy now becomes the new standard policy if the acquired data demonstrates that it is an improvement. Otherwise, the previous policy continues to be applicable. Any unexpected information discovered during the Check phase should, in any case, be included into the Plan phase of the next cycle.

Every time fresh data indicates revising the maintenance strategy, the cycle is repeated. Examples include parts wearing out sooner than anticipated, design modifications, or cost changes that alter the ideal ratio of preventative to corrective maintenance.

The PDCA cycle is continuously used to guarantee that new maintenance policies are only introduced when their efficacy is backed by data and allows for the incorporation of fresh insights into the maintenance plan.

Reliability assessment: One must examine the system and evaluate its RAMS features before deciding what, if any, changes should be made to it to boost dependability. A variety of broadly applicable methodologies have been developed in addition to extremely system-dependent assessments.

Fault tree analysis is the approach used in this thesis, and it will be explained in more depth below. Analysis of failure mechanisms and consequences is a supplementary technique. This spreadsheet-based approach lists all possible failure modes for each component of the system and details the impact of each failure mode separately. It is a rather straightforward technique for swiftly spotting possible reliability issues. Being one of the first dependability analysis techniques, the U.S. military adopted it as a standard in 1949.

REFERENCES

[1] Z. Zhao en C. S. McBride, "Evolution of olfactory circuits in insects", *Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology*. 2020. doi: 10.1007/s00359-020-01399-6.

[2] W. Bogaerts *et al.*, "Programmable photonic circuits", *Nature*. 2020. doi: 10.1038/s41586-020-2764-0.

[3] M. F. Gely en G. A. Steele, "QuCAT: Quantum circuit analyzer tool in Python", *New J. Phys.*, 2020, doi: 10.1088/1367-2630/ab60f6.

[4] S. Blumenstock en I. Dudanova, "Cortical and Striatal Circuits in Huntington's Disease", *Frontiers in Neuroscience*. 2020. doi: 10.3389/fnins.2020.00082.

[5] I. H. Kim *et al.*, "Dysregulation of the Synaptic Cytoskeleton in the PFC Drives Neural Circuit Pathology, Leading to Social Dysfunction", *Cell Rep.*, 2020, doi: 10.1016/j.celrep.2020.107965.

[6] J. Santos-Moreno, E. Tasiudi, J. Stelling, en Y. Schaerli, "Multistable and dynamic CRISPRi-based synthetic circuits", *Nat. Commun.*, 2020, doi: 10.1038/s41467-020-16574-1.

[7] Z. Lukács en T. Kristóf, "A generalized model of the equivalent circuits in the electrochemical impedance spectroscopy", *Electrochim. Acta*, 2020, doi: 10.1016/j.electacta.2020.137199.

[8] A. J. Robison, K. N. Thakkar, en V. A. Diwadkar, "Cognition and Reward Circuits in Schizophrenia: Synergistic, Not Separate", *Biological Psychiatry*. 2020. doi: 10.1016/j.biopsych.2019.09.021.

[9] J. R. Sanes en S. L. Zipursky, "Synaptic Specificity, Recognition Molecules, and Assembly of Neural Circuits", *Cell*. 2020. doi: 10.1016/j.cell.2020.04.008.

CHAPTER 4

MAINTENANCE OF POWER PLANT

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As was already established, maintenance is essential to the continuous operation of the majority of systems. Systems that aren't maintained often malfunction over time, requiring anything from simple jobs like routinely changing the batteries in your smoke detectors to time-consuming, difficult overhauls of whole power plants. Therefore, it's critical to comprehend what upkeep is required to maintain the system functioning well.On the other hand, excessive maintenance is costly and might actually make the system less functional. If you regularly get your automobile examined, it should last for many years with no issues. Additionally, rather of always being in a garage, it will only sometimes be utilised to serve its intended function. When done improperly, maintenance work might also compromise public safety, as was the case when an aircraft crashed because adhesive tape remained on its sensors following repair work. Therefore, the secret to a successful maintenance strategy is to develop a strategy that weighs these drawbacks against the increased dependability[1], [2].

Maintenance is defined as the steps needed to maintain a system operational or to get a failing system back up and running. This includes measures that are taken as part of a larger plan to enhance or maintain the condition but which have no direct impact on the state of the system.Determining the ideal time to do maintenance is one of the important planning problems. In general, there are three types of schedules for the timing: failure-based, use-based, and condition-based. In addition to the other schedules, opportunity-based maintenance is a fourth technique that may be used.

A failure-based approach is waiting for a component to break before replacing it. Such a run-to-failure method performs best on components for which either early maintenance cannot be avoided or for which breakdowns are less costly than maintenance.If waiting until a breakdown occurs is not an option because of the cost or other considerations, preventative maintenance of some kind is necessary. One of the schedules will normally be followed for such maintenance.

Use-based schedules only perform preventative maintenance after a certain level of system use has been met. The typical recommendation to change the batteries in your smoke detector once a year to ensure they never come too near to empty is an illustration of this. Advanced rules, like those that require oil changes for automobiles after a specific amount of miles traveled, depend their scheduling on how the system is actually used.The most sophisticated maintenance schedules are condition-based schedules. Here, the components' present state is assessed in some manner, and maintenance schedules are made with that information in mind. While a component in bad condition is replaced beforehand, a component in extremely excellent condition may simply be left alone for a while[3], [4].

The other maintenance strategies may sometimes be coupled with opportunity-based maintenance. Here, preventative maintenance is done by taking advantage of downtime caused by other factors. For instance, replacing any other worn tyres rather than driving on them for a few more weeks might be more cost-effective when a tyre on your automobile is worn out.

Predictive maintenance has recently gained popularity as a method for planning maintenance. This is an example of condition-based maintenance, in which maintenance is planned to avoid any projected failures using the system's present status to forecast its future behaviour. This kind of planning requires in-depth knowledge of how components deteriorate with time yet enables extremely high dependability with no needless maintenance.

A thorough grasp of how your system ages, the consequences of potential maintenance measures, and the information available to guide choices are essential to choosing amongst various techniques and figuring out the best plan within each of them. With this knowledge, it is possible to identify the activities that are most beneficial, the measures that best signal the timing of these actions, and the values of these metrics.We use the method of including the impacts of maintenance into the well-known reliability engineering formalism of fault tree analysis in order to acquire this insight optimization of maintenance. Since the early 1950s and 1960s, researchers have been trying to determine what maintenance planning is best. The majority of the effort at this time was devoted to estimating the probability distributions of the failure times of different components and developing the best replacement plans based on these distributions[5], [6].

The early work has the disadvantage that it mostly considers components in isolation, and it is much more difficult to identify an effective strategy for sustaining systems with diverse components with varied failure time distributions. Three different kinds of interdependence in multi-component maintenance are identified by Dekker et al.

Economic reliance, in which maintaining many components simultaneously may save maintenance costs.Structural dependency, where the organisation of the system requires simultaneous maintenance of many components. As an example, the circuit boards of many electronic systems are often changed as a whole rather than as separate parts.The failure of one component may provide information about the remaining lifespan of other components due to stochastic reliance.

You may find surveys of multi-component system maintenance models in and. Because the fault tree in this thesis incorporates stochastic dependencies and its inspection and repair models may have an impact on numerous components at once, it is important to emphasise that the fault maintenance trees mentioned in this thesis represent all three kinds of dependencies.

More recently, methods that can handle bigger systems have been devised, albeit at the cost of not yielding precise optima. The use of genetic algorithms to create the best possible rules for opportunity-based maintenance is one example. This thesis presents an analytical approach that may be used inside such an optimisation rather than an optimisation method in and of itself. In particular, many optimisation techniques include a model of the system's degradation and failure behaviour as well as a parameterized model of the maintenance policy. The maintenance policy's parameters are then optimised using techniques like genetic algorithms or integer-linear programming. If the optimisation technique can accept the statistical character of FMT analysis, FMTs may be employed as the model of the system and the maintenance in this situation.The universality of the framework is one advantage of FMTs. There is now a lot of work that shows models to improve maintenance plans for certain settings, such trains, but there is no obvious method to extend the models to other settings. FMTs, on the other hand, provide a broad method for building models for specific contexts. We hypothesise that FMTs can be employed in many disciplines, much as regular fault trees have been in several other industries[7], [8].

It has been shown that these external factors such as use patterns and ambient temperature—are the main reason for variance in the pace at which various components degrade. Monitoring these factors, as opposed to basic time-based maintenance, may thus result in improved maintenance policies, and modelling of these effects using otherwise deterministic deterioration models has been shown to be successful in maintenance optimisation. Through the RDEP gate, FMTs provide some support for these extraneous variables, but they primarily depend on their presence in the probability distributions of the degradation rates. This is especially relevant when, as in our case studies, the environment and use remain mostly constant during the course of the system, and ambiguity in the actual deterioration behaviour leads to more variance than outside influences.

In order to ensure successful maintenance, a number of other elements must be taken into account in addition to the maintenance strategy itself. These include staff, paperwork, and component inventory management. Dynamic fault trees may provide some insight into spare parts management, however these issues are beyond the purview of this thesis.

The need that maintenance optimisation be applicable in practise is a crucial component. According to many evaluations, case studies are not often used in the literature. One suggestion is that maintenance modellers and maintenance engineers work together to make sure the models are relevant to systems in the real world.

Tree Analysis of Faults

An industry-standard graphical modelling method called fault trees is used to illustrate how system failures spread, or how component failures interact to lead to system failures as a whole. Common patterns like component and subsystem redundancy may be illustrated by linking subsystems using boolean connectors. It is possible to study the produced models to derive several qualitative and quantitative dependability measures.They were created in the 1960s to assess the dependability of a missile launch system, and Boeing immediately adopted them as a tool for their safety-critical systems' reliability engineering. Since then, several other businesses have embraced them, and they have been standardised by organisations like the International Electrotechnical Commission and ISO. Regulators, like the Federal Aviation Administration and the U.S. Nuclear Regulatory Commission, have mandated the use of fault tree analysis in some industries.

Starting with an undesirable occurrence (event), fault trees are built by determining the conditions that must be met right away for this event to happen. In order to further refine the detected causes until they are sufficiently fine-grained to not need additional refinement, each of these criteria is further broken down into its own causes. The fundamental events, often known as the tree's leaves, are these last causes. The interconnections between subsystem failures are described by the intermediate events using boolean connectors, or gates.A fault tree that has been used to simulate a system may then be examined for a variety of qualitative and quantitative criteria. The most typical qualitative analysis is to identify cut sets, which are collections of component failures that result in system failure. For instance, one can see from 1.2 that the "Coolant leak" event is sufficient to result in a loss of cooling. Such a single point of failure often indicates design flaws that must be addressed. Quantitatively, one may calculate the likelihood of the undesirable occurrence and add its probability to the fundamental events. One may show that the system satisfies reliability criteria in this manner. Alternately, if the system does not satisfy the criteria, several significance measures may be calculated to establish which system components have the biggest effects on dependability, which helps in determining the best course of action to take[7], [9].

In general, fault tree analysis may be used to accomplish a number of objectives, including:

Describe a system's architecture in terms of dependability to assist understand how the system will fail in general.Display adherence to rules governing the reliability of safety-critical systems.Determine which system components are most affected by reliability enhancements in terms of total system dependability.Determine the most probable reasons of the failure if information regarding which system components are unquestionably operating is available after a problem has occurred.Over time, a broad variety of fault tree extensions and variations have been created that can better manage issues including uncertainty, component dependencies, and repairs. Part I of this thesis gives an outline of these expansions.

Trees for Fault Maintenance

Although fault trees are often used to examine system designs and have been expanded to incorporate certain simple repair procedures, fault tree analysis has generally excluded the effect of maintenance on system dependability. The construction of fault maintenance trees, which enhance fault trees with potent models for maintenance policies, is the major focus of this thesis. This supports the formulation of improved maintenance plans by enabling quantitative examination of the impacts of maintenance on costs and system performance.

Traditional fault trees are extended in three ways by fault maintenance trees: In the beginning, fundamental events are more in-depth and include models of how parts deteriorate with time. Second, a novel gate is used to formally represent interactions between the deterioration of various components. This gate simulates the scenario in which a component or subsystem failure increases the load placed on another component, causing that component's wear to accelerate. Finally, specific repair rules detailing which inspections are conducted when and what actions are done based on the results of the inspection are modelled using inspection and repair modules. Multiple components may be repaired simultaneously by repair modules, simulating possible cost savings from clustering maintenance tasks.

FMTs enable the definition of both preventative and corrective maintenance activities taking into account the maintenance rules. All maintenance operations must be stated in terms of time, with the proviso that we support failure-based, time-based, and condition-based maintenance. In the event that a usage-based policy is required, it must be changed to a time-based one, for example, by utilising data on the system's average use over time. Opportunity-based maintenance may be partly enabled by repair modules that allow for the simultaneous replacement of several components, but these opportunistic replacements cannot be condition-based.

An example of a compressor's fault maintenance tree is shown. The top event is a gate that states that any of the child events is sufficient to result in a failure, much as in a typical fault tree. The RDEP gate, which is a new feature, describes how oil pollution accelerates the wear on the bearings and screws. New are the inspection module I as well as the repair modules R1 and R2, where I and R1 define that the air filter should be regularly examined and, if required, changed, while R2 specifies that the bearings, screws, and oil should be fixed when the compressor fails.Modeling the impact of various maintenance strategies on system performance and cost is a significant advantage of fault maintenance trees. The likelihood of system failure, the anticipated number of failures over time, and the predicted numbers of each maintenance activity may all be calculated quantitatively. One may determine the anticipated overall cost of the system under a specific policy by allocating costs to failures, downtime, inspections, and repairs.

Using FMTs, the maintenance plan may be optimised to discover, for example, the least expensive approach that satisfies dependability criteria or the strategy that gives the highest performance within a certain spending limit.Choosing the probability distributions to employ for the component degradation rates is a crucial step in accurately predicting the system. The ideal maintenance strategy and the overall maintenance cost have been proven to be significantly impacted by this. Modelers may choose the best suitable probability distribution or experiment with other distributions to see how the decision affects the outcomes since FMTs enable arbitrary probability distributions. In order to determine the cost-optimal number of inspections to do each year and to identify maintenance operations whose costs surpass their benefits.

Analysis

This thesis offers two approaches to analyse FMTs: This cutting-edge method uses Monte Carlo simulation to reach statistically reliable conclusions regarding a variety of dependability indicators, such predicted cost or system reliability. When examining very dependable systems, one disadvantage of statistical model checking stands out: As the probability being assessed lowers, more calculation is required to provide an accurate estimate. This calculation time may become unmanageably long in reliability engineering, when failure probability are normally quite low. In this method, the system under analysis is altered to make failure less likely, the failure probability of the altered system is estimated, and the estimate is then corrected to get an accurate estimate of the original likelihood. Our method presently only enables calculating system availability, however it can drastically cut down on computation time when compared to standard statistical model checking analysis.

Checking Statistical Models

Model checking's fundamental goal is to determine if a system model meets a given property. A similar procedure was separately devised by Queille and Sifakis. The phrase was first used by Clarke and Emerson to describe the technique by which a concurrent computer programme was validated to satisfy a condition stated using temporal logic. The Turing Prize was given to Clarke, Emerson, and Sifakis in 2007 for their contributions.Model checking was first used to investigate nondeterministic decision systems. The conclusion was either the condition is met regardless of the decisions made, or it is not, in which case a counterexample demonstrating how the property is violated is provided.

A discrete-time Markov chain is formed when decisions are made using probabilities in probabilistic model verification, which was further developed. Several years later, model verification of continuous-time Markov chains, in which the time required for each step is similarly controlled by a probability distribution, was conducted.We are no longer limited to examining qualitative aspects for such probabilistic or stochastic systems, but instead may pose quantitative queries. For instance, we may inquire "How often, on average, does the model enter a failed state per year?" or "Is the probability of reaching a failed state within 10 years less than 1%?" Such queries are addressed by stochastic model checking, and a number of stochastic model checking tools, including STORM, PRISM, and IscasMC, have been created.

The formal-ism of timed automata presented model checking for real-time systems in. Timed automata are made up of transitions, which allow the model to change from one place to another, and locations, which are discrete control states. Time is measured by clocks, with invariants on places and guards on transitions dictating when such transitions may or must be made. The automaton starts at the "Working" location with clock x set to 0. The guard on the top transition prevents it from starting to be taken before time 5, while the invariant on this location specifies that an outbound transition must be taken before 10 units of time have elapsed. Thus, the model travels to the area designated "Down" at some point between 5 and 10. Additionally, the top transition specifies that when the transition is made, clock x is reset. Between 2 and 5 time units pass from this new position until the system returns to "Working," at which point it is in its initial condition.

We use stochastic timed automata's expanded formalism for the study of fault maintenance trees. By enabling probability distributions to control transition timings rather than only clock limitations, they expand timed automata. The top transition in 1.5b's example is controlled by an exponential distribution with a mean time of 7, as opposed to 1.5a's nondeterministic transition time.

Statistical model verification for analysis.

When analysing complex systems using state space-based formalizations, such as STAs, a typical issue is that the number of locations increases to a point where it cannot be stored in computer memory. While various reduction approaches may aid in this by lowering the number of places, bigger systems will still run out of memory. By employing statistical model verification, which uses relatively little memory, the analysis of FMTs overcomes this issue, albeit at the expense of merely giving confidence intervals rather than precise answers.Monte Carlo simulation is used in statistical model verification to calculate the likelihood that a run of the model will satisfy the desired attribute. We count the number of model runs that fulfil the property and the number that do not in order to achieve this. The chance of the condition being met is then computed with the use of a statistical hypothesis test, which also provides a qualitative conclusion that the probability is higher than a specified threshold. You may find a summary of the numerous hypothesis tests for statistical model checking here.

Situation Description

The ArRangeer project, which is a component of the ExploRail program, is where the research for this thesis was conducted.Part of the ArRangeer project's findings are presented in this thesis. The remainder is covered in Dennis Guck's PhD dissertation and includes more theoretical developments in stochastic model checking and its application to the study of dynamic fault trees.The ExploRailprogramme seeks to lessen the Dutch railway system's susceptibility to delays. Nine research projects comprise this programme. The ArRangeer project, which stands for Smart Railroad Maintenance Engineering with Stochastic Model Checking, is one of these initiatives. In order to augment fault trees with notions from maintenance engineering, the ArRangeer project used stochastic model checking to assess the final model.

Maintenance integration with fault trees: The fault maintenance trees that are extended with sophisticated models of component degradation and maintenance strategies are provided. They enable the modelling of several maintenance procedures and may be examined using statistical model checking to determine costs and dependability metrics like reliability and availability. In order to help maintenance engineers enhance their maintenance plans, they may be used to compare the consequences of various maintenance programmes.An electrically insulated joint and a pneumatic compressor are two examples of real-world systems from the railway industry that are used as a practical demonstration of FMTs. We demonstrate that FMTs are capable of effectively simulating the dependability of these systems and can be used to uncover ways to enhance their maintenance practices while lowering costs and raising dependability.

REFERENCES

[1] J. Rukijkanpanich en M. Mingmongkol, "Enhancing performance of maintenance in solar power plant", *J. Qual. Maint. Eng.*, 2020, doi: 10.1108/JQME-11-2018-0098.

[2] E. Özcan, T. Danışan, R. Yumuşak, en T. Eren, "An artificial neural network model supported with multi criteria decision making approaches for maintenance planning in hydroelectric power plants", *Eksploat. i Niezawodn.*, 2020, doi: 10.17531/ein.2020.3.3.

[3] J. Ballestín-Fuertes *et al.*, "Novel utility-scale photovoltaic plant electroluminescence maintenance technique by means of bidirectional power inverter controller", *Appl. Sci.*, 2020, doi: 10.3390/app10093084.

[4] T. A. Orhadahwe, A. A. Adeleke, P. P. Ikubanni, en O. O. Agboola, "Evaluating the effectiveness of maintenance practices: Case study of a university power generating plant", *Eng. Appl. Sci. Res.*, 2020, doi: 10.14456/easr.2020.18.

[5] P. Li, J. Chu, en R. Han, "Research on the Screening Method of Predictive Maintenance Monitoring Equipment in Nuclear Power Plant", 2020. doi: 10.1109/PHM-Besancon49106.2020.00027.

[6] C. Sigauke en M. M. Nemukula, "Modelling extreme peak electricity demand during a heatwave period: a case study", *Energy Syst.*, 2020, doi: 10.1007/s12667-018-0311-y.

[7] S. R. Palakodeti, P. K. Raju, en H. Guo, "A dynamic process for evaluating the reliability of fossil power plant assets", *Eng. Reports*, 2020, doi: 10.1002/eng2.12277.

[8] Suriyanti, A. Firman, Nurlina, G. B. Ilyas, en A. H. P. K. Putra, "Planning strategy of operation business and maintenance by analytical hierarchy process and strength, weakness, opportunity, and threat integration for energy sustainability", *Int. J. Energy Econ. Policy*, 2020, doi: 10.32479/ijeep.9267.

[9] J. H. Shin en J. O. Kim, "On line diagnosis and fault state classification method of photovoltaic plant", *Energies*, 2020, doi: 10.3390/en13174584.

CHAPTER 5

OPERATIONAL OF NUCLEAR POWER PLANT AND MEDICAL EQUIPMENT

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Risk analysis is a crucial process to assure the safe and dependable operation of essential assets, such as nuclear power plants and medical equipment. One of the most well-known methods utilised here is fault tree analysis, which is used by a variety of sectors including the nuclear, aerospace, and automotive industries. For FTA, many industrial standards have been created, including those for automotive applications by the IEC and ISO.A graphical tool called fault trees is used to represent how system failures spread, or how component failures result in system failures. The management of spare parts and redundancy ensure that not every component failure results in a system failure.FTs serve as a model of this failure propagation and are directed acyclic trees, or more broadly, graphs, whose leaves represent component failures and whose gates represent the failure combinations that result in system failures[1], [2].

Risk analysis use fault trees for a number of applications, including:

Examining possible design solutions the use of more dependable components, the use of additional components in a redundant manner, and other strategies are often available to system designers as alternatives for assuring the dependability of their system. FTA may be used to evaluate the reliability of several designs and assist in making the optimal choice.

Proving compliance: Dependability standards are legally mandated in several businesses. For instance, the US Department of Labor specifies fault trees as a technique to assist show that equipment complies with this requirement when setting criteria for the safety of equipment in workplaces. FTA is also included by the Federal Aviation Administration as one of the techniques for hazard assessments in high-impact choices.

Fault identification: Even in the case of most dependable systems, faults are still possible. In these circumstances, fault trees may be utilised to pinpoint the failure's most probable causes, accelerating repairs. How to carry out such a diagnostic is not included in this thesis.

We differentiate between qualitative and quantitative fault tree analysis (FTA), which computes numbers like failure probability for FTs, while doing a fault tree analysis. Qualitative FTA takes into account the FT's structure. Cut sets are a crucial measurement in the qualitative domain because they show which combinations of component failures result in system breakdowns. A system vulnerability may be revealed if a trimmed set has too few items. We also talk about route sets and common cause failures as additional qualitative metrics[3], [4].

Calculating failure probabilities is a major focus of quantitative system measurements. Quantitative FTA calculates the system failure probability if we assume that the failures of the system's individual components follow a probability distribution. Here, we make a distinction between continuous and discrete probability. The following FT metrics are mentioned for both variants:

1. System reliability is the likelihood that the system will malfunction over a certain time period, t.
2. The amount of time the system is available is measured as a percentage.
3. The average duration until the first failure is known as the mean time to failure.
4. The average amount of time that passes between failures is called the mean time between failures.

These tests are essential to establish if a system satisfies the standards for dependability or whether more tests are required. We also go over significance measures, which provide a way to gauge how much certain leaves contribute to the dependability of the whole system, and sensitivity analysis approaches, which show how sensitive an analysis is in relation to the values in the leaves.We provide fundamental algorithms for analysis, such as boolean algebra for cut sets, as well as more effective algorithms, such as approaches for assessing dependability based on binary decision diagrams. There are descriptions of the different techniques.

SFTs provide a straightforward and illuminating framework, but they lack the expressivity required to characterise certain frequently recurring dependability patterns. In order to convey aspects that are not expressible in SFTs, a number of fault tree extensions have been suggested. Spare management, several operating modes, and dependent events are a few examples. The most well-known are dynamic fault trees, which are covered in the following. There are many other common extensions, such extended fault trees, repairable fault trees, fuzzy fault trees, and state-event fault trees. We'll look at these extensions and the methods used to analyse them. The structure of these s may be shown graphically.We have examined over 150 publications on fault tree analysis in the context of fault trees and their expansions, offering a comprehensive overview of the state-of-the-art in fault tree analysis[5], [6].

Research Techniques

The majority of the literature on topic was discovered in a 2014 survey. Although we tried to be as thorough as possible with our study, we cannot ensure that we have uncovered all pertinent literature.Articles that are not in English or are of low quality were eliminated. Articles that just provide applications of FTA, only construction methods for FTs, or only discuss methods for fault detection based on FTs were also disregarded in order to condense the scope of this study, unless the publication additionally included unique modelling or analytic methods. Only articles that describe a particular, functional tool were included when providing implementations of existing methods.

Relevant Work

There are several different formalisms for dependability analysis in addition to fault trees. The most popular ones are listed. Analysis of Failure Mode and Effects the Failure Mode and Effects Analysis was one of the earliest organised methods for dependability analysis. Users may still be found using FMEA, especially its extension with criticality FMECA, in the safety-critical business, which includes the nuclear, defense, avionics, automobile, and railroad domains. These assessments provide a methodical manner to identify potential failures and their effects. The list might also contain potential remedies for the failings.

Quantitative analysis may also be used to assess system dependability and assign numerical criticalities to likely failure modes and system components if failure probability are known.

Making an FMEA is often one of the first stages in creating a fault tree since it helps in identifying potential component failures and, therefore, the fundamental events. HAZOP evaluation several guidelines and parameters are systematically combined in a hazard and operability research, and each combination's applicability to different system components is assessed. As a consequence, a list of potential risks to the system is produced. The strategy is still in use today, particularly in sectors of industry like chemistry.

A HAZOP and an FMEA are similar in that they both outline potential reasons for a failure. A key distinction is that a HAZOP study takes irregularities in a process into account, while an FMEA evaluates failure modes of system components. Block diagrams for reliability Reliability block diagrams break down systems into subsystems to highlight the impact of errors, much as fault trees do. RBDs are appealing to users in a similar way as FTs because the blocks may often translate directly to physical components and because they provide both quantitative and qualitative examination.

To simulate more intricate component-to-component relationships, Standby states, where components fail less often, and triggers that enable the modelling of shared spare components and functional dependencies are also features of dynamic RBDs. This might increase the dependability and availability calculations' correctness.

AADL for modelling the architectures of safety-critical systems, the industry standard is the Architecture Analysis and Design Language. The descriptions of nominal behavior, error behavior, and a fault injection specification that details how the error behaviour affects the nominal behaviour make up a whole AADL specification. An FMEA may be systematically derived from such an AADL definition. Quantitative analysis may also evaluate the availability and dependability of a system if failure rates are known[7]–[9].

UML the Unified Modeling Language is another industry standard for modelling not only physical systems and processes but also computer programmes. To help developers and analysts describe the behaviour of a system, UML offers a variety of graphical representations including Statechart diagrams and Sequence diagrams. Petri Nets may be created using UML Statechart diagrams so that system dependability can be calculated. Another method models error transmission by combining many UML diagrams in order to get a more precise reliability estimate.Möbius Sanders et al. created the Möbius framework as a multi-formalism method to modelling. The tool enables the specification of system components using several methodologies and their combination into a single model. Depending on the underlying models, the integrated model may then be examined for dependability, availability, and estimated cost using a variety of methodologies.

Legal history

FTA is crucial for product certification and demonstrating compliance with regulatory regulations. Legislation in the European Union requires companies to evaluate and reduce the risks that employees encounter. FTA may be used in this situation, for instance, to identify the circumstances in which a certain equipment is hazardous to employees. The use of FTA for risk assessment in working settings has also received approval from the US Department of Labor.Similar to this, the EU Machine Directive mandates that manufacturers identify and record the hazards associated with the equipment they create. One method that may be utilised for this documentation is FTA.The standards for risk analysis, as well as FTA as a method for carrying out such analysis, have also been embraced by the transportation sector. In 1998, the Federal Aviation Administration passed a regulation mandating formalised risk management plans for major decisions. FTA is included as one of the techniques for hazard analysis in their System Safety Handbook.

Trees of static faults

It is often important to analyse system dependability qualities, as was covered in the section before this one. To achieve this, a fault tree is a graphical model that: It highlights the pertinent system failures that could happen and how these failures interact to potentially lead to a system failure as a whole. The most fundamental fault trees are those that are static or standard. They were first used at Bell Labs to analyse ballistic missiles in the 1960s. A thorough introduction to SFTs may be found in the classic Fault Tree Handbook by Vesely et al. The most popular modelling and analysis methods for SFTs are described here.

Tree Structure of Faults

A fault tree is a directed acyclic graph with gates and events as its nodes. An event is anything that happens inside the system, usually when a component or subsystem fails. Basic events are those that happen on their own, while intermediate events are those that are brought on by one or more other events. The event being studied, which models the breakdown of the system under examination, is the event at the top of the tree, known as the top unwanted event.

Mistaken tree gates

Gates reflect the process through which failures spread across the system, i.e., how subsystem failures might come together to generate a system failure. One output and one or more inputs are present on each gate. In fault trees, the following gates are often utilised. AND If every input event happens, an output event happens, such as gate Ws in the example. OR Any input event, such as gate C in the example, results in an output event. Voting or k/N has N inputs. When at least k input events have place, an output event happens. The OR of all sets of k inputs may be used to substitute this gate, but utilising a single k/N gate is much more understandable. In the above example, Gate Mem is a 2/3 gate.

INHIBIT if both the input event and the conditioning event depicted to the right of the gate happen at the same time, an output event will take place. Since this gate works exactly like an AND-gate with two inputs, it is not discussed further in the remainder of section. It is sometimes used to help readers understand how the system behaves. In the above example, gate F is an INHIBIT gate. A bus, two CPUs, three memory modules, and a power supply make up the system. These elements are as fundamental as a tree's leaves. The important event, a computer system breakdown, is shown at the top of the tree.

As previously mentioned, gates depict how failures spread across the system: Gate F is an INHIBIT-gate, meaning that failures during deliberate downtime do not influence dependability measures and that a system failure is only taken into account when the system is in operation. The OR gate C, simply F, indicates that a system failure is brought on by the failure of either the bus or the workstation subsystem. The workstation subsystem is made up of two redundant components that are coupled using an AND gate (Ws), such that both must malfunction for there to be a system failure. Each workstation may malfunction due to a power supply or CPU issue. For each subtree, the event PS is replicated, but it still only refers to one event. A unit may also die due to a failure of the memory subsystem, although this requires the loss of two memory units. By the second-third gate, Mem. This gate serves as an input to both compute subsystems, making it a DAG, however if the approach had permitted repeated events while still requiring a tree, the subtree may have been replicated as in PS.

Unusual occurrences

Shows additional symbols for events in addition to the fundamental ones denoted by circles. A rectangle denotes a middle event. Intermediate events may be helpful for documentation but won't change the FT's analysis, so they can be skipped. Triangles are used to combine events from numerous FTs into one huge FT if an FT is too large to fit on a single page. Last but not least, there are occasions when subsystems are not really BEs; instead, there is a lack of information or a lack of priority given to the event for the subsystem to be developed into a subtree. A diamond is used to represent such an underdeveloped occurrence.

Extensions

A number of FT additions provide new gates that enable the modelling of systems that are capable of recovering from failure. These "Repairable Fault Trees" will be explained. Simple repairs may be added to static FTs without the need of extra gates by adorning BEs with repair rates.Other additions include a NOT-gate or an equivalent, such that a component failure may make the system transition from malfunctioning to working again or that a component that is operating can trigger a system failure. A noncoherent system is one such example. Some systems naturally display noncoherent behavior, which may point to a modelling problem. For instance, an explosion may occur when a safety valve fails while a pump is operating, but an explosion is always prevented by a failed pump.

Diagrams of binary decisions

By transforming the fault tree into a Binary Decision Diagram, MCS may be quickly found. A directed acyclic graph called a BDD serves as a representation for the boolean function f 0, 1n 0, 1. A BDD has leaves that are either labelled 0 or 1. The other nodes have two kids and are labelled with the variable xi. When xi = 0, the left child represents the function, and when xi = 1, the right child does so. In order to effectively express the state space and transition relation, BDDs are widely employed in model verification.

The BDD generated by converting the FT in 2.6a. Each circle represents a BE, and it has two children: a 0-child that contains the sub-BDD that determines the system status in the event that the BE has not failed, and a 1-child in the event that it has. If the system has or has not failed, the leaves of the BDD are squares holding 1 or 0, respectively. For instance, if E1 and E2 are broken, we start by traversing the BDD's root, notice that E1 is broken, and then follow the 1-edge. Since E3 is running at this point, we go down the 0-edge. As we have now arrived to a leaf that contains a 0, this combination does not cause the system to crash. BDDs for obtaining cut sets By beginning at each tree's 1-leaf and moving upward towards the root, cut sets may be extracted from the BDD. One CS is made up of all the BEs that can be accessed by going around a certain leaf's 1-edge. Depending on the procedure used to create the BDD, the CS achieved by this approach may not be minimum. The BDD may be minimised in order to find just MCSs, which is one method of obtaining MCSs. As an alternative, Rauzy and Dutuit provide a technique for creating BDDs that encode so-called prime implicants, from which MCSs may be calculated immediately. Both and were responsible for the invention of the BDD approach. A minimization method for the intermediate BDD was added to make it better. While the complexity of the conversion to a BDD is exponential in the worst scenario, it is linear in the best situation. BDD techniques are often quicker in use than boolean manipulation. This is significantly impacted by the fact that fault trees display this symmetry because the gates are symmetric in their inputs, and BDDs extremely compactly describe boolean functions with a high degree of symmetry. A programme has been created that uses BDDs to analyse FTs.

The transformation of an FT to a BDD is not special, like any other boolean function: Different BDDs may be produced depending on how the BEs are arranged. It's crucial to have good variable ordering to keep the BDD minimal. Unfortunately, it is an NP-complete task to even determine if a certain ordering of variables is optimum.In their comparison of various alternative approaches for building BDDs from FTs, Remenyte and Andrews came to the conclusion that a combination of the if-then-else technique and the advanced component-connection method by offers a good balance between processing time and BDD size.

Amplification of BDDs

The usage of zero-suppressed BDDs is suggested by Tang and Dugan for computing minimum cut sets. ZBDDs are similar to BDDs, with the exception that nodes are eliminated if their 1-child is a 0-leaf rather than if both of their children are identical. If the majority of occurrences result in 0-leaves, this offers a more minimal encoding. It is shown that this technique is often more effective for FTs than those based on standard BDDs in terms of time and memory utilisation when combined with reduction criteria to assure minimality of the trimmed sets.

The analysis of the full tree takes time and memory, but Dutuit and Rauzy give a technique for locating isolated sub-modules of FTs that may be converted to BDDs independently and examined.The method known as "Parametric Fault Trees" may be used if subtrees of an FT are shared. This approach analyses such a tree in both qualitative and quantitative ways without repeating the study for every iteration of a subtree.Although their work does not seem to support this claim, Miao et al. created an algorithm to find minimum cut sets using a modified BDD and claim its time complexity is linear in the number of BEs. Additionally, we believe that this finding is flawed since the proportion of MCSs to BEs is already exponential.

Alternative qualitative analysis techniques

Since a k/N voting gate produces different cut sets for any combination of k failed components, FTs with voting gates with multiple inputs cause a combinatorial explosion in the number of mminimal cut sets. In an MCS, the idea of a minimum cut vote was put out to signify any random arrangement of k components. The BDD technique has exponential complexity, while this method has linear complexity in terms of the number of inputs to a voting gate.The method of Carrasco and Sué may be helpful for somewhat big trees with few cut sets. Unlike BDDs, which base their space complexity on the complexity of the tree, MCSs. However, the report claims that this technique does seem to be slower than the BDD strategy.

In actuality, identifying all MCSs is often unnecessary: It's uncommon for all the components in cut sets with multiple parts to fail. Finding MCSs with just a few components, at most, is often adequate. Consequently, the amount of intermediate expressions may be significantly decreased, which may result in a reduction in calculation time.The memory requirements of the preceding approaches for discovering MCSs may be high due to the possibly extremely large intermediate expressions. An option is to employ the Monte Carlo approach. According to the failure probability, random subsets of components are assumed to have failed in the approach by. A subset is a cut set if it results in a top event failure. These cut sets are converted into MCSs by further simulations. Even while the Monte Carlo approach uses far less memory, the many simulations might significantly lengthen calculation times. Additionally, it's possible that not all MCSs will be discovered.

Fewer path sets

A minimum path set is basically the reverse of an MCS in that it consists of a small number of parts that, provided they do not fail, keep the system running.

Analysis

Any method that can calculate MCSs can also calculate MPSs. Simply put, we discover the minimum cut sets of this negated tree by negating the fault tree and the fundamental events. In other words, we identify the smallest collections of functioning parts that do not result in system failure. We may negate the tree without using a NOT-gate by using Boolean reasoning, such as De Morgan's laws: k/N voting gates are changed to /N voting gates, AND gates to OR gates, OR gates to AND gates, and BEs to their complement. The MPSs of the original FT are the MCSs of this dual tree.

Common reasons for failure

The examination of failures with suspected common causes is another qualitative component. These are distinct failures that may happen as a result of a single, but unidentified, common cause. One cut set would include a component and its spare, for instance, if replacing the component with the spare would prevent failure. If both the component and the spare are made by the same company, a common manufacturing error might cause them to malfunction simultaneously. To prevent overestimating the system dependability, these typical reasons should be explicitly modelled if it is determined that they are too likely to occur.

Analysis

Since CCF rely on outside elements that are not modelled in the tree, automated approaches from the FT alone are often not sufficient to analyse CCF. Instead, specialists could strive to identify any cut sets that contain several parts that might fail due to a similar reason. Such an examination is often extremely casual and depends on professional knowledge.

By introducing common causes as BEs and replacing the BEs they influence with OR-gates that combine the CCF and the various failure modes, common causes may be incorporated to an FT. A two-engine aircraft is modelled as an example. While each engine may fail on its own, both engines can fail simultaneously if the common cause is gasoline.

Statistical evaluation Single-time

Relevant numerical values for fault trees are derived using quantitative analysis techniques. Due to the fact that they provide relevant information like failure probability, stochastic measures are widely used. Measures of importance show how crucial a group of parts are to the system's dependability. Furthermore, it's crucial to consider how sensitive these measurements are to changes in BE probability.Stochastic measurements may also be used to determine if it is safe to keep running a system with a few failed components or whether the system should be shut down for repairs as a whole.

We take into account two FT kinds for quantitative analysis: Single-time FTs abstract away the moment at which the failure happens and adorn each fundamental event with a single chance of failure. For systems with predictable, set mission durations, this is helpful.Each basic event has a time-dependent failure probability attached with continuous-time FTs, which enables the generation of extra metrics like mean time to failure or average uptime. For systems whose lifetime is not determined or understood in advance, such FTs are helpful.The definitions and analytic methods for numerous measures relevant to single-time FTs are provided, which begins by outlining some fundamental concepts in probability theory. We focus on the more sophisticated techniques of binary decision diagrams and Bayesian networks as well as the fundamental techniques of bottom-up propagation and Monte Carlo simulation.

Modelling the likelihood of failure

We start by taking into account the single-time FT's very straightforward instance. Here, we analyse a defined time horizon during which each component may fail only once rather than the development of a system across time. This is true for many systems that have a well-defined duration of interest, such as rockets, where the designers are aware of the likelihood that each component would fail during launch but are not interested in precisely when this failure could occur.We presum that each of the BE failures is stochastically distinct. The failures of the gates are not independent if the FT contains shared subtrees. We assign a failure probability to each BE as the first step in our analysis, and we then add these probabilities at the gates to produce failure probabilities for the gates and, finally, the whole tree. We claim that each BE is either failed or not, and that each gate is similarly either failed or not based on the states of its child elements, in order to explain how the probabilities are combined. Additionally, BEs with many states are permitted by Bobbio et al. Components may be in distinct failure modes, such as degraded operating modes or a valve that is either stuck open or jammed closed, rather of being either up or failing. For multiple-state fault trees, the same Bayesian inference guidelines apply, with the exception that the random variables are no longer boolean but instead have several potential values, increasing the conditional probability s. Furthermore, Bobbio et al.'s common cause failure model includes a likelihood that a gate may malfunction even if not enough of its inputs have, however this has the drawback of making the possible failure reasons less clear. Finally, gates may be "noisy," which means they may malfunction. For instance, there is a remote chance that a system failure may result from the failure of a single component in a group of redundant components.

The capacity of Bayesian Network Analysis to calculate both the probabilities of each of the leaves given the top event as well as the probability of the top event itself is a key feature. This is highly helpful in fault diagnosis when determining which leaves are the most likely sources of a failure after it has already happened. The use of additional evidence, such as specific leaves that are known not to have failed, is also an option.

Monte Carlo analysis

The system dependability may also be calculated using Monte Carlo techniques. The majority of strategies are developed for qualitative analysis or continuous-time models, however single-time model adaption is simple. Based on its failure probability, each component is given a failure condition at random. The FT is then assessed to see whether the TE was successful. When there are enough simulations, the reliability is about the percentage of simulations that do not fail.

Number of Failures Anticipated

The Expected Number of Failures details how many TE occurrences are anticipated during a certain time frame. This metric is often used to assess systems with established operating lifetimes and failure modes that are extremely expensive or risky.A major advantage of the ENF is that the combined ENF of multiple inde- pendent systems over the same timespan can very easily be calculated, namely ENF =ENF + ENF. For example, if a power company requests a number of 40-year licenses to operate nuclear power stations, it is easy to check that the combined ENF is sufficiently low.

Analysis

Since a single-time system can fail at most once, it is easy to show that the ENF of such a system is equal to its unreliability. Let NF denote the number of failures system F experiences during its mission time, so that

$\mathbb{E} = \sum i \cdot \mathbb{P}$

i

$= 0 \cdot \mathbb{P} + 1 \cdot \mathbb{P}$

$= 0 + \mathbb{P}$

= Re

Statistical evaluation: Continuous-time

Whereas single-time systems regard a system's whole lifecycle as a single event, it is sometimes more beneficial to take dependability metrics into account at various points in time. To prevent the aircraft from needing maintenance or being pulled out of service before that point, an aero plane manufacturer, for instance, could be interested in knowing when the failure probability surpasses a certain threshold. Continuous-time fault trees provide methods to get such measurements, if sufficient data is available. Following an explanation of the fundamental theory, this part offers definitions and methods of analysis for various measures.

Probabilities of BE failure

Continuous-time FTs take into account how the system failures evolve over time. The component failure behaviour is usually given by a probability function De: $\mathbb{R}+ \mapsto$, which yields for each BE e and time point t, the probability that e has failed before time t $= \mathbb{P}$).In practise, the failure distributions can often be adequately approximated by exponential distributions, and BEs are specified with a failure rate R: BE $\mapsto \mathbb{R}+$, such that $R = \lambda \leftrightarrow De = 1 - \text{e}{-\lambda t}$.

If components can be repaired without affecting the operations of other components, BEs have an additional repair distribution over time. Like failure dis- tributions, repair distributions are often exponentially distributed and specified using a repair rate RR : BE $\mapsto$ $\mathbb{R}+$. More generally, BEs can be assigned repair distributions as RDe: $\mathbb{R}+ \mapsto$. More complex and realistic models of repairs are discussed.

Operational semantics. Like for the single-time case, we can use random variables Xe to describe failures of basic events, and derive a stochastic semantics for the FT. However, due to the possibility of repair, it is helpful to introduce some additional variables. Consider a BE e with a failure distribution De and repair distribution RDe. Now we take Fe, 1, Fe,2, … as the relative failure times, and Qe,1, Qe,2, … as the relative repair times, with Qe,1 = 0 for convenience. It follows that $\mathbb{P} = De$ and $\mathbb{P}$ = RDe for i> 1. We can now define the random variables Xe and Xg.

For basic events, Xe is 1 if t is some time after a failure, and before the subsequent repair. Depending on the failure distributions, the random variables of the BEs can have relatively easy distributions. For example, a BE with exponentially distributed failures with rate λ has probability $\mathbb{P}$ = 0) = $1 - \text{e}{-\lambda t}$. The distributions of the gates typically do not follow convenient distributions, as e.g. the maximum of two exponentially distributed variables is not exponentially distributed.

Reliability

Definition

The reliability of a continuous-time FT F is the probability that the system it represents operates for a certain amount of time without failing. Formally, we define a random variable YF = max $\{t|\forall s<tXF = 0\}$ to denote the time of the first failure of the tree. The reliability of the system up to time t is then defined as ReF = P**.**

Analysis

It is feasible to ascertain the dependability in a certain time frame by turning continuous-time systems into single-time systems and utilizing BE probabilities as the chance of failure within the specified timeframe. Monte Carlo approaches may also be used to determine system reliability. The method by uses the BE distributions to produce random failure times and, if required, repair times. The system simulates these failures, and the availability and dependability of the system are monitored. Enough simulations might result in accurate approximations. The method may be easily modified to include more failure metrics.For quicker speed than standard computer simulation, a method for programming a model of an FT into a specialised hardware chip called as a Field Programmable Gate Array has been developed. Each MC simulation may be run on this device very quickly.

REFERENCES

[1] C. Lu *et al.*, "Nuclear power plants with artificial intelligence in industry 4.0 era: Top-level design and current applications—a systemic review", *IEEE Access*. 2020. doi: 10.1109/ACCESS.2020.3032529.

[2] A. A. Eluyemi *et al.*, "A GIS-based site investigation for nuclear power plants (NPPs) in Nigeria", *Sci. African*, 2020, doi: 10.1016/j.sciaf.2019.e00240.

[3] H. Grganić, D. Grgić, en S. Šadek, "Room classification based on EMC conditions in nuclear power plants", *Energies*, 2020, doi: 10.3390/en13020359.

[4] S. Lee, J. H. Huh, en Y. Kim, "Python tensorflow big data analysis for the security of korean nuclear power plants", *Electron.*, 2020, doi: 10.3390/electronics9091467.

[5] Y. Wu *et al.*, "A two-stage decision framework for inland nuclear power plant site selection based on GIS and type-2 fuzzy PROMETHEE II: Case study in China", *Energy Sci. Eng.*, 2020, doi: 10.1002/ese3.640.

[6] Y. Jang en E. Park, "Social acceptance of nuclear power plants in Korea: The role of public perceptions following the Fukushima accident", *Renew. Sustain. Energy Rev.*, 2020, doi: 10.1016/j.rser.2020.109894.

[7] Y. Zhao, J. Tong, L. Zhang, en G. Wu, "Diagnosis of operational failures and on-demand failures in nuclear power plants: An approach based on dynamic Bayesian networks", *Ann. Nucl. Energy*, 2020, doi: 10.1016/j.anucene.2019.107181.

[8] P. Heng-ming, W. Xiao-kang, W. Tie-li, L. Ya-hua, en W. Jian-qiang, "A multi-criteria decision support framework for inland nuclear power plant site selection under Z-Information: A case study in hunan province of China", *Mathematics*, 2020, doi: 10.3390/math8020252.

[9] M. Fukasawa *et al.*, "Long-lasting effects of distrust in government and science on mental health eight years after the Fukushima nuclear power plant disaster", *Soc. Sci. Med.*, 2020, doi: 10.1016/j.socscimed.2020.113108.

CHAPTER 6

DEFINITION OF ACCESSIBILITY

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Availability is the probability that a system will be active at a certain time. During the calculation of availability, the percentage of time that the system is functional may also be computed. Accessibility is crucial for systems that can be repaired because it accounts for the prospect of system recovery in the event of a breakdown. For non-repairable systems, the availability in a particular time range could still be advantageous. The long-term availability for nontrivial non-repairable systems inexorably approaches 0 since some cut set will eventually fail and remain dysfunctional[1], [2].

Definition 7 The availability of FT F at time t is defined as $AF = \mathbb{E}$).

The availability over the interval is defined as $A = 1 \int bXdt$.

F $b{-}aa$ F

The long-run availability is $AF = \lim t{\to}\infty\ AF$ or equivalently, $AF = \lim t{\to}\infty\ AF$

When this limit exists.

Analysis

Since availability at a given time is a probability, it is feasible to consider the FT as a single-time FT by substituting the chance of being in a failed condition at the required time for the BE failure distribution. The availability of the original determines the single-time dependability of the generated FT. According to the failure time distribution, failure probability of the BEs are often simple to calculate, even for repairable FTs.It is not possible to compute availability over an interval so simply. There isn't a closed-form expression in the general case since this availability is defined as an integral over any expression. If this availability is required, numerical integration methods may be used.

Definition of Mean Time to Failure

The Mean Time to Failure expresses the anticipated interval between the system's first operationalization and its eventual failure. Formally, we create a new random variable ZF that represents the total number of system failures up to time t.

MTTFF = lim$t{\to}\infty$ MTTFF.

In repairable systems the time to failure depends on the system state when it becomes operational. The first time, all componentsare operational, but when the system becomes operational due to a repair, some components may still be non-functioning. This difference is made explicit by distinguishing between Mean Time to First Failure and MTTF.To illustrate this difference, consider the FT in 2.16. Here, failures will initially be caused primarily by component 3, resulting in an MTTFF slightly less than 1. In the long run, however, component 1 will mostly be in a failed state, and component 2 will cause most failures[3], [4]. This results in a long-run MTTF of approximately 1.

Even while in practise MTTF and availability are often connected, only the MTTF can differentiate between frequent, short failures and uncommon, lengthy failures.

Analysis

There are expressions in many failure distributions that may be used to determine the components' MTTF right away. A component with an exponential failure distribution and rate, for instance, has an MTTF of 1. The Vesely failure rate can be used to approximate the MTTF, and can do so effectively even for larger trees, even though the combination of multiple BE frequently does not have a failure distribution of a standard type, and algebraic calculations produce very large equations as the FTs become more complex.

Mean Time between Failures

Definition

For repairable systems, the Mean Time between Failures denotes the mean time between two successive failures. It consists of the MTTF and the Mean Time to Repair. In general, it holds that MTBF = MTTR + MTTF.The MTBF is defined similarly to the MTTF except ignoring the unavailable times. Formally, MTBF$F = t$, and in the long run MTBFF =lim$t \rightarrow \infty$ MTBFF when this limit exists. The MTBF is useful in systems where failures are particularly costly or danger- ous, unlike availability which focuses more on total downtime. For example, if a railroad switch failure causes a train to derail, the fact that an accident occurs is much more important than the duration of the subsequent downtime.

The MTTR is often less useful, but may be of interest if the system is used in some time-critical process. For example, even frequent failures of a power supply may not be very important if a battery backup can take over long enough for the repair, while infrequent failures that outlast the battery backup are more important[5], [6].

Sensitivity research

For a certain FT, quantitative procedures yield numbers, but it is often helpful to understand how susceptible these values are to the input data. For instance, if the probabilities are based on approximate estimations, the computed reliability may not be relevant if tiny changes in BE probability cause a significant variance in system dependability. On the other side, a component may be a suitable candidate for improvement if the dependability is very sensitive to its failure rate. It could be feasible to analyse this expression to identify the sensitivity to a specific variable if the quantitative analysis approach utilised yields an algebraic expression for the failure probability. There is a suggested way to do this. But often, sensitivity analysis is carried out by performing numerous studies with marginally different values for the relevant variables. System sensitivity may be examined using a Fuzzy Fault Tree, an extension to FT, if the BE probability' uncertainty is constrained.

Important parameters

It is often helpful to identify the system components that contribute the most to a reliability metric in addition to calculating reliability measures for the system. These components are often excellent choices for enhancing system dependability.It makes sense to calculate the relative weights of the cut sets and the individual components in FTs. Several metrics are discussed, along with how well they work.

MC Size

The amount of components in a set may be used to sort minimum cut sets. Since a cut set with many components is often less likely to have all of its members fail than one with fewer components, this ranking roughly correlates to ordering by likelihood. Therefore, Small Cut sets are an excellent place to start when trying to increase system dependability.

Sporadic measurements

The stochastic metrics previously mentioned may also be derived for each cut set and used to organise them for a more precise arrangement. Probability for systems stated using exponential failure distributions. This approximation asserts that the failure of every component in C results in a system failure, necessitating the assumption that no other cut set failed prior to C. Therefore, the approximation can only be used if all alternative cut sets have sufficiently low failure rates. If so, it may be used to sort cut sets according to how often they lead to system failures. This approximation's whole derivation[7], [8].

Structural significance

Several different metrics of component significance have been offered in addition to ranking according to failure probability. Defines a system state as the synthesis of all component states. If altering the component state also affects the TE state, the component is now considered vital to the state. The Birnbaum significance of a component is now determined by the percentage of states in which it is crucial.

Formally, an FT with n components has $2n$ possible states, corresponding to different sets χ of failed components. A component e is considered critical in a state χ of FT F if $\pi F \neq \pi F$. Extended this notion to noncoherent systems, in a way that does not

The Vesely-Fussell importance factor VFF is defined as the fraction of system unavailability in which component e has failed. That is, given that a set of components S has failed causing the FT to fail, what is the probability that e is one of the failed components. Formally, VFF = = 1).

Significance of initiating and facilitating

Introduce a new relevance metric that evaluates the relative importance of starting events that actively contribute to the TE and enabling events that can only fail to prevent the TE in systems where certain components have a failure probability and others have a failure rate.Take a look at an oil platform to see this contrast. Burst pipes would be an initiating event if the event of interest was an oil leak since, without any intervening factors, this occurrence would result in an oil spill. An enabling incident occurs when an emergency valve becomes jammed open. It only fails to stop the ruptured pipe from creating an oil leak, not the spill itself. Since both of these events would only be coupled by an AND gate, the difference is often not clear in the FT.

Often, initiating events last relatively short until they either create the TE or are swiftly "repaired." Since doing so would also stop the catastrophic TE, repair in this situation might also include shutting down the system. Enabling events, on the other hand, can stay in a failed condition for a very long period.Due to this distinction, it is possible to increase the overall dependability of such a system by lowering the frequency of starting event failures, or by lowering the frequency or raising the repair rate of enabling events. One of the reasons for the analysis's differentiation between the two is due to this[9], [10].

Joint significance

The Joint Reliability Importance and its opposite, the Joint Failure Importance, were established to measure the relationships between components. These measurements provide more weight to pairs of components, such as a component and its only spare that are found together in numerous cut sets than to two relatively independent components. Finding components for which common cause failures are especially relevant may be possible using this.

The creation of minimum cut sets is the only qualitative analysis that is supported

The programme may calculate availability at particular moments as well as long-run mean availability for qualitative analysis. It can also compute reliability, projected number of failures up to a certain time constraint, and availability. Additionally supported is failure frequency up to a certain time. Additionally, the programme has the ability to calculate the BEs' importances and sensitivities.CARTE EPRI EPRI created the CAFTA tool for FTA. It supports non-coherent FTs and the PAND gate from dynamic FTs, as well as single- and continuous-time FTs. Different probability distributions, such as the normal and uniform distributions, may be found in continuous-time BEs. CCF models come in a variety of forms.

Cut sets may be calculated using CAFTA. The programme can calculate reliability as well as a number of important and sensitivity metrics for quantitative analysis.FaultTree+ for isographs one of the most often used FTA tools is the Isograph FaultTree+ software. It does fault tree analysis both quantitatively and qualitatively. It can analyse FTs with different failure distributions and can utilise Markov Chains in lieu of BEs to let the user arbitrarily close to any distribution. Analysis is also possible for dynamic FTs and non-coherent FTs, including NOT gates. The programme helps the investigation of common cause failures and the selection of minimum cut sets qualitatively. Additionally provided for issues like circular dependencies is a static analysis.

Static fault trees, which were previously described, explain how various combinations of component failures result in subsystem failures and ultimately the breakdown of the whole system. No matter when each of the component failures happened, such static FTs can only simulate systems in which a combination of failed components leads in a system failure. In practice, many systems can withstand certain failure patterns but collapse if the same components fail in the wrong order. When a switch in a system fails after it has already activated the spare, it does not result in a failure, for instance, if the system has a switch to alternate between a component and it’s spare.

To simulate these temporal relationships in FTs, NASA, among others, created dynamic fault trees. To be more precise, DFTs introduce extra gates and SPARE gates) whose conduct is dependent upon the succession of failures of their offspring.More sophisticated analytical methods are also required due to DFTs' higher expressive capability. Similar to static FTs, qualitative analysis may be used to produce cut sets as well as cut sequences that take into account the temporal links between occurrences. Numerous quantitative methods have been developed to calculate metrics like availability and dependability. Many strategies fit into one of two major groups, with the exception of those that take quite distinct approaches:

Exact methods that convert the DFT into a simpler formalism, such dynamic Bayesian networks or Markov chains, from which the measure may be derived. The qualitative and quantitative analysis approaches discussed in this are simulation techniques that pull a large number of samples from the probability distribution given by the DFT and estimate the required measure with statistical confidence limits.The majority of the methods in this article are only applicable to irreparable DFTs. Some DFT extensions, like the one developed by Boudali et al., permit repairs,

Structure

With the inclusion of additional gate types, a DFT's structure is quite similar to a static FT's. New gates include:

PAND If all inputs flow from left to right, an output event will take place. All other input events happen when the trigger event on the left happens, but FDEP Output is a dummy and never happens.SPARE represents a part that has one or more spares available to replace it. The first spare is turned on when the main unit malfunctions. The next spare gets triggered when this one fails, and so on until there are no spares left. Although one spare may be linked to numerous Spare gates, once one of them activates it, another cannot utilise it. Spare parts are typically arranged from left to right.

Instance 15 a DFT illustration. Although this DFT has the same cut sets as the subtree rooted at G3, its casual explanation is more understandable: M3 is plainly shown as M1 and M2's shared spare. Additionally, the PS power supply does not directly support the system. Instead, the failure of PS causes the failure of both CPUs, better describing the system while removing the shared event at the cost of adding a shared trigger.

The dormancy factor is an extra parameter that BEs may have. If the BE is an inactive input to a SPARE gate, this parameter, which normally has a value between 0 and 1, lowers the failure rate of the BE to that portion of its normal failure rate. A spare tyre, for instance, won't degrade as quickly as one that is being used. Has no impact on BEs that aren't inputs to a SPARE gate. It is possible to provide dormancy factors larger than 1, although doing so is seldom helpful since it would mean that a component would break down more quickly when not in use than when it was.

A DFT is not normally coherent due to the addition of the PAND and SPARE gates. For instance, an increase in the right input failure rate of a PAND might enhance the gate's dependability. When a component is forced to fail right away when a system is launched, overall dependability is often increased, demonstrating that this kind of non-coherence is frequently an indication of a modelling mistake or an inadequate system design.

The FDEP gate may be removed from non-repairable DFTs by switching each of its children for an OR gate of that child and the FDEP trigger. The usefulness of this strategy in repairable DFTs relies on how the FDEP gate is defined: The transformation is incorrect if the FDEP-related faults need separate remedies. The transformation does keep the behaviour if fixing the FDEP trigger also gets the triggered components working again.

A DFT is a tuple DF = $\langle$BE, G, T, I, DORM $\rangle$, where BE and G are the same as in a static FT. The function. T denotes the gate type, but now $T{:}G\mapsto$ DGT, with the set of dynamic gates DGT = GateTypes$\cup$ {FDEP, PAND, SPARE}. I is replaced by an input function: $I{:}G\mapsto E*$ yielding an ordered sequence of inputs to each gate. DORM $:BE\mapsto$ $\mathbb{R}\geq 0$ provides the dormancy factor for each the BEs.Use of a pruned input function that excludes FDEP inputs and outputs is often beneficial since the FDEP gate's output is a fake output and has no bearing on how the FT behaves.

There are extra gates in certain forms of DFT that are not included in the previous definition. Which are:

1. Warm spare Special case of SPARE gate, when the spares' dormancy factor is 1, meaning that the rate of failure for the spares is equal to the rate of failure for the primary component.

2. Warm Spare Special case of SPARE: Spares cannot fail before being activated due to a zero dormancy factor.
3. OR Priority when the input on the left fails before the others, fails. Replaceable with a PAND and an FDEP.
4. Enforcer of the order prevents input failures until every input to the left has failed. If the inputs are not shared with other gates and failure times are exponentially dispersed, SPARE may be used in its substitute.
5. When the trigger event occurs, there is a chance that the dependant events may fail, which is known as a one-shot PDEP special case of the FDEP gate.
6. An increase in the failure rates of the dependent events is caused by the occurrence of the trigger event in the persistent PDEP special case of the FDEP gate.
7. We see that most tools agree that this encapsulates the typical behaviour of DFTs. According to Junges et al., several DFT constructions have different implementation-specific features.

Qualitative research

The same methods employed for SFTs may be used to do a straightforward qualitative analysis of a DFT, particularly by substituting AND gates for the PAND and SPARE gates, and OR gates for the FDEP gates. The temporal needs of the tree will not be covered by this study. However, because a system failure requires the total failure of at least one cut set, the cut sets may be employed to increase system dependability.

Mathematical analysis

Merle et al. demonstrate how one may describe the system's dependability using the cut sequences produced by qualitative analysis. The probability distributions of the failure times of the BEs are then substituted into this function after first describing the system's failure probability in terms of the BEs.

Now, expressions for the failure probabilities within a given time can be substituted. We denote the cumulative failure probability Fe as the probability of e failing before time t, and the corresponding probability density as fe. While feasible for simple DFT, larger DFT with nested temporal dependencies $<C$) quickly result in deeply nested integrals making the approach computationally infeasible. Long et al. provide an alternate technique that computes availability at a certain period and the long-term anticipated number of failures per unit time. It employs a logical framework known as "Sequential Failure Logic" to explain the time constraints seen in cut sets. Due to the large number of multiple integrals, the equations generated are very difficult to solve, and only a particular situation where all failure and repair rates are the same is shown.

Markov Chain Analysis

Dugan et al.'s first technique for analysing DFTs computes the system's unreliability across a certain time range. The DFT is transformed using this way into a Markov Chain, where the states describe the DFT's history in terms of which components failed and, if necessary, in what sequence. This strategy is impractical for really complicated systems since the number of rejected subsets increases exponentially with the number of BEs.

A straightforward DFT turned into a Markov Chain. Three transitions are conceivable from the initial state S0, in which every component is functional, and they stand in for the failures of the three BEs. Two additional BEs may fail after the first BE fails, and then the last BE may fail. System failure happens in the circled stages of the MC if all three BEs have failed and E2 failed before E3. The system is still in use in the other states. Calculating the likelihood of attaining A desired state within a certain period of time, which corresponds to system unreliability, may be done using existing tools like PRISM and STORM.

The estimated probability might be altered without impacting the MC. For instance, no target state can ever be achieved from S3. Therefore, it is acceptable to substitute an absorbing state for S3 in order to simplify subsequent analysis. The scope of this thesis does not allow for a comprehensive consideration of minimization strategies.

DFTs are first transformed by Codetta-Raiteri into stochastic Petri nets, which are then subjected to Markov chain analysis. The Petri Nets are smaller, simpler to comprehend, and easier to expand than this method's Markov Chain, which nonetheless experiences a combinatorial explosion.

DFT compositional analysis

An alternative approach is used by Boudali et al. to determine a DFT's trustworthiness, which lowers the combinatorial explosion in many typical scenarios. They provide a compositional semantics for DFTs, in which each DFT component is seen as an Interactive Markov Chain, and the semantics of the DFT is the parallel composition of the components. The articles provide numerous approaches for reducing the size of the resultant Markov Chain. Additionally, it enables the extension of DFTs with reparable parts and special events.

A DFT is transformed into an input/output interactive Markov chain and then subjected to analysis in this manner. The parallel composition of the I/O IMCs for various branches of the tree, down down to individual gates and events, is computed to create this model. The overall I/O IMC may be significantly less than the Markov Chain generated by prior approaches, and the combinatorial explosion is decreased since intermediate models can be examined to eliminate pointless stages. This whole procedure is shown.

Arnold et al. created the programmeDFTCalc to examine the availability and reliability of DFTs using the I/O IMC technique.The fundamental event E1 and gate A of the DFT in 3.5's I/O IMC counterparts. The parallel composition of the two components is shown below that. The output signal of the BE permits the transition with input signal fE? in the gate's IMC, making this composition behave as if the two distinct parts are run in parallel.

I/O IMC may simulate nonde- terminism between activities, unlike conventional Markov Chains. This method is used by Guck et al. to simulate maintenance methods when it is unclear which of many failing components should be repaired first. More recently, Volk et al. have shown a novel state-space generation method that uses the DFT's structure to apply a variety of reduction approaches. This strategy, which may be used with other reduction approaches, is proved to be much quicker than the compositional method.For the purpose of calculating dependability, Pullum and Dugan created a programme that splits a DFT into independent submodules. If a submodule just has static gates, it can be solved using the conventional BDD technique; if it also has dynamic gates, it can be solved using Markov Chain analysis.

Using dynamic Bayesian networks for analysis

Later, Montani et al. enhanced the approach developed by Bobbio et al. for transforming an SFT into a Bayesian Network by analysing DFTs using a Dynamic Bayesian Network. The conditional probabilities at the present time might rely on the values of the random variables at previous times thanks to the addition of the concept of time in a DBN, which enhances the capabilities of traditional Bayesian networks.

In this method, the state probability distributions are carried over from one timestep to the next while the DBN is assessed at several points in time. Dynamic behaviour may be taken into account in the analysis by enabling nodes to have probabilities conditional on their own state in the preceding timestep. The findings from this approach are not precise because of the discretization. Although the calculation time grows linearly with the number of discrete timesteps, results may be made arbitrarily accurate by reducing the timesteps. This approach only analyses non-repairable FTs, however Portinale et al. provide a comparable method for repairable FTs. Other additions from the earlier BN work, including loud gates, are still relevant.

Boudali and Dugan developed the Bayesian Network technique to represent DFT gates. This approach may provide results that are comparable to those of a discretized Markov Chain solution for the DFT, but it can also be expanded to include dependent component failures and multi-state components by altering the generated DBN. There is currently no comparison between this approach and the method developed by Montani et al. the prior timestep. Otherwise, their failure rate determines the likelihood of their failing in the current timestep. The first two conditional probability rules are explained by this.

The PAND gate B's behaviour is described by the following two rules. If the prior timestep had a failure. If neither input succeeds nor E3 hasn't already failed, it fails otherwise. Keep in mind that this model's behaviour in the case of simultaneous failure is deterministic. And AND gate A's state is solely determined by its inputs. Similar to other analytic techniques, the FT may be made more efficient by employing more effective techniques for the static subtrees. Rongxing et al. suggested such a strategy that combines BDD and DBN. A BN makes it feasible to provide arbitrary conditional probabilities, thus in addition to the failure rates suggested by the tree topology, gate failure rates may also be included. This increases precision and lessens the impact of modelling mistakes. Graves et al. presented such a strategy. This is helpful since many real-world systems don't diagnose every defect to the level of the BE, but instead record component failures at an intermediate level.

To determine the dependability of non-repairable systems, Mo also provided a technique for transforming a DFT into a multiple-valued decision diagram. This method solves subtrees with dynamic gates by converting them into a CTMC before the results are incorporated in the MDD, whereas subtrees with just static gates are immediately turned into MDDs. In many typical situations, this method lessens the state-space explosion issue, but in the worst scenario with a dynamic gate as the TE, a complete CTMC still has to be addressed.

Simulation

Monte Carlo simulation may be used to carry out quantitative analysis. The impact that failures have on the system is estimated using samples of failures and/or failure periods taken from their respective distributions.

A programme to analyse DFTs using Monte Carlo simulation was created by Boudali et al. Because it enables BE failure distributions to vary over time and even depending on various clocks for various BE, non-Markovian models are produced. This is helpful, for instance, when a system takes a while to warm up and this has an impact on failure rates.It is feasible to build a hardware circuit to execute Monte Carlo Simulations significantly quicker than a typical computer simulation if extremely high performance is necessary. Aliee and Zarandi present such a strategy.

Rajabzadeh and Jahangiry suggest converting a DFT into an analogue electrical circuit that generates a voltage that corresponds to the likelihood of a system failure. Some of the gates in this method do need to be approximated, and it has not been shown that it is accurate for bigger models. Ou and Dugan provide a technique for assessing the sensitivity of different model parameters. In this article, we have shown how the formalism of dynamic fault trees extends static fault trees by adding new gates that reflect more typical dependability patterns, such as order-dependent failures, warm and cold spare components, and functional dependencies. A summary of the different qualitative and quantitative techniques for analysing such dynamic fault trees is also given. In order to integrate information regarding the order in which components fail, the cut sets employed in SFTs have been qualitatively enlarged to cut sequences, and several algorithms have been developed to detect such cut sequences. The basic quantitative techniques include simulation, converting a DFT to a Markov chain or dynamic Bayesian network, and so forth.

REFERENCES

[1] A. Alsaeedi, "Comparing web accessibility evaluation tools and evaluating the accessibility of webpages: Proposed frameworks", *Inf.*, 2020, doi: 10.3390/info11010040.

[2] E. Vitale Brovarone en G. Cotella, "Improving rural accessibility: A multilayer approach", *Sustain.*, 2020, doi: 10.3390/su12072876.

[3] A. Malekzadeh en E. Chung, "A review of transit accessibility models: Challenges in developing transit accessibility models", *International Journal of Sustainable Transportation*. 2020. doi: 10.1080/15568318.2019.1625087.

[4] K. Lättman, M. Friman, en L. E. Olsson, "Restricted car-use and perceived accessibility", *Transp. Res. Part D Transp. Environ.*, 2020, doi: 10.1016/j.trd.2019.102213.

[5] F. R. Ashik, S. A. Mim, en M. N. Neema, "Towards vertical spatial equity of urban facilities: An integration of spatial and aspatial accessibility", *J. Urban Manag.*, 2020, doi: 10.1016/j.jum.2019.11.004.

[6] G. Sarlas, A. Páez, en K. W. Axhausen, "Betweenness-accessibility: Estimating impacts of accessibility on networks", *J. Transp. Geogr.*, 2020, doi: 10.1016/j.jtrangeo.2020.102680.

[7] M. Ferati en B. Vogel, "Accessibility in web development courses: A case study", *Informatics*, 2020, doi: 10.3390/informatics7010008.

[8] K. Dashper en R. Finkel, "Accessibility, diversity, and inclusion in the UK meetings industry", *J. Conv. Event Tour.*, 2020, doi: 10.1080/15470148.2020.1814472.

[9] M. Friman, K. Lättman, en L. E. Olsson, "Carpoolers' perceived accessibility of carpooling", *Sustain.*, 2020, doi: 10.3390/su12218976.

[10] J. Sauer, A. Sonderegger, en S. Schmutz, "Usability, user experience and accessibility: towards an integrative model", *Ergonomics*, 2020, doi: 10.1080/00140139.2020.1774080.

CHAPTER 7

INSULATION MATERIALS

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The advantages of house insulation are many. Insulating a building will increase comfort, improve indoor air quality, save energy costs, and have a good effect on the environment. In areas with harsh weather, adding insulation to an existing house will control the temperature and improve the quality of life. The house will be more energy-efficient with insulation. The house will stay warmer in the winter and cooler in the summer thanks to insulation. As a result, fewer heating and cooling systems will be required to maintain a pleasant indoor environment. As a result, house insulation will save energy prices as well as cooling and heating expenses. The sound control will also improve with the addition of acoustic insulation. Through the creation of a sound barrier, insulation protects privacy by preventing the noises inside from being heard outside. By insulating the house, unwanted moisture is kept out and a more pleasant living environment is provided within. The house will be safe from any electrical shocks if the electrical outlets and the accompanying components are properly insulated. Home insulation has several advantages, including protecting the environment from pollution as well as the people living within the home. Building insulation will help buildings use less energy for air conditioning. This will lessen the carbon footprint and the quantity of pollutants that air conditioners discharge into the environment. Insulation is thus a crucial component of the so-called "green home policy[1], [2]."

Insulation Resources

Materials for insulation are created to keep the facilities and building parts in good condition for as long as feasible. There are many different kinds of insulating materials, depending on the construction and function.

1. Different Insulators
2. Insulators against heat
3. Soundproofing materials
4. Insulators with water resistance
5. Radiation shields
6. Electricity insulators
7. Heat Dissipators

Materials known as thermal insulators stop or lessen certain types of heat transmission. (Conduction, convection and radiation). Whether the surrounding temperature is high or low, the insulator prevents the transmission of heat from outside to inside or in the reverse manner. Thermal insulation has various benefits, including insulating a structure from the heat and lowering energy expenses and air-conditioning operating costs. Additionally, it stabilises and prevents fluctuations in the building's interior temperature. Buildings must be segregated in order to prevent heat loss in the winter and heat gain in the summer. This will decrease the transfer of heat. It is discovered that around 60% of the heat losses occur directly through the building's walls and ceilings, 15% via the glass, and approximately 25% through cracks, doors, and gaps[3], [4].

The following elements should be carefully selected in order to make the building's thermal insulation an affordable process:

1. The thickness and quantity of the insulating material
2. The price of the insulating material and the installation labour expenses.
3. Energy savings and greenhouse gas emissions are also measured.
4. Thermal insulation location

It is used to choose an insulating material grade that strikes a balance between financial savings and energy savings. Buildings in warm climates and buildings in cold climates are the two categories into which buildings fall in terms of thermal insulation location. Because of the high solar intensity and the temperature disparities between the inside and external environments, the majority of the heat absorbed in hot regions enters the structure via its exterior. In comparison to the internal heat produced by the different activities, more heat is obtained from exterior sources. Increased thermal insulation in the building's exterior shell will inevitably lower the quantity of heat gained, which will minimise the energy required for cooling. The U-value is a key consideration when determining the ideal insulator thickness for a structure. The total cost is the sum of the cost of all the insulation materials plus the cost of the energy that was conserved within the structure during that time. Heat is transmitted from inside to outside in cold areas, hence the insulating layer should be placed on the internal face of the surfaces to minimise heat losses[5], [6].

Thermal insulator types

All heat transfer-reducing isolators systems are referred to as thermal insulation. Thermal insulation keeps heat inside buildings in the winter and keeps heat outside out in the summer. In order to limit all sorts of heat transmission modes, including conduction, convection, and radiation, the finest thermal insulation materials need to be used. One of the most popular thermal insulators is glass wool, which is also used often in cork, polyurethane, and other materials.

Soundproofing materials

Acoustic isolators strive to absorb or distribute sound and prevent sound penetration. Because sounds travel through the air, we can discern between various speech kinds and noise. To stop the transmission of sound from outside to inside or from one location to another, solid building items, particularly concrete bodies, should be segregated. Sounds move through solid things like buildings as waves as well.

Acoustic insulation's purpose

1. Limit the transmission of sound via the walls and ceilings between the barriers and from outside.
2. Stop the transmission of machine noise and vibration.
3. Internal sound absorption.
4. Architectural techniques for regulating the acoustics

The positioning of the house in relation to exterior sound sources like streets, markets, and industries should be planned, as should the proper orientation of windows and doors, among other things.

1. Design techniques for the building's interior areas.
2. Ways to choose the ideal soundproofing material.

Acoustic insulator types

Often grainy and constructed of coloured quartz, acoustic and sound-absorbing tiles have two sides and are held together by resin. It is distinguished by its capacity for endurance and simplicity in washing.Aluminum foil might be used to cover glass wool panels, which would absorb sound and reject heat. It might be put in place on the ceiling, floors, and walls.Layers of plastic that might have a grainy or perforated face. Compressed and perforated cellulose sheets.

1. Gypsum slabs that might also have glass fibres.
2. Such as rubber, cork (EPS), and foam.
3. Perlite-like rocks.

Insulators for waterproofing

All structures need insulation against moisture since rain, groundwater, surface water, and moisture all contribute to the deterioration of construction materials, the growth of pests like mice and insects, and the transmission of illnesses. The walls that are exposed to rain but get little sunshine are more prone to dampness.

Effect of moisture

a. Damage to the house's components and construction materials
b. Walls, floors, and ceiling efflorescence.
c. Destroying the paint.
d. The use of subpar wood and the wooden decorations
e. The corrosion of metal components.
f. The growth of fungus and the unhealthiness of the environment for building occupants.

Causes of Moisture

Rainfall: In the absence of gutters, rainwater has the potential to penetrate the roof's thin surfaces. Without overhangs, rain might go through the outside windows.

Surfacing water: This refers to a river, sea, or pond where the water combines with the clay-containing soil that is close to the building's foundations and seeps into the structure by capillary action[7]–[9].

Water accumulating under the earth's surface created underground water. Osmosis is the process through which water travels through soil pores and into building foundations.The process known as "condensation" occurs when a film of dew forms on a window or even a wall during the winter. After some time, the moisture that has built up on the floors, walls, ceilings, and windows penetrates into some areas of the home, making the building materials more brittle and causing the growth of rust, mildew, and odours.Poor sewage drainage may create moisture in adjoining building components when sewage builds up beneath a structure and is unable to move downstream due to obstructions.

In contemporary architecture, freshly built walls spend some time in a moist condition.

Various waterproofing insulation types

It is recommended to utilise and install barriers to stop water from seeping into the various building components. Asphalt, flancoat, bitumen, and polyethylene are typical waterproofing materials asbestos, white cement, and acrylic.

Radiation shields

As indicated in the graphic below, radiation energy may be discharged as electromagnetic waves like light, UV, infrared, x-rays, and gamma, or as tiny particles like alpha and beta. Radiation may originate from the sun, the earth, nuclear reactors, numerous gadgets, or even the human body. Sun radiation has short wave lengths, including gamma, ultraviolet, infrared, and light. Long-wavelength radiation known as microwaves or radio waves.Ionization is the process of atoms or molecules losing their electrons as a result of radiation passing through a medium. Ionizing radiation may have major side effects, including skin redness, hair loss, burns, radiation sickness, and in rare instances cancer, if the dose is greater than the threshold level.

Ways to reduce the radiation danger

The following three measures may be taken to lower the danger of radiation:

1. Time: shortening the exposure period is indicated.

2. Distance: The percentage of exposure is reduced the farther away a person is from a radioactive source.

3- Shields: Putting up barriers will lessen exposure near the radioactive source.

Electronic Insulators

Various atoms may be found in every material. These atoms have a small number of "free electrons" in their outer orbit. The unbound electrons may be made to leave their exterior orbit and go to another atom quite easily. The term "electrical current" refers to the movement of electrons from one atom to another. Insulators are substances like wood, plastic, and ceramic that prevent the passage of electric current. Because there are so few free electrons in their atomic structure, these materials primarily impede electrical flow due to this. When there is an imbalance and the positive charges attract to the electric field while the negative charges displace away, the electric field is still active even in an insulating material. This division of electrical charges produces the "dipole" and the associated phenomenon known as "polarization."

Electrical systems utilise a variety of insulators with a wide range of functions. For instance, electrical lines are covered with plastic to prevent electrical shock. There are several different materials that may act as electrical insulators, including rubber, wood, ceramics, paper, glass, and oils.

Electrical insulator properties

Resistance is a material's capacity to fend against an electrical current.

Permittivity: which makes insulation more capable of absorbing larger quantities of electrical charges without transferring energy. The most effective insulator is one with a high permittivity.

Polarization is a material's capacity to endure the separation of electrical charges and a measure of its toughness.

Two Thermal Insulation

Thermal insulators are substances that, regardless of the ambient temperature, prohibit or significantly lessen different forms of heat transmission (conduction, convection, and radiation) from the outside to the inside or vice versa.

Benefits of Thermal Insulation

1. Reduce the quantity of heat that is distributed throughout the home.
2. Cut down on the energy needed to heat or cool the home.
3. Create a steady, non-volatile internal temperature for the structure.
4. Maintain constant construction component temperatures for long-lasting durability.
5. Decrease energy costs.
6. Reduce the amount of fuel that power plants burn.
7. Limit the release of greenhouse gases.
8. Thermal Insulators are categorised.
9. The structure suggests
10. Materials made of organic substances including cellulose, cotton, wool, cork, and rubber.
11. Materials that are inorganic, such as calcium silicate, asbestos, glass, perlite, rockwool, and vermiculite.

Metallic materials: tin reflectors and aluminium foil, for example.

Rolls: range in pressure, bendability, and degree of elasticity. Glass wool, rock wool, polyethylene, and foil-ceramic rolls could all be secured with nails.

Sheets: Materials with precise dimensions and densities, such polyethylene layers, polystyrene, cork, and cellulose, are available.

Gaseous or liquid substances that are poured or sprayed on to create the required dielectric layer, such as epoxy and polyurethane foam.

Grains: Granules or powder are often put in the crevices between the walls, however they may also be combined with other substances. Cork and polymers are two examples of such substances.

Industrial Insulators

The term "thermal insulation" is used to describe any isolators, systems, and procedures that lessen the heat transfer between the interior and the outside. In hot climes, thermal insulation is used in buildings to stop heat from entering the structure. Utilizing thermal insulation materials thereby minimises heat transmission. The most significant thermal insulators are evacuated panels, glass wool, cork, polyurethane, and other polymeric materials. Because of its high availability (everywhere) and low coefficient of heat conductivity (0.025 W/m.K), air is one of the finest thermal insulators.

The most typical insulators are:

Cellulose is a material that is derived from wood or recycled paper and is known for its propensity to absorb dust and water.This is made from a cork tree. Expanded Polystyrene, which is manufactured industrially from petroleum products, (EPS). It serves as a thermal and acoustic insulator and is used in panels.Boilers, reservoirs, and structures are all often insulated using glass wool.

Rock wool is used to insulate buildings and storage areas.Foam or insulated panels made of polyurethane are often used to cover fractures.Both EPS and XPS Astrofoil (XPE) layers of polystyrene cork are formed of two aluminium foils and air bubbles made of polyethylene components. In the summer, the aluminium layers reflect solar rays, and the high air isolation of the air bubbles prevents heat from transferring through the walls. This substance effectively insulates against air and water leaks.

Polycarbonate panels: These thin sheets, which serve as thermal insulators and can absorb shocks, are made of many layers and have air spaces between them.

Aluminum panels, aluminium-cobond, and reflective coatings are examples of reflective materials. Solar radiation on the outer walls is reflected using these materials.

Wooden panels that are fire retardant are distinguished by their capacity to slow the spread of fire in addition to their thermal insulating properties.

Phase Change Materials (PCM) are substances that, as a result of switching between the liquid and solid states, either absorb or release heat depending on the temperature of the environment. There are several compounds, such as paraffin and salt hydrates, that may function as phase change materials. These materials might be utilised in moderately warm climates with high daytime temperatures and chilly evenings. This substance absorbs heat from interior air on warm days and transforms into a liquid. The substance sheds its heat throughout the chilly night and returns to its solid condition. The interior air temperature may be kept steady without electricity by repeating this technique. The phase change plasterboard created by National Gypsum meets the following requirements:

1. Micronal Paraffin is the phase-change substance.
2. In plasterboard, tiny paraffin spheres (5–10 micrometres in diameter) are combined with gypsum and protected by shells made of acrylic.
3. The melting point is 24 oC, and the product may be used up to 32 oC.
4. The heat output is 125 W/m2.

Insulator Thermal Properties

The less conductivity coefficient there is, similar to the thermal conductivity coefficient, the better the heat transfer resistance. Reflectivity, absorptivity, heat capacity, density, coefficient of thermal expansion, and coefficient of thermal bridging are the other thermal characteristics. A material's ability to transmit heat is known as thermal conductivity. In comparison to materials with low thermal conductivity, high thermal conductivity materials transmit heat more quickly. In line with this, materials with high thermal conductivity are often utilised as heat sinks, whereas those with low thermal conductivity are used as thermal insulation. A material's thermal conductivity changes as a function of temperature. Thermal resistance is the inverse of thermal conductivity. The conductivity metre aperture may be used to measure a material's thermal conductivity in a variety of methods. Thermal conductivity is measured in (W/m.K) units.

Heat capacity is a material's capability to store heat. Thermal mass is the term for a substance having a large heat capacity.The mass of substance contained in a given volume is known as density. (kg/m3) is the unit used.The amount that a material's volume changes as a consequence of a change in temperature is known as the thermal expansion coefficient.The quantity of heat movement in specific regions known as thermal bridges is described by the thermal bridge coefficient. The breakdown of building materials, the spread of moisture, and the development of mould are all caused by thermal bridges, which are parts of the building envelope with higher heat transmission than nearby locations. Some instances of these areas:

The seams between the walls and ceiling

1. Connect spaces between walls and windows
2. Pile and groundwork

Additional Properties of Thermal Insulators

Mechanical: Including resilience, tensile, compression, and shear stresses. Some insulators are stronger and more resilient than others. That makes sense to utilise in addition to the objective of thermal insulation for sustaining the structure.

Moisture absorption: The presence of water or humid air in an insulator lowers the material's thermal insulation value and may cause the substance to degrade quickly. The result of moisture absorption and permeability is used to calculate the amount of moisture.

Acoustical: Some insulating materials may serve both as thermal and acoustic insulators.

Safety: During storage, installation, and use, certain insulating materials might cause harm to people. These might lead to physical abnormalities in people, poisoning, infections, or allergies in the skin and eyes, which makes it crucial to understand the chemical make-up of the substance and its capacity to attract mold, bacteria, and insects. Physical characteristics like the capacity for combustion and sublimation should be taken into account.

Heat Transfer Methods

Conduction is the process of moving heat from a hot surface to a cool surface across a wall's thickness. Different materials have different thermal conductivities. In contrast to an insulating substance like cork, concrete and steel, for instance, have high conductivities. The quantity of heat transmission through conduction is affected by the difference in temperature between the wall's surfaces, the thickness of the wall, the area of exposed surfaces, the material's coefficient of thermal conductivity, and the lag time.

Convection is the process through which heat is transferred from a wall to the surrounding air. The movement of air molecules from hot to cold zones removes thermal energy, replacing it with colder, less dense air molecules. Convection current is the term for this procedure. Heat transmission is accelerated by air movement.

Radiation is the process of transferring heat that is radiant but does not necessarily need a medium, such as when the sun heats the earth. The source of the radiant heat radiates it to the cooler areas. The walls' ability to absorb heat is decreased by reflecting materials like metal foils that reflect thermal radiation.

Thermal Insulation in Construction

Buildings may be categorised into two categories based on how they acquire heat: those in hot regions and those in cold climates. In warmer regions, the majority of the heat is drawn in from the outside via windows, walls, and ceilings. Increased thermal insulation in the building's exterior shell must inevitably result in less heat being gained, which in turn results in less energy being used for cooling. Heat does, however, go from inside to outside in frigid areas. As a result, the insulating layers are within.

According to research, the house's components transport heat as follows:

The building's walls and ceilings allow for the transmission of around 60% of the heat.The windows transfer around 15 percent of the heat.The doors and vents of the building allow for the transmission of around 25% of the heat.

Expression of Thermal Insulation

Before starting the design, some ideas must be clarified. Examples include: Thermal resistance: the capacity of a substance to withstand heat. The coefficient of thermal conductivity and thermal resistance are inversely related. Convection resistance close to the exterior and interior surfaces, as well as the collection of resistors for all materials, should be considered when calculating the overall resistance of the wall or ceiling. These resistors may be arranged either in parallel or series, much like electrical resistors. Resistance is also known as R-Value. In light of the various standards, it is important to note that the US R-Value is around six times more than the SI R-value.

To establish the ideal thickness of insulating material for structures, one consideration is the overall heat transfer coefficient. It is also known as U-Value. And it may be determined using the relationship shown below: Using the following relationship, determine how much heat is transferred through the wall:

T is the surface's temperature, and A is its surface area.(W/m2.K) is the symbol for U-Value. The U-Value of an uninsulated wall ranges from high (1–5) to low (1–1), whereas that of an insulated wall is less than (1) and that of a super-insulated wall is less than (0.2). The goal of the zero energy construction is being pursued by the global community by standardising the U-Value for residential structures as little as feasible.

Calculations in engineering

These are a few illustrations of how thermal insulation helps in energy conservation.

Instance 1 in the winter, heat is lost through the wall.

The convective heat transmission coefficients for a 1 m2 wall are as follows:

1. 10 W/m2.K for external surface
2. 5 W/m2.K for internal surface

Reduced Electricity Demand

Insulation helps maintain a constant interior temperature while lowering thermal loads and, thus, the need for power. The usage of power is often taken into (kWh). Use the following calculation to get the Annual Energy Demand (AED):

AED = Qtotal * N / 100

N is the number of days that are in use.

The performance of a building is based on its yearly electric power usage. Depending on the floor area, the following relationship might be used to compute the building performance factor:

BPF = AED / Floor Area

The building performance factor (BPF) is used to determine the type of building in terms of energy consumption, where high-energy building consumes more than (250 kWh/m2) per year while medium-energy building consumes an average between (100-200 kWh/m2) per year and low-energy building consumes less than (50 kWh/m2) per year.

Reduce Oil Consumption

It is found that roughly about 3,000 liters of oil equivalent each year are burned to produce electricity for heating or cooling for uninsulated house. This could be saved up to 60% through the using of thermal insulation techniques. The approximate equation to determine the relationship between energy demand and the annual oil consumption in (liters/m2) of floor area is:

Oil Consumption = 1.5 * Exp (BPF/ 20)

Economic Impact

In order to achieve effective insulation and lower energy consumption, the calibre of the insulation materials is selected. Thermal insulation of the building must be carefully selected in accordance with the following elements to make the procedure more affordable:

1. The thickness and volume of the insulating material.
2. The price of the insulating material and the labour required to install it.
3. How much power is saved for the building? Hence, the money was saved.

The cost of the insulators less the cost of the air conditioning equipment that are postponed for a particular time period is the economic value of insulation. Super insulation of the structure has been shown to raise construction costs by up to 20%, but these costs would be made up in a few years by decreased power bills. Some nations reward energy-efficient houses by waiving their power payments.

Practical Applications

The contribution of thermal insulation to energy savings, fuel consumption, and CO2 emissions may be calculated using a few different methodologies. The training comprised two hours in the computer lab for the following applications:

A visual basic-based design tool called the Iraqi Passive House Planning Package (IPPP) is used to determine the full energy balance of passive or active structures in Iraq. The application bears a large portion of the blame for Iraq's scorching temperature. It has the following characteristics:

1. Weather-related data (18 cities in Iraq)
2. A library of properties for various insulations and building supplies
3. Calculation of cooling and heating loads for residential buildings
4. Consumption of electricity and the contribution of renewable energy
5. Ventilation and indoor air quality system
6. Verification of passive house criteria
7. CO_2 emissions and oil usage\

[1] N. Llantoy, M. Chàfer, en L. F. Cabeza, "A comparative life cycle assessment (LCA) of different insulation materials for buildings in the continental Mediterranean climate", *Energy and Buildings*. 2020. doi: 10.1016/j.enbuild.2020.110323.

[2] B. Durakovic, G. Yildiz, en M. E. Yahia, "Comparative performance evaluation of conventional and renewable thermal insulation materials used in building envelops", *Teh. Vjesn.*, 2020, doi: 10.17559/TV-20171228212943.

[3] Y. Li, Y. Sun, J. Qiu, T. Liu, L. Yang, en H. She, "Moisture absorption characteristics and thermal insulation performance of thermal insulation materials for cold region tunnels", *Constr. Build. Mater.*, 2020, doi: 10.1016/j.conbuildmat.2019.117765.

[4] K. Wang, L. Yang, en M. Kucharek, "Investigation of the effect of thermal insulation materials on packaging performance", *Packag. Technol. Sci.*, 2020, doi: 10.1002/pts.2500.

[5] C. Hou, S. Xin, L. Zhang, S. Liu, en X. Zhang, "Foundation research on physicochemical properties of mine insulation materials", *Coatings*, 2020, doi: 10.3390/coatings10040355.

[6] S. Wang, H. Li, S. Zou, en G. Zhang, "Experimental research on a feasible rice husk/geopolymer foam building insulation material", *Energy Build.*, 2020, doi: 10.1016/j.enbuild.2020.110358.

[7] C. Martínez-García, B. González-Fonteboa, D. Carro-López, en J. L. Pérez-Ordóñez, "Mussel shells: A canning industry by-product converted into a bio-based insulation material", *J. Clean. Prod.*, 2020, doi: 10.1016/j.jclepro.2020.122343.

[8] E. Tumusiime, J. B. Kirabira, en W. B. Musinguzi, "Performance evaluation of cellulose fiber's effectiveness as a thermal insulation material for productive biogas systems", *Energy Reports*, 2020, doi: 10.1016/j.egyr.2020.12.014.

[9] G. Qi *et al.*, "Numerical simulation and optimization of heat-insulation material and structure for CFB boiler", *Therm. Sci. Eng. Prog.*, 2020, doi: 10.1016/j.tsep.2020.100692.

CHAPTER 8

THREE ACOUSTIC INSULATION

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Insulation against noise

Acoustic insulators are substances that can block or absorb sound. Pressure waves in the air are used to carry sound, allowing humans to discriminate between different voices and background noise. Solid things may also conduct sound. The constant noise that surrounds humans may cause nervous strain and have an impact on their behaviour. Environmental engineers thus determined the right noise levels for both living and working. Since concrete components easily transmit sound, it is usually advisable to manage the building's architecture and choose the best soundproofing materials. The building's insulation stops sound from travelling from one room to another, both within and outside[1], [2].

Acoustic insulator classification

Three basic components may be identified in the incident sound that strikes a surface. The first portion of the light is reflected off the surface, the second portion is absorbed by the surface, and the last portion is transmitted through the surface and into the interior. Thus, the following categories might be used to describe the soundproofing materials:

1. Reflective components
2. Absorbing substance
3. Business Insulators

Acoustic tiles are able to absorb sound and are long-lasting and simple to clean. They are often formed of composite materials like fiberglass, which is created when glass wool and epoxy are combined, and composite materials like quartz mixed with granular resin. The purpose of these tiles is to absorb machine noise.

They may be installed on the walls and ceiling and are known for their capacity to absorb sound and provide thermal insulation. These might be used to industrial and commercial structures.

1. Available polyurethane foam products include spray, layers, and tiles.
2. Panels made of compressed, perforated cellulose.
3. Gypsum board with fibres added to the surface.

There are several types of rubber, including mass loaded vinyl layers, industrial chloroprene (neoprene or polychloroprene), and natural rubber panels. (MLV). These come in rolls and panels, are very sound-absorbing, and are used to cover walls as well as to dampen vibrations.

Either natural or artificial cork (EPS)

Plastic packing sheets are suitable for use as ceiling layers in companies with expansive spaces. Both moisture and dust are resistant to them.Perlite is a white material extracted from volcanic rocks that acts as an excellent sound and heat insulation. It provides a dependable fire-resistant to the surface. Insulation for the ceiling, walls, and flooring is provided with perlite.Viscoelastic damping compound (VDC), a viscous glue that dries quickly, is used to dampen floors, absorb noise, and dampen vibrations from ductwork and equipment[3], [4].

Engineering Acoustics

A kind of mechanical energy, sound. Pressure waves that cause vibrations in the surrounding environment, such as the air or building materials, are how sound moves from one location to another. And it can tell the difference between sounds made by an ear or by audio equipment. Only a medium can move sound; a hoover cannot. The science of acoustics addresses the origin, transmission, and perception of sound.

Basic definitions in acoustics science include the following:

1. The characteristic that separates various kinds of sounds is called type of sound. A man's voice, an animal's voice, a machine's voice, etc.
2. The quality of the sound is the characteristic that led to a shift in pitch from the same source. It relies on the sound wave frequency, which determines how loud sounds are. For example, the sound of men and women, the sound of adult and youthful voices, and the sound of pleasure and sadness are all different.
3. Sound intensity is the characteristic that distinguishes between sounds based on how loud or quiet they are.
4. Sound frequency is the number of times per second that air molecules change as a consequence of the passage of sound energy. It is measured in Hertz units. (Hz). The majority of sounds we perceive are a fusion of frequencies.

Wave classification for sound

Infrasonic: waves that have less than 20 Hz frequency.

Sonic: waves that have frequencies between 20 Hz and 20,000 Hz.

Ultrasonic: waves that have frequencies above 20,000 Hz.

Sound power: it is the energy carried by the acoustic wave in a period of time. And it is measured in watts.

Sound intensity: mathematically, it is the amount of acoustic energy on a unit area. Human ear can feel a sound has 10-12 W/m2 intensity as minimum. The highest intensity of sound within earshot is 1 W/m2.

Iref = 10-12 W/m2

Sound Intensity Level (SIL): The sound intensity value is too small and it is difficult to compare with, so it is looking for a value more acceptable like (Decibel) which is symbolized by (dB). The lowest sound level value is zero dB. The sound level could be accounted from the relation:

SIL = 10 log (I/Iref)

Based on that, the sound is classified in terms of the level of intensity to:

- 0 - 40 dB : Quiet
- 40 - 80 dB : Noisy

- 80 - 120 dB : Very noisy
- 120 db : Intolerable

Sound pressure: It is the change of atmospheric pressure in a region as a result of the passage of sound. The less sound pressure feeling by human ear is about 2x10-5 Pa and this is called the hearing threshold. At a pressure of about 20 Pa the ear starts feeling of pain.

Pref = 2x10-5 Pa

Sound Pressure Level (SPL): it is a value similar to the sound intensity level, and also measured in decibels. It is calculated from the relation:

SPL = 20 log (P/Pref)

Transmission of sound

It refers to the building's capacity permeability allow sound to travel from one area to another. There are a number of methods for sound to move, including:

1. The term "airborne transmission" described sound that travels via windows and other apertures. These are processable with effective sealing.
2. Impact transmission: This refers to the sounds made by machinery and moving humans on the higher level. These may be handled by adding absorbent layers and dampers, such rubber and carpet.
3. Flanking transmission: This refers to the sound propagating through the building's components. In their processing, insulating materials are used. Any area of the building has a number that indicates how much of a barrier there is to sound permeability[5]–[7].

Loss of transmission

It is a measurement of the sound pressure level differential across the barrier. For instance, imagine that one side of the wall has a sound that is 100 decibels loud. The sound was then tested on the other side, and we discovered that it is 55 dB. The wall's 45 dB transmission loss is then stated. The higher value denotes excellent acoustic insulation and resistance. The frequency of the sound source affects this number.

Class for Sound Transmission (STC)

It measures the degree of transmission loss at a 500 Hz sound frequency that occurs through a wall or barrier. A crucial design consideration is the sound transmission class, which shows how well a building element resists the transmission of sound.

Sound amplification

In addition to having the capacity to reflect sound, each material also has the capacity to absorb sound. The absorbed energy is transformed into heat. The ability of sound absorption is quantified by the sound absorption factor. In comparison to dense solids, porous materials have a higher absorption.The ratio of total energy incident up on the surface to the total energy absorbed by the surface is known as the coefficient of sound absorption.

The table above demonstrates how the material's absorption coefficient fluctuates depending on the source frequency. The so-called Noise Reduction Coefficient (NRC), which is often used to characterise the value of the absorbance of the insulating material, is the average of these values and is chosen in certain circumstances.The number of acoustic units that the wall or barrier can absorb is known as its absorption capability. The term "sound absorption unit"

(Sabin). According to the connection, the absorption capacity is dependent on the space area and the absorption coefficient:

$C = \alpha \times A$

Noise Reduction (Attenuation)

The total amount of reduction in the acoustic energy as a result of reflection and absorption when moving from a room to another or abroad is called the noise reduction. This amount is expressed in the relationship:

$NR = TL + 10 \text{ Log } (C/A)$

Where:TL stands for the walls' loss transmission. C is the room's capacity for absorption. A is the location of the wall's separation.

Note: 500 Hz is often used in design calculations, which is still within the range of human and vehicular speech.

Industrial Noise Pollution

The auditory system is permanently damaged as a consequence of the constant rise in loudness, along with certain related symptoms including decreased heart rate, altered blood pressure, and breathing difficulties. As the psychological effect on the individual worker manifests via the modification of his sleeping habits, exhaustion in the body will follow, which will impair the productivity of the job. The worker's hearing threshold will decrease by roughly 15 dB over a number of years if he is subjected to an 80 dB continuous noise level while at work.

The reduction of noise pollution while maintaining the standards for industrial safety demanded in the lab, factory, and warehouse[8], [9]. Thus, it must adhere to these guidelines:

1. When using high-vibration machinery, use the proper damper.

2. Use soundproofing to reduce sound transmission and absorb sound.

3. Employers require all employees to wear ear protection.

Example: As indicated in the image below, fibreglass noise control baffles are hung above the noise source to lower the overall noise level in an industrial facility (80' L x 40' W x 20' H). The carpeted floor contrasts with the concrete walls and ceiling. Determine how many baffles you'll need to reduce noise by 8 dB. Employ the nomogram

Four Waterproofing Insulation

Waterproofing

All structures need insulation against moisture, rain, groundwater, and surface water because moisture damages building materials, creates unpleasant odors, encourages the development of pests like mice and insects, and spreads illnesses. Walls exposed to rain without receiving enough sunshine are more prone to becoming moist.

Damage to building materials and housing components is a result of dampness.

a. The walls, floor, and ceiling efflorescing.
b. Destroying the paint.
c. The wooden furniture and décor were a flop.

d. The corrosion of metal components.
e. The growth of fungus and the unhealthiness of the environment for building occupants.

Dampness's root causes

1. Rainwater: Because of the building's roof's weak surfaces and lack of gutters, rainwater may enter the structure. Without overhangs, rain may enter the windows.

2. Surface water, such as a river, the ocean, or a pond. Water penetrates into the building's foundations or interior by capillary action after mixing with nearby soil and generating clay.

3. Groundwater: Water that has built up under the earth's surface might be transferred via soil pores by capillary action and rise to a building's interior or foundations, harming the structural components that were used to create it. It could even overflow inside the structure.

4. Condensation: On cold winter days, you may see a film of dew forming on a window or even a wall. This occurrence is referred to as "condensation." After some time, the moisture that has built up on the windows, walls, ceiling, and floor permeates into the interior spaces of the home, making the building components more brittle and causing the growth of rust, mildew, and odours.

5. Poor sewage drainage: When sewage builds up underneath a structure and cannot move downstream due to obstructions, moisture may develop in the adjoining building components.

6. In contemporary architecture, freshly built walls spend some time in a moist condition.

Water may move through a material's tiny pores by a process known as capillary action, which relies on the forces of adhesion and cohesion. In porous materials like sponge, brick, concrete, and many other building supplies, the capillary action takes place.

Various kinds of waterproofing insulation

Waterproofing materials are used to keep moisture and water away from structural components of buildings. It is necessary to consider the climate and the kind of ground (concrete, stone, clay, or metal) while selecting the right humidity isolator. The approach is distinguished by the creation of an insulating layer or membrane that resists water pressure and the use of materials to stop water or moisture from seeping into building components.

These are the primary categories of waterproofing materials:

Bitumen: It is a dark substance created from the leftovers of crude oil distillation. Due to its affordability as compared to alternative insulating materials, flexibility, and resistance to the growth of fungus and insects, bitumen is highly popular in waterproofing isolation. Bitumen is sold in barrels, and it has to be heated to roughly 80 degrees for it to melt. The most well-known kinds are:

Bitumen liquid that is used to patch concrete or roof tile fractures. Sometimes "mastic" is created by mixing glue with the resin components. For the foundations and walls that are in direct touch with the earth, bitumen might be painted (1-2 mm thick).

Bitumen (asphalt) solid that has been combined with sand and stones to create the roadway paving material.Flancoat is a bitumen-based waterproofing coating applied to concrete surfaces in direct contact with the soil to keep them from becoming moist. It works well, is simple to use, and doesn't need any compounding. Where a brush or a roll is used to paint the surfaces, it does not need to melt. Although there are numerous different hues, it is often offered in black.

Rolls of bitumen: These layers have great waterproofing and insulating properties. They are constructed of bitumen and may have a metallic sheet covering applied to deflect heat. The bitumen layer, which comes in thicknesses of 3, 4, and 5, is often used to insulate ceilings and walls.

Acrylic is a water-resistant substance that is widely used to waterproof pool floors and building roofs. This substance is made of polyester fibres dipped in a polyacrylonitrile liquid resin, where the necessary surface should be coated (in several layers) and left out in the open to dry fast and turn into a flexible insulating layer. This compound adheres to diverse construction materials with a high degree of receptivity. It is an environmentally friendly and long-lasting substance.

Waterproofing fluid: This substance is created by combining paraffin wax with volatile oil. The necessary surfaces are sprayed with or painted with the waterproofing liquid.

Epoxy: A polymeric substance used to fill holes and fractures that is sticky and quickly solidifies.

Cement: If free of contaminants, cement has the potential to be an effective resistive insulator. There are two types of cement: - Portland cement, which boosts resistance by adding more cement to a cement-sand combination.

White cement: This substance is used to patch up cracks in marble bathroom and balcony tiles.

Fiberglass is a hard material made by combining glasswool with epoxy. It is utilised in tank building because of its excellent resistance to water. For the goal of reinforcing the bitumen waterproofing layer, glasswool may also be combined.

Surfaces may be segregated by utilising numerous layers, such as: Membrane made of polyethylene: Polyethylene is a flexible substance that resists moisture and is often present as a very thin layer.

a. Sheets of rubber
b. Layers of extruded polystyrene.
c. Mass loaded vinyl layers (MLV).
d. Nylon: This material may be utilised to cover the building's foundations as well as to connect various structural components or layers of insulators.
e. Metallic sheets: A thin coating of metallic sheet, such as copper and aluminium plates, might be used to cover slabs, roofs and walls. Water storages are often made from these metals.

Shingle: These tiles are used to cover incline surfaces and drain stored water. They have excellent isolation. A shingle has a lovely look and is composed of a long-lasting material, such as brick, stone, or composite material.

Asbestos: This material is used in ceiling panels and is known for its low weight and resistance to fungus, acids, heat, and water. Although asbestos panel is often used in roofing, it has lately been outlawed because to its detrimental effects on human health and the environment.

Rocks: Including granite and marble. They are distinguished by their hard surfaces and strong water resistance. Kitchen and bathroom floor tiles made of marble are very popular. The sculptures might be crafted from these pebbles.

Engineering Water Transport Calculations

Permeability is the inverse of resistance since it measures how easily liquids may move through a porous substance. Darcy is the symbol for permeability (D).

1 Darcy ≈ 10–12 m2

Velocity of the liquid in a permeable material is given by:

Where:

υ = flow velocity through the medium (m/s)

k = coefficient of permeability of the medium (m2)

μ = dynamic viscosity of the fluid (Pa·s)

ΔP =Applied pressure difference (Pa)

Δx = thickness of the bed of the porous medium (m)

Five Radiation Insulation

It is well recognised that various electromagnetic waves and particles released by radioactive sources affect living things in both direct and indirect ways. When exposed to radiation in excess of what is safe, several symptoms can develop. Due to radioactive particles entering the body through inhaling and food, workers in nuclear facilities and X-ray labs are at danger for internal exposure as well as external radiation that can harm the face, hands, and body. Knowing the type of radiation and isolation techniques, as well as adhering to the prevention guidelines outlined, are requirements for reducing the radiation risk in this region.

Radiation

Radiation, which is energy produced as electromagnetic waves, may take on many different forms, including light, ultraviolet and infrared rays, as well as tiny radioactive particle forms like alpha, beta, and gamma rays. The universe, the sun, nuclear power plants, as well as commercial and academic uses, are the sources of this radiation. Some earthly substances also exhibit radiation properties. The body has a small amount of radioactivity. Gamma rays are the shortest and radio waves are the longest of the photons that make up electromagnetic waves.

Radiation classification

According to how dangerous it is, radiation can be categorised as follows:

Ionizing radiation: This category includes cosmic rays, gamma rays, alpha and beta particles, among others. Its ionising capacity makes it harmful.

Radiation that isn't Ionizing

The sun or industrial processes are the sources of these photons. Although these rays are not fundamentally harmful, extended exposure to them has been linked to incidents of pain, headaches, nausea, dryness of the hair, and occasionally mild skin burns. We are shielded from harmful rays by clothing, sunglasses, and covering.

Non-Ionizing Radiation Types

Light is a particularly practical form of radiation (the visible spectrum). It produces light and regulates a wide range of biological processes, including the development of bone tissue, maintenance of blood pressure, diabetes, cholesterol levels, and psychological comfort. Through photosynthesis, it plays a significant part in the growth of plants.

There are several uses for infrared, including remote sensing, short-range wireless communications, night vision, and providing warmth.Except for one band, ultraviolet radiation is a helpful form of radiation. These rays assist in giving the body vitamin (D). UV has various uses, including sterilising water and medical equipment and preventing babies from becoming yellow. The skin and the eyes are damaged by prolonged UV exposure. It is important to note that these rays can break chemical bonds, which makes them the culprit for the destruction of plastics and insulating polymeric materials.

Radio waves: These include the wavelengths used in telecommunications, radio, television, and microwaves. Despite the fact that these rays aid in the transmission of information, they can be damaging to people, particularly when it comes to the nervous system and the senses.

Atomic Radiation

Rays or particles from the sun, the universe, or radioactive materials are included. (such as radium, uranium, plutonium, thorium, iodine, potassium, zircon, phosphor and radon). These sources' radiation has the potential to ionise the medium, which implies it could separate atoms' electrons.

Radioactivity

The majority of chemical elements have a nucleus with the same number of neutrons and protons. Since some elements have more neutrons than protons, they are unstable and are referred to as radioactive isotopes. These isotopes release gamma rays, beta particles, and alpha particles from their nuclei. These elements change into other elements with different chemical and physical properties throughout time and lose weight. Ionizing radiation is the term used to describe the released rays and particles. The type, energy, and half-life of the radiation all affect the properties of radioactive isotopes.

Half-Life: It is the time needed to disintegrate half of atoms of a radioactive element, hence reducing the activity by half. For example, the half-life of (iodine -131) is 8 days while the half-life of (radium -226) is 1600 years.

Types of Ionizing Radiation

Alpha particles: During nuclear disintegration, the nucleus releases alpha particles. The nucleus of alpha has a positive electrical charge because it is made up of two protons and two neutrons, which is comparable to the helium atom's nucleus. As these particles leave the radioactive element, they rapidly lose energy. As a result, alpha particle penetration of the skin is poor and might be stopped by a thick piece of paper. When alpha particles penetrate the body's interior organs by breathing, eating, or injuring, there is a chance of adverse effects.

During nuclear decay, beta particles are released from the nucleus. Beta particles may be created during the breakdown of neutrons as either electrons (negative charge) or positrons (positive charge), or sometimes full neutrons are released to the outside. Certain beta particles may enter the skin and cause harm because they have a greater penetration force than alpha.

If it is ingested, it also has negative consequences. A piece of wood or a sheet of metal might serve as a barrier against beta radiation (10-20 mm).

Gamma rays: This kind of radiation is a representation of the energy released during nuclear breakdown. Gamma rays are produced when the nucleus enters the stability phase as a result of the production of alpha and beta particles, which drives the nucleus into that state. Gamma rays that are created by the interaction of electrons and positrons are known as annihilation radiation. This radiation has a very high penetrating power, making it one of the most harmful forms of radiation. It may readily infiltrate the human body and be absorbed by tissues. A concrete wall or a lead coating might serve as barriers (4-12 mm).

X-rays: These rays have characteristics with gamma rays but come from a different source; gamma rays come from within the nucleus, while X-rays come from the outside (electron transit between energy levels). These rays have a lower permeability and penetration force than gamma rays, which may be stopped by a thin coating of lead (1-3 mm).

Galaxy rays: These are high-energy space-derived particles. A small percentage of this radiation enters the atmosphere, but the majority is dispersed via the higher layers. A layer of composite materials or chemical compounds could be able to prevent this harmful radiation.

Ionizing Radiation Hazards

Ionizing radiation has the potential to ionize the medium, which would result in the separation of atoms' electrons. The recipient's body's biological components are ionized, causing changes in the size of the cells or fragmentation, which results in the creation of hazardous chemicals that may spread to other organs and cause severe injury. In addition to the inherited effects of genetic factors, these impacts might manifest early or late in the form of symptoms or illnesses like cancer. Employees working at radiation facilities may be exposed inside or externally. When radionuclides enter the circulation or are inhaled or swallowed, they cause internal exposure to ionizing radiation. The skin becomes exposed to radioactive materials when they cling to it. According to the degree of exposure, the sort of damage is caused by the body's radiation dosage. Radiation dangers often include skin redness, burns, hair loss, radiation sickness, hemorrhage, infertility, and, in rare circumstances, cancer.

Methods to Reduce Radiation Danger

Depending on the nature of the job, a person who works in the radiation field may be exposed to a dosage of radiation. The following commitments are crucial for lowering the danger of radiation exposure.

Date of Exposure

Reducing the exposure duration makes radiation less hazardous (time spent by the person beside the radiation source). The guidelines of international organisations like (ICRP) and state that the maximum exposure limit for humans is (0.05 Sv/yr) (USNRC). The exposure limit is divided by the entire working hours to determine the amount that is allowed for people who work in the field of radiation. Hence, the permitted maximum is 17 Sv/h over a period of 8 hours and 360 days.

Shielding

Metal or other materials with the potential to either absorb radiation and turn it into heat or reflect it might be used as barriers to minimize radiation. According to the radiation's energy and intensity, there is a suitable barrier setting for each kind of radiation. The linear attenuation coefficient shows how susceptible a substance is to absorbing radiation. The value of the linear attenuation coefficient for various materials is shown in the following table. It is observed that when radiation energy (eV) traveling through the material increases, the value of the linear attenuation coefficient falls.Value Half Layer: The thickness of the substance must be at least twice as thick to attenuate radiation by 50%. It is denoted by the sign and measured in centimeters as (HVL). The table that follows displays some HVL for various components.

Nuclear power facilities

The reactor, which houses the nuclear fuel units, is the primary component of a nuclear power plant (uranium, thorium, plutonium or iodine). A 25 cm thick steel wall surrounds the reactor because nuclear fissions occur repeatedly, maintaining a high vapor pressure and preventing radiation leakage (particles) outside. Moreover, a covering comprised of a substance that is extremely absorbent to neutrons, such as a cadmium alloy, should be placed over the surfaces that come into direct contact with nuclear explosions. The water that surrounds the reactor absorbs the energy released (photon). This energy causes the water to boil before being sent to the turbine to produce electricity.

REFERENCES

[1] D. Kumar, M. Alam, P. X. W. Zou, J. G. Sanjayan, en R. A. Memon, "Comparative analysis of building insulation material properties and performance", *Renewable and Sustainable Energy Reviews*. 2020. doi: 10.1016/j.rser.2020.110038.

[2] N. H. N. Do *et al.*, "Heat and sound insulation applications of pineapple aerogels from pineapple waste", *Mater. Chem. Phys.*, 2020, doi: 10.1016/j.matchemphys.2019.122267.

[3] M. Belmokaddem, A. Mahi, Y. Senhadji, en B. Y. Pekmezci, "Mechanical and physical properties and morphology of concrete containing plastic waste as aggregate", *Constr. Build. Mater.*, 2020, doi: 10.1016/j.conbuildmat.2020.119559.

[4] G. Lucas, M. Rocha, B. Castro, J. Leão, en A. Andreoli, "Stator Winding Fault Phase Identification Using Piezoelectric Sensors in Three-Phase Induction Motors †", *Eng. Proc.*, 2020, doi: 10.3390/ecsa-7-08183.

[5] K. Ikeda en A. Kamimura, "Hammering acoustic analysis using machine learning techniques for piping inspection", *J. Robot. Mechatronics*, 2020, doi: 10.20965/jrm.2020.p0789.

[6] W. Sikorski, K. Walczak, W. Gil, en C. Szymczak, "On-line partial discharge monitoring system for power transformers based on the simultaneous detection of high frequency, ultra-high frequency, and acoustic emission signals", *Energies*, 2020, doi: 10.3390/en13123271.

[7] W. Larbi, C. Soussi, J.-F. Deü, en R. Sampaio, "Sound transmission loss through double glazing windows in low frequency range", *arXiv*. 2020.

[8] H. Darvish Gohari, M. R. Zarastvand, en R. Talebitooti, "Acoustic performance prediction of a multilayered finite cylinder equipped with porous foam media", *JVC/Journal Vib. Control*, 2020, doi: 10.1177/1077546319890025.

[9] J. Nurzyński, "The acoustic performance of circular openings and wall-mounted vents", *Appl. Acoust.*, 2020, doi: 10.1016/j.apacoust.2019.107200.

CHAPTER 9

RADON-PRODUCING GARBAGE

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It denotes nuclear plant debris or anything to do with chemical anti-armor weaponry. Even before the issue of radioactive waste became a concern, it was discovered that these substances continue to function and emit particles that may be absorbed by neighboring plants and insects and then transferred to people and cause interior infections. Nonetheless, there are a number of measures to prevent the threat posed by these compounds, such as: a. Storage in the ground and in desert regions, or in plastic barrels.

Storage in salt- or gypsum-lined concrete tanks.

An X-ray lab

The X-ray lab should get considerable consideration in hospitals. It ought to provide a windowless, secluded space for X-ray imaging. Brick or concrete should be used to construct walls, however if there is an interior divider, door, or control window, a layer of lead should be used to separate it (2 mm). Place the X-ray tube at least half a meter away from the body[1], [2].

Airplanes

In order to save weight and money, composite materials have recently replaced the aircraft's exterior components. Since polymeric material has a relatively low attenuation coefficient, this method raises the danger of radiation exposure. To solve this issue, either a thin coating of lead must be deposited or tiny grains of absorbent substances (like bromine) must be intercalated into the composite material.

Spacecraft's

High-energy gamma rays, cosmic rays, and particles may enter spacecraft. Thus, it has to utilize precise shielding materials. Alloys made of high-z materials including lead, tungsten, gold, vanadium, and titanium are used to coat the external shells. Use materials with a high hydrogen content, such as lithium-hydride, for the inner layers. Shields must encompass certain magnetic components composed of ferromagnetic materials such as in addition to shielding against radiation (iron, nickel and cobalt). The magnetic field that is created shields the ship from solar storms and cosmic radiation[3]–[5].

Advanced Shielding Methods

Because of the practical and qualitative advantages, composite materials technology is often used in radiation barriers. The table below lists a few composite materials used in radiation shields along with their intended uses.

Six Electrical Insulation

Insulators have several uses, including wrapping electrical wires and separating electrical conductors in electrical equipment. The supports that are used to fasten transmission lines for electric power to poles and towers are also referred to by the more precise name "insulator." Without letting the electricity to pass through the tower to the ground, they maintain the weight of the dangling wires. An electrical insulator is a substance that prevents the free movement of electric charges inside, making it practically hard to conduct an electric current when subjected to an electric field. In contrast, some materials more readily transmit electric current. Since even insulators include minute amounts of mobile charges, there is no such thing as a perfect insulator.

Materials are categorized

Every material, it is known, has a variety of molecules and atoms. These atoms have a small number of "free electrons" in their outer orbit. A flow of electrons known as "electric current" is created when free electrons are readily ejected from their exterior orbit and made to go easily to another atom.

Materials are categorized based on how well they transmit electricity to:

Conductors

An item or category of material that permits the passage of electrical current in one or more directions is referred to as a conductor. The electrons are typically the moving charged particles. Metals (copper, aluminum, iron, etc.), electrolytes, superconductors, semiconductors, plasmas, and certain nonmetallic conductors like graphite and conductive polymers are examples of conductor materials.

Due to its excellent conductivity, copper is utilized in a variety of products, including busbars, motor windings, cables, and construction wire. Copper is still the material of choice for the majority of light-gauge wires due to its simplicity in soldering or clamping connections. Aluminum has certain drawbacks despite having a conductivity that is greater than copper's. Where it may create a resistive oxide that prevents heat from terminating in wires. In addition to having a different coefficient of thermal expansion than steel, aluminum may creep under strain, gradually deforming and finally causing device connections to become loose. This quickens the link weakening. To avoid heating at joints, suitable connections and installation techniques must be utilized when using aluminum wires for low voltage distribution, such as underground cables and service drops. Together with steel, aluminum is the most popular metal used in high-voltage transmission lines for structural reinforcement. Silver is more conductive than copper, but it is not practical since it is expensive. To reduce skin effect losses at high frequencies, it is employed as a thin coating in specialist equipment like satellites[6], [7].

Insulators

Materials include wood, plastic, quartz, and ceramic that don't permit the passage of electricity. The fact that there are so few free electrons with room to travel in the atomic structure is the primary factor in these materials' capacity to limit electrical flow.

A substance that has a lot of free electrons is called a "conductor," while a substance with few free electrons is called an "insulator."When there is an imbalance and the positive charges attract to the electric field while the negative charges displace away, the electric field is still active even in an insulating material. This division of electrical charges results in the creation of the "dipole" and the associated "polarization" process. "Dielectric substance" refers to an insulator that may become polarized when an electric field is applied.

Types of Electrical Insulator

Electrical systems utilize a variety of insulators with a wide range of functions. Materials like plastics, rubber, wood, ceramics, glass, cellulose paper, and oils are examples of electrical insulating materials. According to their use, electrical insulators may be divided into the following categories:

Plastic wiring materials

The electrical lines are covered with plastic to prevent electrical shock. In most cases, polytetraflouroethylene is used to insulate twisted pair wires. Plastics including PVC, PP, PEEK, PTFE, PET, PES, PEI, ECTFE, PBT, and FE are excellent for electrical insulation.

Insulators for electrical wires in overhead transmission lines

The insulator has to be strong enough to support the conductor load even in the worst leading circumstances, be able to endure high working voltages and lightning-induced overvoltages, and have great mechanical endurance. To lessen harm from power flashover, it also has to have a strong tolerance to temperature variations. Overhead lines discs are often made of porcelain, silicon, and glass. For overhead lines, there are three primary kinds of insulators.Type supported by a forged steel pin that is fastened to the cross arm of the supporting structure is the pin type.

A suspension insulator is one that is made up of a number of independent insulator disc units that are linked together by metal lines to create a flexible string or chain.

Kind of Strain (Tension): Strain or tension insulators are designed to handle mechanical loads at angles where the direction of the line changes or at the ends of the lines.

Oil for insulating

These oils have good electrical insulating qualities and are stable at high temperatures. Transformers, high-voltage capacitors, and fluorescent light ballasts all employ oils.

Coated with powder

In comparison to wet applications, powder coating technology is acknowledged as being a better way to impart a protective finish to objects of all shapes and sizes. Epoxy powder coating is one method that works well as a high dielectric insulator on copper or aluminum conductors. Due to its longevity, it is utilized to provide a constant insulating barrier. Epoxy powder coating eliminates worries about cable insulation cut-through or high-voltage spikes. The surface has to be cleaned and dried before applying the powder[8], [9].

Vaselines that insulate

Use varnish as a sealer. For electrical motor insulators, a variety of solventless resins and organic varnishes are often utilized. They have several benefits, including: - Increasing the dielectric characteristics. Strengthening the mechanical link between the winding wire and the winding; Shielding the winding from chemical and moisture corrosion

Capacitors

A passive two-terminal electrical component called a capacitor, often referred to as a condenser, is used to store electrical energy in the form of an electrostatic field. It is composed of two electrical conductors (plates) that are spaced apart by an insulator (dielectric) that may store energy via polarization. Metal foils or conductive electrolyte serve as the conductors. Glass, ceramic, plastic film, air, vacuum, paper, mica, polymer, or oxide layer are all examples of dielectrics.

Electrical Insulator Properties

Resistance is a material's capacity to fend against an electrical current. A conductor's resistance is a function of its size and the substance it is constructed of. R = L determines the resistance for a particular material.

1. The substance's resistivity (ohm.m) L stands for wire length (m)
2. A is the wire's cross-sectional area (m2)

The characteristic that sets insulators apart is their resistivity, which is greater in insulators than in semiconductors or conductors. High resistivity materials like Teflon, glass, and paper are excellent electrical insulators. A considerably greater range of materials are utilized as insulation for electrical wiring and cables even though they may have lower bulk resistivities since they are still capable of obstructing considerable current passage at commonly used voltages. Rubber, polymers, and the majority of plastics are among examples.

A dielectric medium's permittivity may be used to gauge how an electric field affects it. In other words, a medium's permittivity tells us how much electric field is produced there for every unit of charge. Due to polarization effects, a medium with a low permittivity has a higher electric flux. The most effective insulator is one with a high permittivity. It is possible to state that when permittivity grows, the insulation's capacity to absorb more electrical charges and prevent the transmission of energy also increases. This is because rising permittivity causes the material's capacitance to rise. The capacity of a substance to withstand an electric field is known as permittivity. Permittivity () is expressed in farads per meter (F/m) in SI units.

Electric susceptibility, a measurement of how quickly a dielectric polarizes in response to an electric field, is directly linked to permittivity as follows:

The capacity of an insulating material to experience the separation of electrical charges from its strength is known as polarization. When a sufficiently high voltage is supplied, the electric field separates the electrons from the atoms, making all insulators electrically conductive. This is referred to as an insulator's "breakdown voltage." In light of this, "dielectric strength" refers to the highest electric field that an insulating material can support under ideal circumstances before degrading. When expressing breakdown voltage gradient as a voltage drop per unit length (V/m), the insulator's dielectric strength is often described.

Technical calculations

Capacitors

Suppose that positive (+Q) and negative (-Q) charges are present on two parallel plates of area (A) that are spaced apart by a little distance (d). The formula for the voltage between plates (V) is: V = Q / C.

Q equals charges where (coulomb)

C stands for the capacitance of two plates. Another formula for voltage is V = D d /.

Where: Q / A = D = field density (coulomb/m2)

(F/m) = Absolute Permittivity

Thus, C = A / d

Discs that insulate

Selecting the insulation level has a significant impact on cost and operational dependability and is a key consideration in constructing the discs for power transmission lines. The operating voltage is mostly dependent to the insulating disc. Electricity is transferred from a producing station to a distribution station through a transmission line. Typically, this voltage is between 11 and 33 KV. Long-distance power transmission at these voltages would result in significant power loss. Hence, step-up transformers are used to increase this voltage to a larger value. According to the chart below, several nations use 66 KV, 132 KV, 220 KV, 275 KV, 345 KV, 380 KV, and 400 KV for long-distance transmission lines. A balance between the likelihood of failure and the expense of increased insulation strength should be achieved in the number of insulator discs (string)[10], [11].

Historical Overview

As soon as significant quantities of electricity could be produced, the methods to convey this energy were needed for its utilization. The first major problem was creating a part that would isolate the live wire from the earth. It was quickly discovered that it is challenging to create an efficient insulator for usage in damp and polluted environments, despite the fact that practically any solid non-conductive substance can insulate several hundred or a few thousand volts from ground in dry conditions. Early power line insulators from the 1880s were similar to telegraphic insulators that had been developed around 50 years earlier. During the next 30 years, several designs were tested utilizing various fundamental ideas. These ideas still hold true today. The solid material must possess strong mechanical qualities, a high dielectric strength, and a surface that is effective in the presence of electrical discharges. Even better, the surface characteristics need to be able to minimize the incidence of such discharges. It's interesting to see how similar many modern insulators are to those created over a century ago.

Cap-and-pin disc insulators, both old and modern

All insulators were constructed of porcelain in the early 20th century. Long rod insulators, a development of the originally Swiss-designed Motor insulator, were made possible by the invention of high strength porcelain. In the 1930s, toughened glass insulators were first made possible by a novel method for toughening glass. In the late 1960s, the first composite insulators debuted, heavily using polymeric materials. They are longer than their porcelain counterparts, have a superior strength-to-weight ratio, and can be produced in larger lengths. In actuality, the length of composite insulators is mostly limited by the logistics of shipping and handling.

Pioneer of composite insulation

Modern insulators, whether cap-and-pin disc, long rod, post, or apparatus type, first seem to be straightforward gadgets. Yet, these are sophisticated parts. Some of the insulators that are now on the market have an extraordinarily high degree of dependability because to years of design and material research and refining. For instance, for every 10,000 installed units per year of high-quality, properly sized cap-and-pin insulators, less than one fails.

The Essential Function of Insulators

While the cost of the insulators makes up a very tiny portion of the total cost of constructing a new transmission line, failure of this apparently minor component may have significant negative economic effects. Nonetheless, market forces have led to lower insulator costs, particularly during the past 20 to 30 years. Throughout the last 80 years, there has been a dramatic reduction in the price of a line insulator in comparison to the average daily income of a worker in Western culture. This may help to explain why, with the exception of the invention of composite insulators, the fundamental structure and materials have remained mostly unchanged for over a century.

Using an insulator of lower quality or with features that don't meet the needs of the application might have effects that are significantly more costly than the cost of an early replacement. Additional maintenance expenses, coatings that reduce pollutants or improve performance, and regular washing all have a big financial effect. A major power line's unavailability may cost hundreds of thousands of dollars each day in repairs and maintenance.

A rise in requirements

In the 1880s and 1890s, the first overhead wires for the transmission of electrical energy were constructed. The greatest working voltage was between 50 and 66 kV until about 1910. The operating voltage had more than multiplied by ten by the 1960s. Insulators had to be able to handle both the much greater mechanical loads that came with these new lines as well as the additional electrical stresses required by these very high working voltages.

About the same period, the pollution burden placed on insulators rose due to an increase in global population density and the concomitant rise in industrial and agricultural activity. As a result, one of the most important aspects to take into account while choosing insulators was environmental stress. Modern insulators must also work at the greatest level possible since electronic equipment and apparatus now demand a quality and a consistency of supply that were not necessary in the past.

In 1912, a 66 kV electricity line was being built

An extensive set of test procedures and standards have been developed by organizations like the International Electrotechnical Commission with the help of technical experts from insulator users and manufacturers in order to ensure that modern insulators comply with the requirements of contemporary electrical networks.

Potential Demands

The network for supplying power must be rapidly expanded in order to support industrial growth. As a result, construction is underway on or is planned for thousands of kilometers of new high voltage lines and the related substations. They all need insulators. Several lines and substations in the previously industrialized regions of the globe need to be renovated because of their advanced age. It will be necessary to update or upgrade other lines. Existing lines may need to be replaced with more compact designs due to environmental pressures. All of this calls for new insulator testing and assessment methods, maybe new selection criteria, as well as better insulators.

Types and Characteristics of Insulators

This serves to provide a general overview of the main insulator kinds that are accessible, as well as information on their basic constructions, constituent parts, electrical and mechanical properties, and intended uses.

Insulator Supplies

An essential step in designing an outdoor insulator is taking the qualities of the insulating materials into account. The material must not only be a superb dielectric with the ability to tolerate high electrical stresses over an extended period of time, but it must also be able to survive the frequently harsh environmental impacts imposed, such as UV radiation, pollution, and lightning overvoltages. Also, it has to have enough tensile, compressive, and cantilever strength to withstand the loads placed on it and preserve its mechanical integrity for the duration of the installation in issue. A succinct summary of the typical materials used.

Porcelain

It has been the most popular kind of outdoor insulation since the invention of the first porcelain insulators in the middle of the 19th century. Clays and inorganic elements are used to create electrical porcelain, which, after being fired in a kiln, is composed of a glassy matrix of different oxide and silicate crystals. It is absolutely impenetrable to moisture after it has been thoroughly vitrified by the firing process. The insulators are often glazed to provide a smooth surface that prevents pollutants from adhering and makes it easier for rain to naturally wash away dirt. A secondary function of the glaze is to create a compressive outer layer, which reduces the occurrence of surface cracks and boosts mechanical strength. As a non-homogeneous material made of naturally existing minerals, the qualities of porcelain are greatly influenced by the actual attributes of the raw materials used, their processing, and the fire cycles utilized. As a result, the materials produced at each plant vary, and the insulator design must take these variations into consideration. Yet there are standard grades of ceramics, and IEC 60672-1, "Specification for Ceramic and Glass Insulating Materials - Part 1: Definitions and Classification," defines their minimal properties.

The main advantages of porcelain are:

Due to its inert, inorganic nature, it is resistant to environmental factors like ultraviolet radiation and aggressive contaminants. It is also resistant to surface electrical discharge and leakage current activity. Its high compressive strength and ease of shaping into various shapes make it ideal for a wide range of applications. Porcelain has a number of drawbacks, including its brittleness, which makes it susceptible to breakage, chipping, and cracking; for some insulator types, the possibility of electrical puncture, which is very difficult to locate; its low tensile and cantilever strength-to-weight ratios; and the potential for cracking and failure due to the thermal effects of power arcs.

Durable glass

The great majority of glass units are of the "toughened" kind as opposed to the "annealed" type in order to fulfill the mechanical requirements of high voltage insulators. The insulator surface cools more quickly during the toughening process, whereas the interior cools more slowly. A persistent compressive pre-stressing is created in the outer layers due to the differential solidification rate, which effectively prevents the development of surface microcracks and stops crack spread.

The benefits of glass include its high dielectric strength, resistance to electrical penetration, resistance to damage from UV radiation and other environmental factors, inclination to fracture when damaged, which makes it easy to spot defective equipment, and its strong compressive strength.

Among glass' drawbacks are:

Because to its mechanical limitations, such as its propensity to fracture, which makes it an attractive target for vandals, and its vulnerability to leakage current degradation, which may hasten shattering.

Acrylic resin

Epoxy resins were only used inside until the introduction of cycloaliphatic resins with silanized silica flour filler in the late 1960s. The most recent units may be created in a broad range of forms to satisfy a variety of industrial applications and have enhanced resistance to the effects of UV light. Moreover, the necessary metal fittings may be included into the mold while it is being created. Yet, since it is an organic substance, epoxy resin may degrade as a result of surface partial discharge activity. The design of insulators destined for usage in severely contaminated areas must carefully take this into account.

Resins' advantageous qualities include:

Integral metalware may be given, negating the need for the connection of external fittings, and they can be moulded in a number of shapes to suit a range of purposes.

These are the drawbacks of epoxy resins:

The use of resins is often restricted to medium voltages because to the potential for substantial leakage current erosion and potential electrical weakness at the mould line that may result in material deterioration for overhead lines.

Composites of polymers

Insulators having a fiberglass core which provides the mechanical strength—covered by a housing, which shields the core from the elements and produces the necessary electrical properties, are referred to as "composite" insulators. Composites are produced using a broad range of architectures and materials, therefore generalizing about their features might be deceptive. The two primary families of housing materials now in use are those based on silicone and those based on ethylene propylene diene monomer. High mechanical strength and tracking resistance characterize EPDM. The silicones, on the other hand, offer a stronger resilience to UV deterioration and the unusual ability to retain a hydrophobic surface even under very challenging contamination conditions. They are thus more often used in places with high industrial and marine pollution.

About the cores, they are made up of unidirectional, continuous glass fibers embedded in a resin matrix. The fibers are often made of one of two kinds of glass: regular electrical "E" glass or special acid-resistant "E-CR" glass. The resin is typically of the epoxy, polyester, or vinyl-ester type.The advantages of composite materials include their extremely high tensile strength-to-weight ratio, improved performance in heavily polluted areas, inability to serve as a target for vandals, extreme resistance to projectile damage, flexibility, improved seismic capabilities, prevention of cascade failure of post units, for apparatus bushings, and avoidance of damage to nearby equipment in the event of explosive equipment failure.

The following are composite materials' drawbacks:

Prone to leakage current erosion if improper material and/or dimensioning employed; potential electrical brittleness at the mould line; extra attention required in design and production to guarantee the removal of moisture infiltration at interfaces; and deflection under load in certain applications.

Basic Physical Elements

The electrical and mechanical capabilities of the insulator are determined by its size as well as the characteristics of the materials employed in its manufacture. The arcing distance, the creepage distance, and the puncture distance are the three essential parameters that have an impact on an insulator's electrical performance. They are described below, and in 3, they are looked at in greater depth. The majority of the definitions come from materials published by the International Electrotechnical Commission.

Arcing separation

The shortest distance in air, outside of the insulator, between the components that typically have the working voltage between them is referred to as the arcing distance.

Radius of an insulator arc

The arcing distance is crucial because, when the insulator is pure, it greatly affects the power frequency and impulse flashover voltages. Hence, enough arcing distance must be provided in order to satisfy the system's electrical needs. The physical dimensions of the insulator to be utilized at a certain voltage level are often determined by this dimension.

Creepage separation

The term "creepage distance," also known as "leakage distance," refers to the smallest distance between two sections of an insulator that typically have the working voltage between them, or the sum of the shortest distances along the contours of their exterior surfaces.

Distance between insulators that creep

Creepage distance is another crucial factor because, when an insulator's surfaces are contaminated, it significantly affects the power frequency flashover voltage. The term "Specific Creepage Distance" is often used to describe this crucial parameter. Its values are mm/kV and it is calculated by dividing the total creepage distance by the phase-to-phase system's greatest voltage.Whereas the phase-to-ground voltage is what is really supplied to the insulator, tradition mandates that the phase-to-phase voltage be utilized. When comparing particular creepage distance values for single phase AC and DC systems, it is crucial to take this anomaly into account and take the proper into account. The IEC may eventually standardize the formulation of particular creepage distance based on phase-to-ground voltage to eliminate any possible ambiguity.

Puncture distance

The shortest distance through the insulating material between two components that typically have an operational voltage between them is referred to as the puncture distance.

Space between insulator punctures

To prevent the insulator from suffering lasting damage when exposed to overvoltages, especially steep-fronted lightning impulses, it is essential to provide a suitable puncture distance.

Protector class

Insulators are categorised into two groups based on their design, as stated in IEC 60383 "Insulators for overhead lines with a nominal voltage exceeding 1000V":

Class A: An insulator or insulator unit where at least half of the arcing distance may be punctured through the solid insulating material. Insulators classified as Class A are thought to be impermeable.

Insulator or insulator unit classified as Class B if the distance required to penetrate the solid insulating material is less than half the arcing distance. Insulators classified as class B are thought to be pierceable.

Kind of insulators

This is a definition of the several kinds of outdoor insulators. There are also descriptions of the typical building materials and their uses.Insulator with a pin that passes up through it is known as a pin insulator. It is a rigid insulator made composed of an insulating component that is meant to be installed firmly on a supporting structure. One or more pieces of insulating material may be permanently joined together to form the insulating component. The insulating component's connection to the pin may be temporary or irreversible.

Insulator for line posts

A rigid insulator is a permanently constructed piece of insulating material that typically has a metal base and, on occasion, a cap. It is designed to be installed securely on a supporting structure using a central stud or a few bolts.

Insulator for composite line posts

A rigid insulator made up of an end fitting connected to the insulating core, a housing, and a load-bearing cylindrical solid core. The following are the three primary designs for composite insulators:

The individual shed type involves sliding individual, moulded shelters onto the core while smearing silicone grease on the interfaces between the sheds and the core. Molded housing portions are slid onto the greased core in a version of this technique.

The Moulded Type - With this method, a mould is used to contain the core before housing material is injected to create a single-piece covering. The molding may be done in segments for lengthy insulators.

The Sheathed Type – For this kind, the core is extruded with a continuous rubber sheath. The sheds, made of a similar material, are then vulcanized to the sheath.

Insulator with a cap and pin

An insulator with an insulating component in the shape of a disc or bell and fastening elements made up of an axially connected inner pin and an external cap.

Insulator with long rods

An insulator includes an insulating component with an internal or exterior metal fitting at either end or a cylindrical core covered in sheds.

Insulator for composite long rods

An insulator intended for tension application that consists of at least two insulating components a core and a housing and has metal end fittings. Regarding the line posts, composite long rods may be built in one of three ways: individually shed, moulded, or sheathed. A station post insulator is a rigid insulator that is made up of one or more pieces of insulating material that are permanently joined together and have external metal fittings attached at the ends. It is designed to be securely mounted on a supporting structure using one or more bolts.Insulator for a pedestal post consists of two metal parts: a cap that partially encloses an insulating component and a "pedestal" that is glued into a depression in the insulating component. The pedestal has a flange with plain holes for bolts or screws to connect to, whereas the cap often contains tapped holes.

Bushing

A device that shields conductors from partitions like walls and tanks while allowing one or more conductors to flow through them.

Instrument insulator

Insulators for apparatus are hollow structures with open ends that are used in electrical equipment. Insulators that are hollow may have flanges.

Insulator for stay wiresa stopper that is meant to be put into stay wires in order to electrically separate the bottom of the stay from the pole top.

Man-made insulator

A stay wire insulator with a high lightning impulse withstand voltage, similar to the one described above.

Sheds for Insulators

The extensions made from an insulator's core with the goal of extending the creepage distance are referred to as "sheds." It is clear from that the geometry and shape of the sheds have a big impact on how well the insulator works in the real world. The terms "Regular," "Alternating," and "Under-ribbed" are used to denote the three main profiles in the description of the shelters.

Fittings for Insulator Ends

Metal caps are offered to make it easier to connect the insulator to the supporting structure, the conductor, or other insulators. They are often formed of ductile iron that has been hot-dip galvanized, malleable cast iron, or forged steel. While aluminum alloy is utilized in certain applications, it is not advised for smaller cap sizes, such as those found on composite long rods, due to the severe damage that power arcs may do. The Y-clevis, clevis, tongue, ball, socket, and eye are typical fittings for those insulators designed to sustain tensile stresses.

REFERENCES

[1] W. Whiteley, W. K. Luk, en J. Gregor, "DirectPET: full-size neural network PET reconstruction from sinogram data", *J. Med. Imaging*, 2020, doi: 10.1117/1.jmi.7.3.032503.

[2] K. C. Stamoulis, K. G. Ioannides, en D. C. Patiris, "Radon Measurements in Bottled Waters in Greece", *HNPS Proc.*, 2020, doi: 10.12681/hnps.2950.

[3] K. Nicoll *et al.*, "First In Situ Observations of Gaseous Volcanic Plume Electrification", *Geophys. Res. Lett.*, 2019, doi: 10.1029/2019GL082211.

[4] W. Whiteley, W. K. Luk, en J. Gregor, "Direct Neural Network 3D Image Reconstruction of Radon Encoded Data", *arXiv*, 2019.

[5] A. Panghal, A. Kumar, en S. Kumar, "Seasonal variation of indoor radon–thoron levels in dwellings of four districts of Haryana, India", *Sci. Technol. Built Environ.*, 2019, doi: 10.1080/23744731.2018.1500395.

[6] S. Rosales Starcevich, G. Provenzano, en T. J. Henstock, "A Comparison of Multiple Attenuation Strategies for Shallow Water Ultra-High-Resolution (UHR) Seismic Reflection Data", 2019. doi: 10.3997/2214-4609.201902424.

[7] R. Kaibou en M. S. Azzaz, "Performances Improvement of Chaos-Based Robust Digital Image Watermarking using Advanced Techniques", 2019. doi: 10.1109/ISPA48434.2019.8966894.

[8] F. Perrier, F. Girault, en H. Bouquerel, "Effective radium-226 concentration in rocks, soils, plants and bones", *Geol. Soc. Spec. Publ.*, 2018, doi: 10.1144/SP451.8.

[9] E. Petermann *et al.*, "Coupling End-Member Mixing Analysis and Isotope Mass Balancing (222-Rn) for Differentiation of Fresh and Recirculated Submarine Groundwater Discharge Into Knysna Estuary, South Africa", *J. Geophys. Res. Ocean.*, 2018, doi: 10.1002/2017JC013008.

[10] M. Y. A. Mostafa, M. Vasyanovich, en M. Zhukovsky, "A primary standard source of radon-222 based on the HPGe detector", *Appl. Radiat. Isot.*, 2017, doi: 10.1016/j.apradiso.2016.12.012.

[11] L. Tositti *et al.*, "Assessment of lithogenic radioactivity in the Euganean Hills magmatic district (NE Italy)", *J. Environ. Radioact.*, 2017, doi: 10.1016/j.jenvrad.2016.07.011.

CHAPTER 10

ELECTRICAL CONSIDERATIONS

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Atmospheric air is the primary dielectric utilized in high-voltage networks. As long as the electric stress is maintained below the ionization threshold, air is an excellent insulator and self-restoring material. As air cannot sustain high voltage conductors physically, numerous kinds of insulators were created over the course of the last century to serve the dual purpose of mechanically supporting and electrically insulating the lines and equipment. With the several high pressures present mechanical, electrical, and environmental such a job is very difficult. This focuses on the electrical factors that are important for choosing insulators, with a focus on reducing the likelihood of electrical flashovers.

Flashover between Dry and Wet Power Frequency

The insulator must be able to resist the system power frequency operating voltage and overvoltage in both dry and wet circumstances. The wet power frequency flashover voltages and the dry power frequency flashover voltages are both largely dependent on the arcing distance typical curves for withstand.

Lightning and a flashover of switching impulses

The insulator must be able to tolerate both naturally occurring lightning and system switching impulse overvoltages without suffering irreversible damage[1], [2].

There are lightning strikes on electricity grids

The dry lightning and wet switching impulse flashover voltages are both dependent on the arcing distance. These are typical withstand curves. For standard system voltages, the necessary lightning and switching impulse withstand values are provided.As switching impulses at system voltages below 300 kV are insufficient to cause flashover, lightning impulse flashover predominates there. The switching impulse flashover is often more dangerous at system voltages of 300 kV and above. The switching impulse has greater time to close the gap due to the streamer or leader breakdown mechanism's design for big air gaps. Moreover, lightning impulses are primarily determined by the quality of grounding of the towers and the intensity of the lightning, while switching impulse magnitudes are connected to the system voltage.

Strength Frequency Pollution With a conducting electrolytic pollution layer existing on its surface, the flashover frequency and flashover voltage of an insulator may be lowered by an order of magnitude. As a result, an insulator's pollution flashover performance has a big impact on how reliable the power system is, therefore it has to be able to survive the pollution circumstances it is exposed to. Pollution is neglected under these settings since it has minimal impact on lightning and switching impulse flashover levels. The underlying concepts of the power frequency insulator pollution flashover process.

Process of a pollution flashover

The characteristics of the insulator surface have a major role in determining the process of pollution flashover. If the surface is hydrophilic, as it usually is for ceramic and glass insulators, the surface will totally wet out, resulting in an electrolytic coating covering the insulator. When water contacts hydrophobic materials like silicone rubber, it separates into individual droplets, preventing the growth of a continuous conducting layer.The Cigre Electra document No. 64 describes the pollution flashover process for insulators with a hydrophilic surface as follows: "The insulator gets covered with a layer of pollution including soluble salts or dilute acids or alkalis. Stages may begin right away if the pollution is applied as a coating of liquid electrolyte, such as salt spray. When the pollution is dry, it cannot conduct, hence some wetting method is required.

Fog, mist, light rain, sleet, melting snow, or ice soak the contaminated insulator's surface fully or in part, making the pollution layer conductive. A complicating aspect is heavy rain, which may wash the electrolytic components off some or all of the pollution layer without starting the subsequent phases of breakdown or may encourage flashover by bridging the gaps between sheds.

When a conducting pollution layer covers an energized insulator, a surface leakage current runs, and its heating impact begins to dry up some of the pollution layer. The drying of the pollution layer is never uniform, and in certain spots, dry bands separate the conducting pollution layer and stop the leakage current from flowing. Next, across these potentially very narrow dry bands that are just a few centimeters broad, the line-to-earth voltage is delivered. Air breakdown occurs, and the dry bands are crossed by arcs that are electrically connected in series with the resistance of the pollution layer's undried component. Every time the dry bands on an insulator flash over, there is a burst of leakage current. The arcs connecting the dry bands are able to burn continuously and may expand along the insulator, so reaching more and more of its surface, if the resistance of the undried portion of the pollution layer is sufficiently low. As a result, the resistance in series with the arcs is reduced, the current is increased, and more insulator surface may be bridged by the arcs. A line-to-earth fault is ultimately formed once the insulator has been fully bridged. The interplay of the insulator, pollutants, wetting conditions, and applied voltage may be used to summarize the whole process[3], [4].

Surface resistance and the magnitude of the leakage current

Leakage current is often acknowledged as one of the key factors in determining how well insulators operate. Moreover, it has been shown that when the insulator leakage current exceeds a certain threshold value, the flashover risk increases significantly. Based on experimental work by Verma et al., this value has been defined as the amplitude of the leakage current peak of the half cycle just before flashover:

Electrical considerations in general

Poisoning potential

There is a chance that the solid insulator material may get internally punctured in lightning-prone places, which might cause the insulator to completely fail or cause unwelcome line tripping. When using Class B insulators that are puncture-resistant, the danger is extremely severe. It is advised to utilize unpuncturable Class A insulators in heavy lightning settings because of this. A minimum puncture voltage should be stated for Class B insulators. These are suggested minimum power frequency puncture values for tests conducted in compliance with IEC 60383. If impulse puncture values are provided, the puncture voltage to 50% lightning impulse flashover voltage ratio must be at least as follows:

It should be emphasized that the proper quality of material must be utilized when using porcelain insulators in high temperature applications, such as precipitators, to avoid puncturing[5], [6].

Corona

The insulator and any related gear should have a corona extinction voltage higher than the maximum voltage in the system. Corona also produces UV radiation, ozone, and, in the presence of moisture, acids, all of which may have a negative impact on polymeric insulating materials. These emissions are in addition to those of acoustic noise and radio and TV interference, which may be ecologically unaccept. Live-end corona rings are often employed on systems with voltages higher than 200 kV. Earth end rings or the use of rings at lower voltages, however, may be taken into consideration depending on the cap design and string hardware.

Protection against power arc damage

It should be assured that the insulator and any accompanying gear can resist a power arc under flashover circumstances with a current and duration appropriate to the system. For porcelain long rod insulators, arcing horns or rings should be employed to direct the arc away from the insulating material since thermal stress might cause mechanical failure. Moreover, it is advised that they be joined to the nearby hardware rather than the insulator end fittings directly. Dimensioning an aluminum end fitting for long rod insulators to withstand the impact of power arcs is challenging and expensive.

Flashover of ice and snow

In order to prevent inter-shed bridging caused by snow and ice accumulation, the insulator-shed spacing should be carefully considered. Snow and ice-covered insulators may have power frequency flashover voltages that are 25 to 35% lower than those under situations of light pollution.

Flashover in conductive fog that is instantaneous or quick

The term "instantaneous pollution" describes a high conductivity contamination that rapidly accumulates on insulator surfaces, causing the insulator to go from a clean, low-conductive state to flashover in a short amount of time, and then back to a low conductive state after the incident has passed. The same procedure as previously mentioned applies in order to make instantaneous pollution flashover easier to grasp. Nevertheless, since the initial pollution is often deposited as a thin layer of highly conductive liquid electrolyte, such as salt spray, salt fog, or industrial acid fog, phases may occur right away. These phases blend together in nature and do not exist in insulators with hydrophobic surfaces. The most dangerous areas are those that are near to chemical factories or the seaside. Increasing the creepage distance or changing the profile may not work in areas that sometimes suffer conductive fog conditions. In these circumstances, using insulators with hydrophobic surfaces should be taken into consideration[7], [8].

Bird streamer overpass

The sudden pollution flashover caused by bird streamers is one such instance. This particular kind of bird feces, when released, creates a continuous, highly conductive stream that is so long that it reduces the air gap to the point where flashover occurs. The shape and properties of the insulator are hardly or not at all relevant here. Thus, it is advised that bird guards be built in the case of a bird streamer flashover.

Environmental Considerations

Natural science defines nature as being exposed to our manner of inquiry; it does not only describe and explain nature; it is a part of the interaction between nature and ourselves. Heisenberg, Werner. The following factors have an impact on how well high voltage insulators operate in the environment:

The ultimate pollution deposit on an insulator surface is determined by the wind direction and speed, precipitation, relative humidity, and the location of the pollution sources. Before they fall to the ground, particles may be transported over long distances by the wind. A highly conductive electrolytic layer may develop on an insulator surface as a consequence of salt storms or conductive industrial fogs. Moreover, solar radiation may heat an insulator's surface throughout the day to aid avoid wetness or heat the atmosphere around dawn to cause dew to develop. Hence, insulator pollution flashovers are caused by the environment.

Environmental factors like UV sun radiation may have a negative impact on how quickly non-ceramic materials age.The mechanical forces acting on an insulator may be influenced by factors including temperature, ice and snow loading, wind speed and direction, and seismic activity.The performance of an insulator during a flashover may be impacted by lightning activity, soil resistivity, and changes in air density, and bird streamers[9], [10].

The different environmental factors.

Pollution

There are two primary types of insulator pollution: instantaneous pollution, which is already a conducting electrolyte, and pre-deposited pollution, which builds up over time and must be wetted to become a conducting electrolyte.

Pre-existing pollution

Active pollution that produces a conductive layer and inert pollution that binds to the conductive pollution and increases the area accessible for leakage current flow are the two primary kinds of pre-deposited pollution. Pre-deposited active pollution is weighed in terms of mass, while inert, non-soluble pollution is evaluated in terms of conductivity.

Immediate pollution

A contaminant with a high conductivity that quickly deposits on an insulator's surface is referred to as "instantaneous pollution," and it causes the insulator to go from a clean, low-conductive state to flashover in a matter of seconds before returning to its original state after the event has passed. Salt or conductive industrial fogs are two examples of sources that might cause pollution episodes to occur right away. Surface conductance or leakage current measurements may be used to identify sudden occurrences.

Polluting factors

Pollutants from insulators often come from:

1. Pre-deposit contamination
2. Seaside: sand and salt

Industrial: waste materials and chemical emissions Agriculture: crop burning, weed herbicides, fertilizers, and soil Sand and salt in a desert

Other: bird droppings and salted roadways.

Immediate pollution:

Marine: saline haze Commercial: acid fog Agriculture: spraying of crops Desert: fog off the shore

Other: streamers with birds.

The final electrical and/or mechanical performance of high voltage insulators may be impacted by weather factors such as temperature, humidity, rain, fog, wind, sun radiation, snow and ice, lightning, and air density.

Temperature

The wetting of insulators is influenced by the surrounding temperature. Dew will develop on an insulator surface when the temperature drops below the atmospheric dew point temperature. This occurrence often happens in the early morning hours when the insulator is colder than the surrounding air and the moist air is being heated by the sun's first rays. A little impact of temperature may also be seen on air's breakdown strength. When discussing the air density adjustment for withstand voltage, this is taken into consideration. Due to its impact on conductor tension, ambient temperature has some bearing on insulator loading.

Humidity

An indication of the amount of moisture in the air is relative humidity. There is a substantial risk that the pollutants on an insulator surface may get wetted when the relative humidity is high. This could then dissolve, leading in the formation of a conductive electrolytic layer and the passage of leakage currents. Pollution on the surface of an insulator may also be washed off by prolonged periods of high relative humidity. Electrical activity and relative humidity have a strong relationship. Some insulator materials may become overstressed in environments with continual high humidity, particularly when paired with high temperatures, leading to hydrolysis-based breakdown. A general rule of thumb is that for every 1 g/m3 increase in absolute humidity, the withstand voltage of air rises by 0.2%. Thus, it is important to understand that although a high humidity level has no direct negative effects on an insulator's withstand voltage, the consequent soaking of pollutants on the insulator surface might result in a pollution flashover.

Rain

Rain also moistens the pollutants on the surface, forming a conductive layer. Moreover, acid rain may raise the conductivity. Rain may also be used to clean pollutants off of insulating surfaces, which is a good thing. Up to 90% of the pollutants on a ceramic or glass insulator surface may be removed by rain falling faster than 10 mm per hour. Light rain may also wash away pollutants that are still active. An excellent natural insulator cleanser is a mix of rain and wind.

Fog

When the temperature of a volume of air falls below its dew point—due to the cooling of the ground—or when warm air travels over a colder surface, moisture condenses on particles. A conductive fog arises when conductive and soluble particles, such salt, are present. Fog affects insulator performance negatively by moistening surface impurities, which might cause flashover before any meaningful cleaning can take place. Even though the insulator was originally clean, flashover may occur in a short amount of time if the fog is conductive.

Wind

Pollution and moisture are transported and deposited on insulator surfaces mostly by wind. According to the correlation between salt deposit density and wind speed, pollutant deposit grows as wind speed rises by a factor of three. While not uniform, pollution deposition on an insulator surface is highly influenced by shed shape. Pollution on an insulator surface may be removed by strong winds delivering sand particles or rain. Wind affects the mechanical stress on an insulator because of the pressure it puts on conductors.

Solar energy

An important factor in the ambient air mass's heating is solar radiation. Relative humidity levels and wind direction and speed are subsequently impacted by this. The insulator surface is heated by solar light as well. Wetting of the insulator surface happens when the temperature of the surface is lower than the ambient dew point. Surface wetness is less likely because solar radiation keeps the insulator surface warmer than the surrounding air throughout the day. The UV-B photons with high energy may damage polymeric materials.

Lightning

Insulator flashover may be brought on by lightning striking the phase conductor directly, striking a shield wire or building and creating back flashover, or by induced overvoltage. The insulator has to be able to sustain impulses of lightning that occur naturally without being punctured or suffering flashover damage. The intensity of the lightning must be taken into account while choosing insulators. This may be assessed using the ground flash density or, in the absence of such data, the isoceraunic level. The position and intensity of the lightning activity are provided by lightning locating systems, which may also provide detailed information. It should be noted that the influence of pollution on the lightning impulse flashover voltage in terms of BIL is minimal and is often not taken into account when sizing the insulator.

Site Severity Evaluation

The environment in which an insulator is intended to function must be defined by a site severity evaluation, which is based on the measurement of pollution levels and an analysis of the weather. The surface deposit on an insulator or directional dust deposit gauges are used to determine the pollution level. Here, both of these approaches are explained. As a different method of measuring pollution severity, an insulator pollution-monitoring device is also presented. It can handle both pre-deposited and immediate pollution occurrences.

Method for putting pollutants on the surface

In order to estimate the natural pollution deposit on an insulator after a period of time during which some natural washing may have taken place, a surface pollution deposit approach is used. Pollution's active and inert components are both measured. In the location to be evaluated, a string of seven cap-and-pin disc insulators is put at a height of at least 3 m, free of any obstacles. The first and final discs in the string are employed to assure aerodynamic uniformity across the string but are not tested. On disc 2, the active and inert pollution values are calculated monthly; on disc 3, three months; on disc 4, six months; on disc 5, a year; and on disc 6, two years. The site severity class is established using the highest values recorded throughout the test period. If the aforementioned test method cannot be employed, surface pollutant deposit measurements on the network's current insulators may be taken. This poses a greater danger since the measurement just represents a single point in time and can overstate the site's actual level of pollution.

Salt deposit density similar to active pollution

The ESDD value is defined as the equivalent sodium chloride deposit (in mg/cm2) on an insulator's surface that will have an electrical conductivity equal to the real deposit dissolved in an equivalent volume of water. Using the ESDD method, impurities are removed from the insulator surface using distilled water, and the conductivity of the resulting solution is then measured.

The following is the measuring process for a cap-and-pin disc insulator:

1. Cover the metal cap and pin with plastic cling wrap, avoiding the glass or porcelain surface.
2. Demineralized water with a conductivity of less than 5 S/cm in a volume of 500 to 1000 ml should be poured into a clean dish.
3. Put the test insulator's cap in the water and use gentle hand motions to wash the top surface. When finishing, flip the insulator over and clean the underside.
4. Take out the insulator, carefully brushing off any water that is still on it into the basin. Making sure that all the deposits are transferred from the bowl and the gloves, pour the wash water into a container that has been labeled.
5. Use sterile surgical gloves to reduce the risk of contamination.

Before to the measurement, the bowl, container, measuring cylinder, etc. must also be thoroughly cleaned to get rid of any electrolytes.The cap-and-pin disc insulator's top and bottom surfaces may also be handled differently.

When all of the soluble salts have been dissolved, swirl or mix the wash water solution.Volume conductivity and solution temperature should be measured and noted.The volume conductivity, solution temperature, and wash water solution volume data are used to calculate the ESDD value. At the solution temperature ts, a conductivity probe detects the volume conductivity, t. The measurement must be adjusted to a standard temperature of 20 °C using the following calculation if the device being used does not automatically compensate for temperature.

Density of non-soluble deposits from inert pollution

The quantity of non-soluble, inert pollutant deposit per square centimeter of the insulator surface is defined by the NSDD. The wash water solution acquired from the ESDD measurements is often used to conduct the NSDD measurement. The liquid is filtered through filter paper of grade GF/A 1,6 m or a comparable grade that has already been dried, cleaned, and weighed. The contaminated filter paper is then dried and weighed.

Using a directional dust deposit gauge

The four vertical tubes that make up the dust gauge each have a slit machined into their side, and they are positioned such that they face north, south, east, and west. Each tube has a detachable container connected to the bottom that catches the deposits that are blown into the slots. The contents of these containers are withdrawn every month, mixed with 500 cc of demineralized water, and their conductivities are measured. The conductivities of the four directions are averaged, expressed in S/cm, and normalized to a 30-day period to create the pollution index. The slot size should be applied in order to make results comparisons across borders easier.

Each collection jar needs 500 ml of demineralized water. Water must have a conductivity of no more than 5 S/cm. If the vessel already has rainwater in it, add demineralized water to bring the volume up to 500 ml. No additional water is needed if the jar contains more than 500 ml because of heavy rains.Until all of the soluble salts have been dissolved, swirl or stir the contents.

Use a conductivity meter that automatically adjusts the reading to 20 °C to measure the conductivity of the solution. Measure the temperature of the solution as well if the meter is not 20 °C compensated.Measure the actual volume if the solution's volume is less than 500 ml, such as if the jar has accumulated too much rain.

When it rains, some pollution that has accumulated within the tubes will be carried into the collecting jars. Hence, the pollution indices for the rainy months can have somewhat higher readings than those for the dry ones. This has no effect if the values are averaged across a time frame. Nevertheless, before the collecting jars are removed for analysis, the inside walls of the tube may be washed out using a squeeze bottle of demineralized water if very exact monthly measurements are necessary.

Class of site severity

Surface deposit and dust gauge data may be used to define the site severity class.LESDD sampling instrument and toolkit with accompanying measurement tools.The identical formulae used to compute the ESDD are also used to calculate the LESDD, with the surface area examined and amount of distilled water used being the only variations. Nonetheless, caution must be used when interpreting the findings. It must be understood that the ESDD values shown in 4.1 refer to the contamination averaged across the insulator's whole surface, not just a single tiny spot. The hand probe detailed in IEC 60507 may be used to test the conductivity of a pollution layer on an insulator. A probe with two spherical electrodes that are pushed on the insulator surface is attached to the hand-held meter. Demineralized water is softly sprayed across the test area to help the contaminant dissolve. The meter then displays a value for the surface conductivity between 0 and 500 S. Nevertheless, the quantity of wetness is a factor in the observed conductivity and cannot be precisely regulated. The values from the hand probe often don't agree with those from ESDD or the majority of other pollution monitoring equipment. The probe measurements are more often utilized to contrast small-scale deposits.

Automated monitoring of insulator pollution

Instruments that automatically analyze the pre-deposited pollution's intensity at predetermined intervals and record instantaneous pollution occurrences have been developed for more frequent and thorough site condition assessments. On some, the leakage current amplitudes on in-service insulators may also be monitored.

The usual measures made are:

1. Conductivity of an insulator's surface when it is moist and polluted naturally.
2. Insulator surface conductivity with artificial wetness but under natural pollution.
3. The size of the leakage current on operating insulators.

When pre-deposited and instantaneous pollution levels approach critical levels, an alert might be sent off, and the data gathered could be downloaded through a mobile modem and displayed together with pollution profiles over time.

Natural pollution and wetting episodes are not averaged out over a month as both pre-deposited and instantaneous pollution levels are monitored daily. This is the case with both the surface pollution deposit and directed dust deposit gauge approaches, this removes the chance of missing isolated severe pollution incidents.

Performance of current insulators

The effectiveness of the insulators currently present at the site may provide important information about how harsh the environment is. To determine if pollution may be a concern, the history of system flaws and operating experience should be examined. The examination of current line behavior may be aided by a few strategies that are offered. Moreover, the insulators should be checked for indications of leakage current activity. Common warning indications include flashover evidence, dielectric material degradation, or metal fitting corrosion. A good signal of large leakage current activity across the insulator surface, for instance, is pin corrosion on disc type insulators. This corrosion may be interpreted as a warning sign for high pollution severity or under-insulation.

Pin corrosion on insulators of the disc type

A reliable indicator of the severity of the site may be acquired by keeping an eye on the leakage currents on the surrounding in-service insulators. The possibility of flashover for the monitored unit and the necessary specific creepage for the location are shown by comparing the greatest amplitude observed with Imax.

Additional Environmental Factors

Streams of birds

The potential of flashovers caused by bird streamers, should be taken into account in areas where birds like eagles, herons, geese, cranes, egrets, storks, crows, and buzzards are present.

Surface resistance

The resistivity of the soil and the caliber of the earthing influence the footing resistance of buildings. This may significantly affect the likelihood of rear flashover of the insulation. It could be necessary to take particular steps in locations with significant soil resistivity.

Earthquake activity

Earthquakes have the potential to mechanically harm insulators. As a result, while choosing insulators, this must be considered for places with a history of seismic activity. For example, more flexible composite modules may be chosen over hard ceramic station post busbar supports. Using the equations outlined in, it is possible to determine if an insulator is suitable for seismic loads.

Corrosion

End fittings for insulators may suffer negative effects on their performance and lifespan in highly corrosive conditions. Non-ferrous fittings may be chosen in these conditions, or more galvanizing may be required. A sacrificial zinc collar may be chosen for disc insulators. High rates of corrosion in a region often mean that high pollution levels might be anticipated as well.

Vandalism Insulators of the right design and material should be used when building lines or substations in locations where vandalism may pose a risk. Due to their inherent mechanical pre-stress and potential for dramatic shattering, toughened glass discs make an alluring and rewarding target. Thus, they shouldn't be utilized in places where shooting and hurling rocks are common. While composite insulators are preferable under these conditions, it must be understood that any damage may not be seen from the ground and might eventually lead to failure.

Material Considerations

“The ideal engineer is a hybrid. He is not a scientist, mathematician, sociologist, or writer, but he can employ the skills and knowledge from any or all of these fields to solve engineering challenges. Dougherty, N. W.Almost all contemporary outdoor insulators include solid dielectric components consisting of porcelain, glass, or polymeric materials. In terms of their fundamental makeup, porcelain and glass are comparable. The reason for the discrepancies in both their look and characteristics is the production method. Composite and resin insulators are two categories of polymeric insulators. The properties of glass and porcelain materials vary from those of the different polymers used to make composite insulators significantly less. The kind of insulating material utilized in the production of electrical insulators has a big impact on how well they work. The performance of the insulator pollution has a significant impact on how well a surface is wetted. It is governed by both the bulk qualities of the material, such as thermal conductivity, as well as its surface properties, such as surface energy. Most insulators include one or more metallic fittings on the insulating section that are used to attach the insulator to other electrical system parts.

Production and characteristics of porcelain

The three basic ingredients of porcelain used to make insulators are clay, feldspar, and quartz. Alumina may be used in lieu of quartz to get improved mechanical properties. The raw materials are ground to the required particle size if they are too coarse. Either dry or wet conditions are used for this. Water is used as a carrier to fully combine all the components. This combination, known as slip, is filtered to eliminate any impurities that can degrade the fine porcelain required for electrical insulators. The slip may be spray-dried into pellets that contain no more than 8% water. As an alternative, it is pressed into cakes that contain at least 20% water. These cakes are put into a vacuum extrusion machine, which eliminates the air and turns them into solid or hollow cylinders with the desired diameter and length for producing the completed product. These cylinders may be turned on vertical or horizontal lathes to create long rods, line posts, station posts, and hollow insulators, or they can be pressed into the form of things like pin insulators or cap-and-pin disc shells.

Semi-dry pellets are squeezed into the final form of the insulator during the isostatic process. The pellets are placed in a flexible mold within a pressure chamber to accomplish this. When dry pellets are employed, drying is not necessary before to the fire process because the extremely high pressure applied eliminates voids in the pressed insulators material.Before placing these "green" porcelain components into the fire kiln, a glazing solution is painted, dipped, or sprayed upon them. Grit may be placed to the insulator surface areas where metal fittings will be mounted before firing. The glaze creates a hard, smooth covering that increases mechanical strength while also preventing impurities from sticking to the surface. Since the underlying porcelain is entirely vitrified and non-porous, the glaze is not meant to serve as a moisture barrier and is not necessary. Hence, little glaze chipping does not shorten the life of the insulator.

These results are suggestive and greatly rely on the test specimen and measuring technique. Glazes may be created to do a number of more specialized tasks. To lessen radio interference, semi-conductive kinds, for instance, are used on the heads of pin insulators. For more dependable functioning in contaminated conditions, resistive glazes may be used to completely cover the porcelain surface. They enable the steady flow of a modest current that warms the insulator surface, preventing wetness by condensation, and also reduce voltage distribution distortion, preventing the creation of dry bands. The persistent leakage current of roughly 1 mA does imply a significant energy loss, despite the fact that these insulators are quite good in preventing contamination flashover. The accumulated charge recorded on the resistive glazing insulator during testing at the heavily polluted Koeberg Insulator Pollution Test Station was about five times greater than that on the conventionally glazed unit. The anticipated lifespan of the glazing is another issue. This would form a persistent dry zone and signify a breach in the continuity, leading to extreme field stresses and partial discharges, for instance, and deterioration at the glaze/fitting contact. As a highly strong material, porcelain is resistant to leakage current activity and UV ray deterioration. Yet, a power arc's thermal shock might harm the glaze and break the porcelain.

In addition to the formulation and the caliber of the raw materials used, porcelain insulators' quality also much rely on how well their producer has perfected the craft of creating porcelain. The composition of the material and the firing procedure have an impact on the sizes of the grains and crystals, the distribution and size of the pores, and the properties of the glaze. The majority of early porcelain shell failures may be traced to porosity brought on by poor production. Modern technology has almost eradicated this.

The porcelain shell's puncture may not be apparent from the outside. This manner of failure may be immediately caused by steep-fronted lightning surges or develop as a result of the spread of small fractures. Porcelain Class a insulators are often impervious to puncture.

Building porcelain insulation

Porcelain is used to create a wide variety of insulators, including hollow insulators for equipment and bushings, post insulators for lines and substations, and cap-and-pin insulators for lines.

The cap-and-pin method

A conventional porcelain disc insulator with a cap and pin. The insulating shell, the cap and pin metal fittings, and the cement that holds the shell and fittings together make up their four primary components. IEC 60305 standardizes the dimensions and mechanical strength ratings. It describes the metal fittings. Cements of the Portland or alumina types are also acceptable. The metal fittings' surfaces that will come into touch with the cement are coated to allow for relative mobility and prevent adherence. Bitumen or polymer-based mixtures are used to create these coatings. Cement is either steam- or water-cured.

The porcelain shell and the cement function primarily under compression when a tensile force is applied because of the form of the insulator's component parts. Moreover, there are shear stresses. Typical properties of Portland cement with alumina. Fillers like silica sand or glass fibers may sometimes be added to the mixture to prevent the cement from contracting too much during the curing process.

Standard porcelain disc insulator with a cap and pin

Free lime may become visible when certain portland cement formulations age. The extra gypsum and lime in the cement might also cause it to expand in rare cases. This causes extra strains and might be detrimental to the insulator shell's structural integrity.

Fabrication of long rod insulators

Ceramics that can withstand greater tensile stresses were produced as a result of material technological advancements. As opposed to the cap-and-pin disc construction, this made it possible to build insulators without needing to convert tensile loads into compressive stresses. Hence, the long rod insulator was invented, consisting of a solid cylindrical porcelain body with metal fittings at either end.Several kinds of cements are used to secure the metal fittings to the porcelain body's end. Sulfur and lead antimony cements are further employed in addition to portland and alumina kinds of cement.

REFERENCES

[1] F. A. Koeck, M. Benipal, en R. J. Nemanich, "Electrical contact considerations for diamond electron emission diodes", *Diam. Relat. Mater.*, 2020, doi: 10.1016/j.diamond.2019.107607.

[2] R. M. Caston, E. H. Smith, T. S. Davis, en J. D. Rolston, "The cerebral localization of pain: Anatomical and functional considerations for targeted electrical therapies", *J. Clin. Med.*, 2020, doi: 10.3390/jcm9061945.

[3] D. Ristanovic, M. Taher, en N. Bhatia, "Turbo-Expander Generators for Supplemental Power Generation in LNG Liquefaction Plants", *IEEE Trans. Ind. Appl.*, 2020, doi: 10.1109/TIA.2020.3012933.

[4] R. Martis, F. Pop-Piglesan, S. Cosman, en C. Martis, "Considerations on design, development and testing of Electrical Machines for automotive HVAC", *MATEC Web Conf.*, 2020, doi: 10.1051/matecconf/202032201042.

[5] L. Bongini, R. A. Mastromauro, D. Sgrò, en F. Malvaldi, "Electrical damping assessment and stability considerations for a highly electrified liquefied natural gas plant", *Energies*, 2020, doi: 10.3390/en13102612.

[6] J. A. Van Kan *et al.*, "Considerations for the nano aperture ion source: Geometrical design and electrical control", *Rev. Sci. Instrum.*, 2020, doi: 10.1063/1.5128657.

[7] R. Yang, Y. Yuan, R. Ying, B. Shen, en T. Long, "A novel energy management strategy for a ship's hybrid solar energy generation system using a particle swarm optimization algorithm", *Energies*, 2020, doi: 10.3390/en13061380.

[8] P. Birbarah *et al.*, "Water immersion cooling of high power density electronics", *Int. J. Heat Mass Transf.*, 2020, doi: 10.1016/j.ijheatmasstransfer.2019.118918.

[9] H. Iijima, R. Eguchi, K. Shimoura, K. Yamada, T. Aoyama, en M. Takahashi, "Transcutaneous Electrical Nerve Stimulation Improves Stair Climbing Capacity in People with Knee Osteoarthritis", *Sci. Rep.*, 2020, doi: 10.1038/s41598-020-64176-0.

[10] Y. Soluyanov, A. Fedotov, A. Akhmetshin, en V. Khalturin, "Monitoring of electrical consumption, including self-isolation during the COVID-19 pandemic", 2020. doi: 10.1109/USEC50097.2020.9281179.

CHAPTER 11

MAINTENANCE OF ELECTRIC POWER GENERATION

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In 1972, OSHA last published regulations for the building of transmission and distribution systems. The more modern general industry standard covering the operation and upkeep of electric power production, transmission, and distribution lines and equipment has superseded those rules, making them out of date and incompatible with it. OSHA is making changes to the general industry standard as well as the construction standard in order to make them more compatible with one another. The final rules for general industry and construction contain new or revised provisions on host employers and contractors, training, job briefings, fall protection, insulation, and working position of employees working on or near live parts, as well as minimum approach distances, protection from electric arcs, deenergizing transmission and distribution lines and equipment, protective grounding, operating mechanical equipment close to overhead power lines, and working in manholes and vaults. The updated standards will guarantee that, where necessary, employers must adhere to uniform criteria for work done in accordance with the construction and general industry standards[1], [2].

The new rules for host employers and contractors stipulate that they must provide information about risks as well as the circumstances, traits, design, and functionality of the host employer's installation. In accordance with these new standards, contract employers and host employers must coordinate their work policies and practices to safeguard all workers. The updated training regulations eliminate the previous need that the employer certify training and include standards for line-clearance tree trimmers and a degree of training to be assessed by the risk to the employee for the hazard involved. The new mandate for job briefings includes a duty for the employer to notify the employee in charge of current features and circumstances. The updated fall protection regulations now contain additional guidelines for qualified personnel ascending or changing positions on poles, towers, or other similar structures, as well as for the use of fall restraint devices or personal fall arrest systems in aerial lifts. There are additional criteria for where an employee who is not wearing electrical safety equipment may operate under the amended regulations on insulation and the working posture of workers operating on or near live components. The updated guidelines for minimum approach distances now call for the employer to do an engineering study to identify the maximum expected per-unit transient overvoltages, or, alternatively, to assume specific maximum anticipated per-unit transient overvoltages. Also, these regulations substitute requirements for the employer to create minimum approach distances using predetermined formulae in favor of requirements for stated minimum approach distances. In accordance with the updated provisions for electric arc protection, employers are now required to assess the workplace to determine which employees are exposed to flames or electric arc hazards, estimate the incident heat energy to which each employee would be exposed, ensure that the outer layer of clothing worn by employees is flame resistant under certain circumstances, and generally ensure that employees exposed to electric arc hazards wear protective clothing. The updated rules for deenergizing transmission and distribution lines and equipment make it clearer how they should be applied to deenergizing network protectors and numerous workers. Employers are now allowed, under some circumstances, to install and remove protective grounds on lines and equipment working at 600 volts or less without using a live-line tool, according to the new protective grounding regulations. The updated rules for using machinery close to electricity lines make it clear that only the insulated parts of aerial lifts are exempt from the need to maintain minimum approach distances. The updated guidelines for working in manholes and vaults make it clear that all guidelines for working in manholes also apply to working in vaults. They also include a new obligation for safeguarding workers from electrical problems where work might result in a cable failure[3], [4].

Also, the final rule updates the construction and general industry requirements for electrical protection equipment. Many national consensus standards are included by reference in the current construction standard for the design of electrical protective equipment, which solely applies to electrical power transmission and distribution operations. The new electrical safety equipment standard, which is applicable to all construction work, substitutes a set of performance-oriented requirements that are in line with the most recent revisions of the relevant consensus standards for the integration of out-of-date consensus standards. In addition to additional standards for the safe use and maintenance of electrical protective equipment, the final construction regulation also contains rules for equipment design.

New specifications for equipment composed of materials other than rubber will be included in the building standards for electrical protective equipment as well as the general industry standards.Moreover, OSHA is updating the industry-wide standard for foot protection. Employers working on electric power production, transmission, and distribution installations as well as employers in other businesses are subject to this criterion. Employees are no longer required to wear safety shoes to protect themselves against electric shock under the final regulation[5]–[7].

Required Regulation

Workers who perform tasks covered by the final rule are exposed to a number of important risks that have the potential to seriously harm or even kill them. After carefully weighing the various potential benefits and drawbacks of using a regulatory approach to reduce risk, OSHA comes to the conclusion that in this case, mandatory standards represent the best option for lowering the risks to employees, as is detailed in Section II.B, Need for the Rule, further in this preamble. Moreover, regulation is required in this situation to replace outdated, unclear, and inconsistent safety rules.

Employers trying to establish suitable work practices for their workers may encounter challenges due to discrepancies between construction industry standards and general industry norms. For instance, if an employer upgrades a cutout on a transmission and distribution system, it is conducting construction work; if it merely replaces the cutout with the same model, it is performing general industry labor. Depending on whether the job is in construction or another sector, various criteria under the current standards apply. The criteria are the same as they are in the final regulation.

Affected Organizations

Establishments involved in the production, transmission, and distribution of electric power are impacted by the final regulation. Firms that build, operate, maintain, or repair facilities for the production, transmission, or distribution of electric power are principally impacted by the regulation. These businesses include electric utilities as well as contractors that are largely employed by utilities in the construction sector. Moreover, businesses who own or manage their own electric power production, transmission, or distribution facilities as a supplementary aspect of their company operations are found in a number of industrial and other sectors. Also impacted by the ordinance are businesses engaged in line-clearance tree pruning[8], [9].

Cost-effectiveness, benefits, and net benefits

OSHA anticipates that the final rule will improve worker safety for those who will be impacted, which will lower the number of mishaps, fatalities, and injuries linked to the relevant tasks and lessen the severity of some injuries, like burns or injuries brought on by arrested falls, which may still happen while carrying out some of the affected work procedures.Employees engaged in the electric power generating, transmission, and distribution activity covered by the terms of this regulation are thought to suffer 74 deaths and 444 severe injuries yearly. OSHA anticipates that full compliance with the final rule will prevent 79.6 percent of the relevant injuries and fatalities, compared to 52.9 percent prevented by full compliance with the existing standards, based on a review and analysis of the incident reports linked to the reported injuries and fatalities. OSHA predicts that the final rule will save around 19.75 more deaths and 118.5 more severe injuries per year. With an average monetary value of $62,000 for each injury avoided and $8.7 million for each mortality avoided, the anticipated yearly monetized benefits come to $179.2 million. When expenses are annualized at 7%, OSHA assessed the net monetized benefits of the final rule to be roughly $129.7 million per year, and $132.0 million when costs are annualized at 3%. Note that any unquantified advantages related to updating current standards to offer updated, consistent, and clear regulatory requirements for electric power production, transmission, and distribution activities are not included in these net benefits. The new regulations, in OSHA's opinion, are simpler to comprehend and put into practice. As a result, the Agency anticipates that the final rule will increase safety by making compliance easier.

Financial Efficiency

According to OSHA, following the final rule will avoid one death and six injuries for every $2.4 million in expenses as well as one fatality and six injuries for every $2.2 million in costs.

Costs of Compliance

The projected costs of compliance with this regulation indicate the extra expenses businesses will incur in order to fully comply. They do not include expenses employers must pay to fully comply with already-applicable standards, nor do they include expenses businesses must bear to comply with the additional requirements imposed by the final rule.

A study created by CONSAD Corp. under contract to OSHA served as the basis for the preliminary regulatory impact analysis and first regulatory flexibility analysis for the proposed rule. In order to provide the analysis of the final rule given here, Eastern Research Group, Inc., working on behalf of OSHA, provided assistance. OSHA revised data on businesses, employment, salaries, and income with the help of ERG, and updated the analyses in the final rule with these additional cost inputs. Costs for final rule provisions that weren't taken into account in the PRIA were also estimated by OSHA. These expenses include the use of upgraded fall protection equipment as a result of updated fall protection requirements, the provision of arc-rated head and face protection for some employees, employee training on the use of new fall protection equipment, the calculation of minimum approach distances, and, in some cases, the use of por protective gaps to comply with the new minimum approach-distance requirements. The PRIA's method of evaluating the price of arc-hazard assessments is likewise modified by the FEA.

According to OSHA, compliance with the proposed rules would cost somewhere between \$47.1 million and \$49.5 million on an annually basis. The majority of the overall compliance expenses, between \$15.7 million and \$17.2 million, are attributable to the final rule's mandate that employers supply arc-flash protective equipment. Costs for host-contractor communications, job briefings, training, minimum approach distances, fall protection, compliance with existing 1910.269 for employees not already covered by that standard, and arc-hazard assessments are among the other nontrivial compliance costs connected with the final rule.

Financial Effects

OSHA created quantitative estimates of the probable economic effect of the requirements in this rule on businesses in each affected industry in order to analyze the economic implications associated with compliance with the final rule. OSHA evaluated possible economic effects by comparing predicted compliance costs with industry revenues and profits.In comparison to the comparable yearly cash flows linked to the regulated activities, the expenses of complying with the final rule are not prohibitive. Averaged over all entities, the anticipated costs of compliance amount to around 0.007 percent of revenues and 0.06 percent of profits; compliance costs in any one sector do not exceed 0.1 percent of sales or 2 percent of profits.

The most probable result of the current rulemaking's economic effects will be an average minor rise in power costs of 0.007 percent. The public's demand for services, or the demands of any other impacted consumers or intermediaries, is not expected to be materially altered by a price rise of the order of 0.007 percent. There may not be much of an impact on earnings if companies can considerably recuperate the compliance expenses associated with the current rules with such a little price increase.

In general, it is probable that employers can pass along part or all of the expenses of compliance via higher pricing for the majority of enterprises. Profits in any impacted industry would be decreased by a maximum of around 2% if exceptional circumstances prevented even a 0.1 percent pricing hike.OSHA comes to the conclusion that every sector of the impacted industries can afford to comply with the requirements of the final rule.Moreover, OSHA comes to the conclusion that the final rule will have little to no impact on international commerce, employment, wages, and economic growth for the United States based on a review of the costs and economic implications related to this rulemaking.

Final Analysis of Regulatory Flexibility

The Small Business Regulatory Enforcement Fairness Act, which modified the Regulatory Flexibility Act in 1996, mandates the creation of a Final Regulatory Flexibility Analysis for specific regulations issued by agencies. According to the law, each such analysis must include the following: a brief explanation of the justification and goals of the rule; a summary of the significant issues raised by the public in response to the initial regulatory flexibility analysis; a summary of the agency's assessment of these issues; and a statement of any changes made to the final rule as a result of these comments.

Final Economic Analysis and Regulatory Flexibility Analysis, which is further in this preamble, OSHA examined the possible effects of the final rule on small and very small companies. This analysis is further discussed under the title "Final Regulatory Flexibility Analysis." According to OSHA, compliance costs are roughly equal to 0.086 percent of profits for affected small businesses generally, less than about 2.9 percent of profits for small businesses in any given industry, and roughly 0.39 percent of profits for affected very small businesses generally, less than about

Required under the Regulation

Electric power generating, transmission, and distribution job-related risks that may and do result in severe injury or death include burn, electric shock, and fall risks for workers. These personnel often come into contact with electrically charged components of the power grid, and the voltages involved are typically significantly greater than those seen in other forms of labor. According to OSHA, these employees suffer from 444 major injuries and 74 deaths on average per year.

OSHA comes to the conclusion that even if employers complied with existing safety regulations to the letter, many, if not nearly half of the fatal and nonfatal injuries to employees covered by the final rule would still happen. This is true even though some of these incidents may have been avoided with better adherence to existing safety regulations. The complete compliance with the final rule is expected to save an extra 19.75 deaths and 118.5 severe injuries per year, even after taking into account events that would have been avoided with adherence to the current requirements.

A further advantage of this regulation will be the provision of updated, precise, and uniform safety standards for the production, transmission, and distribution of electric power. Construction and general industrial work on electric power transmission and distribution networks is now covered by several OSHA rules. Employees often follow the same work procedures whether they are working in the general business or the construction sector. Depending on whether the employer is modifying the system or maintaining it, a different standard may apply to a given task. For instance, if an employer upgrades a cutout on a transmission and distribution system, it is conducting construction work, but if it merely replaces the cutout with the same model, it is performing general industry labor. The relevant OSHA regulations need to be as comparable as practicable since the workers' working methods would almost certainly be the same. Inconsistencies It may be challenging for companies to adopt proper work practices for their workers when there is a gap between the construction and general industry requirements. Presently, it is possible that distinct and contradictory OSHA regulations may apply to work requiring two or more cutouts. Employers and workers have advised OSHA to make the two standards more similar to one another because of this. This last rule does that.

Moreover, the final rule clarifies and provides significant modifications to the current requirements. Subpart V of OSHA's construction standards contains the current requirements for the building of electrical power transmission and distribution lines and equipment, as well as electrical protective equipment.

On November 23, 1972, Subpart V was published, making it over 40 years old. Since then, certain technological advancements have been made in the transmission and distribution of electric power, but these advancements are not reflected in the present standards. For instance, since 1972, techniques for calculating minimum approach distances have improved, and the lowest approach distances in current

1926.950 do not use the most recent methods. The minimum approach distances outlined in the final rule are more technologically advanced and protective than those in the old standard. Even the more recent general industry regulations for the use and upkeep of electrical power production, transmission, and distribution installations as well as electrical protective equipment are not totally in line with the most recent technological advancements.

Eventually, the final rule makes certain murky rules provisions clear. Check out Wisconsin Elec, for instance.

Accident Information

While drafting this final rule, OSHA consulted a number of sources for data on incidents in the electric utility sector. In addition to OSHA's own accident investigation files, the Edison Electric Institute and the International Brotherhood of Electrical Workers produce injury data. Additionally, the National Institute for Occupational Safety and Health publishes accident data as part of its Fatality Assessment and Control Evaluation Program, and the Bureau of Labor Statistics also publishes accident data, including incidence rates for total cases, lost-workday cases, and lost workdays.

While the requirements were still in the proposal stage, CONSAD Corp., working under contract with OSHA, looked into and evaluated various sources of relevant data in order to create estimates of the potential benefits connected with the standards. In agreement with the Agency, CONSAD concluded that OSHA's IMIS data and the Census of Fatal Occupational Injuries produced by BLS were the most trustworthy data sources for this purpose. Accidents that CONSAD evaluated often included electrocutions or shocks. Moreover, a significant portion of individuals had burns on their arms, belly, or legs.Many people died or were injured after falling off of vehicle-mounted aerial lifts, while others perished in electric arc bursts and flashes.

Both a significant risk and a risk reduction

An "occupational safety and health standard" is defined as "a standard which requires conditions, or the adoption or use of one or more practices, means, methods, operations, or processes, reasonably necessary or appropriate to provide safe or healthy employment and places of employment" in Section 3 of the Occupational Safety and Health Act of 1970 (29 U.S.C. 652). According to how this concept has been construed, OSHA must first demonstrate that there is a "substantial risk" before it may publish a safety or health regulation. For instance, have a look at Industrial Union Department.

American Petroleum Institute v. AFL-CIO, 448 U.S. 607; for another example, see UAW v. OSHA, 37 F.3d 665. Yet, the requirement that the Agency demonstrate a serious danger is not a "mathematical straitjacket," as stated in Benzene, 448 U.S. at 655. Id. at 655–56; see also, for instance, Public Citizen Health Research. In fact, the Agency is free to "determine, in the first instance, what it considers to be a'significant' risk" and "is not required to support its finding that a significant risk exists with anything approaching scientific certainty."

Risk estimations for health standards like benzene are often based on mathematical models, and the benefits are measured by projecting how many future deaths will be avoided under different exposure decreases. Risk is predicated on the presumption that historical accident patterns are indicative of future ones, or safety standards. OSHA calculates benefits by estimating the proportion of accidents that will be avoided by standard compliance. . The risks and advantages of this final rule are evaluated by the agency in OSHA's Final Economic and Regulatory Flexibility Study. According to these evaluations, which were previously revealed by OSHA, there are 444 major injuries and 74 deaths among workers who are subject to this final rule every year. The Agency has concluded that approximately half of those accidents and deaths would have happened even if businesses had complied with all current regulations. According to the economic and regulatory analyses and the accident data analyzed for this rulemaking, electric shocks, burns from electric arcs, falls, and other harmful incidents, such as those in which employees are struck by, struck against, or caught between objects, are the leading causes of injuries and fatalities among power generation, transmission, and distribution workers. OSHA has determined that employees working on electric power generation, transmission, and distribution installations are currently exposed to a significant risk of injury or death due to the high number of injuries and fatalities occurring in this industry each year and the fact that current standards are insufficient to prevent nearly half of those incidents.

According to the Agency's projections, the modifications made by this final rule will save 19.75 deaths and 118.5 severe injuries annually. OSHA comes to the conclusion that the considerable risk that presently exists at power production, transmission, and distribution worksites is significantly reduced by this final standard. The many new rules and changes that are being implemented aim to reduce the risks to the Agency, as stated in Section VI, Final Economic Analysis and Regulatory Flexibility Analysis, later in the preamble. The number of injuries or deaths related to the risks covered by the final rule will most likely be lower in sectors where worker exposure is less common than in other industries than it will be in those with a greater incidence of exposure. As a result, there is a significant risk to any worker of any industry exposed to the hazards covered by the final rule. However, even for industries with low, negligible, or even no reported injuries or fatalities, the workers exposed to the hazards covered by the final rule face a "significant risk of material harm." See, for instance, Associated Builders and Contractors, Inc. v. Brock, 862 F.2d 63, 67-68; Lockout/Tagout II, 37 F.3d at 670. has recognized as key risk factors that are involved in the production, transmission, and distribution of electric power. In order to accomplish the projected decrease in total risk, each component of this final rule is thus deemed to be both reasonable required and appropriate.

The conclusion reached by OSHA that the aforementioned estimates create a considerable risk for employment in the electricity generation, transmission, and distribution sectors was not seriously contested by any rulemaking participants. OSHA disagrees that it is obligated to make numerous, hazard-specific substantial risk determinations. EEI, however, maintained that OSHA has a duty to make an independent significant risk showing for each of the hazards addressed by this regulation.

There is no legal necessity for hazard-by-hazard considerable risk determinations in vertical standards, despite the fact that the Agency is able to define the basic categories of dangers covered by its vertical standards and has done so in this rulemaking. Washington, D.C. The notion that "Benzene demands that the agency conclude that each and every feature of its standard removes a major danger faced by workers" has previously been rejected by the Circuit Court of Appeals (Ethylene Oxide, 796 F.2d at 1502, n. 16. After OSHA has determined that there is a serious danger in general, the issue of whether the standard's requirements are rationally connected to that objective arises. See Noise, 773 F.2d at 1447, as an example. Second, although the Supreme Court first interpreted the OSH Act as establishing a considerable risk criterion, it did not refer to specific risks but rather to the Agency's conclusions regarding dangerous workplaces. 448 U.S. at 642 (Benzene). See also, for instance, Texas Independent; id. Marshall v. Ginners Association, 630 F.2d 398, 400. Finally, according to the OSH Act, substantial risk assessments do not need to be broken down along additional categories.

OSHA looked at the sources EEI cited to back up the alleged necessity for hazard-specific risk determinations, but did not find them to be convincing. First, EEI claimed that the Supreme Court's ruling in the Benzene case mandated that the Agency to conduct separate substantial risk analyses for the components of the standard that address air contaminants and dermal contact. A careful examination of the ruling in that instance shows no such conclusion. Instead, the dermal-contact requirements in that case were remanded for further consideration on the identical grounds as the air-contaminant provisions were denied, namely that the provisions were not backed by any meaningful risk determinations. The Court did make the suggestion that OSHA must determine that a dermal contact prohibition is reasonably necessary and appropriate to address a significant risk, i.e., that preventing dermal contact would lower the overall risk associated with workplace exposure to benzene, but it did not address whether a single significant risk determination could ultimately support both the dermal-contact and air-contaminant provisions in the standard. Id.

More than 400 hazardous chemicals have their acceptable exposure levels established by this regulation. While the court in that case ruled that OSHA had to justify its risk assessment for each drug subject to regulation, that rulemaking is easily separated from this final rule. The several regulated compounds in PELs were "unrelated" and had "little in common," according to 965 F.2d at 972. Here, however, the multiple dangers that this final rule addresses are strongly tied to one another. These all occur at power production, transmission, and distribution facilities and together they account for a significant portion of the covered employees' deaths and injuries. The PELs decision, in OSHA's opinion, does not restrict its ability to enact regulations that it determines to be reasonably necessary and appropriate to eliminate existing electrocution, burn, fall, and other risks that, taken collectively, expose covered workers to a materially increased risk at work.

Lastly, EEI should not have relied on the Agency's ergonomics regulation. EEI drew attention to the fact that OSHA's risk evaluation for its ergonomics regulation only took accidents caused by hazards covered by that standard into account. This interpretation, however, provides no support for EEI's argument since the risk assessment for this rulemaking similarly only took deaths and injuries that happened while doing activities covered by this final rule into account.

OSHA disagrees that hazard-specific substantial risk determinations are required, but the agency considers that the evidence is sufficient to support them for the key risks covered by this regulation, namely electrocution and electric shock, burns from arc flashes, and falls. The Agency has discovered that each of these dangers exposes employees to a sizable number of injuries and deaths each year. Moreover, "most of the dangers" addressed by this regulation, according to EEI, "are already covered by the current rules that OSHA now... modifies and supplements." However, several of the dangers covered by this regulation are already covered by generally applicable horizontal standards that are hazard-specific. For examples, see to 29 CFR part 1926, subparts K and M. OSHA simply decides that the additional provisions of this final rule are reasonably necessary and appropriate to reduce a significant portion of the remaining significant risk at power generation, transmission, and distribution worksites because all of these existing standards were supported by findings of significant risk.

Construction of the Final Regulation

The OSHA Standards' History

In 1972, OSHA made the decision to create building guidelines for electricity transmission and distribution equipment. The term "construction work" is broadly defined in 1910.12 and existing 1926.950 to include the initial installation of, as well as the alteration, conversion, and improvement of electric power transmission and distribution lines and equipment. OSHA defines the term "construction work" in 29 CFR 1910.12 as "work for construction, alteration, and/or repair, including painting and decorating."Electric power production, transmission, and distribution systems must operate and be maintained in accordance with the general industry standard in 29 CFR 1910.269. On January 31, 1994, OSHA approved 1910.269 into law. This standard, which deals with work that subpart V of the construction standards did not apply to, is a companion standard. 1910.269 was likewise based on contemporary technology and national consensus norms when it was published.

REFERENCES

[1] H. Paz-Penagos, "Electric power generation from a turnstile", *DYNA*, 2020, doi: 10.15446/dyna.v87n215.86789.

[2] Z. Wang en B. Lim, "Electric power generation from sediment microbial fuel cells with graphite rod array anode", *Environ. Eng. Res.*, 2020, doi: 10.4491/eer.2018.361.

[3] L. G. Wang, M. F. Lin, E. Tedeschi, J. Engström, en J. Isberg, "Improving electric power generation of a standalone wave energy converter via optimal electric load control", *Energy*, 2020, doi: 10.1016/j.energy.2020.118945.

[4] G. N. G. Elgamal en J. Demajorovic, "Barriers and perspectives for electric power generation out of photovoltaic solar panels in the brazilian energy matrix", *Rev. Gest. Ambient. e Sustentabilidade*, 2020, doi: 10.5585/GEAS.V9I1.17157.

[5] H. A. Aldhubaib en R. Kashef, "Optimizing the Utilization Rate for Electric Power Generation Systems: A Discrete-Event Simulation Model", *IEEE Access*, 2020, doi: 10.1109/ACCESS.2020.2991362.

[6] V. Nimesh, D. Sharma, V. M. Reddy, en A. K. Goswami, "Implication viability assessment of shift to electric vehicles for present power generation scenario of India", *Energy*, 2020, doi: 10.1016/j.energy.2020.116976.

[7] X. Liao, "Importance of freshwater for electric power generation", in *Encyclopedia of the World's Biomes*, 2020. doi: 10.1016/B978-0-12-409548-9.11887-1.

[8] B. R. Sreelekshmy, R. Basheer, S. Sivaraman, V. Vasudevan, L. Elias, en S. M. A. Shibli, "Sustainable electric power generation from live anaerobic digestion of sugar industry effluents using microbial fuel cells", *J. Mater. Chem. A*, 2020, doi: 10.1039/d0ta00459f.

[9] M. Basu, "Electric Power and Heat Generation Expansion Planning", *Electr. Power Components Syst.*, 2020, doi: 10.1080/15325008.2020.1793840.

CHAPTER 12

ELECTRICAL PROTECTIVE EQUIPMENT STANDARD

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In 1910, OSHA updated its Electrical Protective Equipment Standard at the same time that 1910.269 was published. The integration of national consensus standards for rubber insulating equipment by reference was removed with the modification of 1910.137 and was replaced with performance-based guidelines for the creation, production, and safe handling and use of electrical protective equipment. On June 15, 2005, OSHA announced a proposed regulation. In that paper, it was suggested that both the general industry standards for electric power production, transmission, and distribution activities as well as the building standard for those tasks be revised. Also, that paper suggested updates to the general industry standards for foot protection and electrical protective equipment as well as a new building standard for that equipment. Public comments were initially expected by October 13, 2005, but OSHA extended the comment time by 90 days to January 11, 2006 in response to requests from interested parties, including EEI. Beginning on March 6 and concluding on March 14, 2006, OSHA conducted a non-competitive public hearing. Interested parties had until May 15, 2006, and until July 14, 2006, respectively, to submit further material and posthearing briefs[1], [2].

On October 22, 2008, OSHA reopened the file for a 30-day period in order to solicit feedback from the general public on particular issues pertaining to minimum approach distances. For the points cited in the reopening notice, EEI asked for a public hearing and an extra 60 days to submit comments. On September 14, 2009, OSHA announced a public hearing to be conducted on October 28, 2009, addressing the limited problems highlighted in the two reopening notices. OSHA also opened the record for an additional 30 days to accept new comments on minimum approach distances.

After the hearing, interested parties had two deadlines to submit further material and post hearing briefs: December 14, 2009, and February 10, 2010. The prehearing comments, the two public hearing transcripts, all exhibits filed before and during the two hearings, and all posthearing submissions and briefs make up the record for this rulemaking. In addition to closing the record, Administrative Law Judge Stephen Purcell certified it to the Assistant Secretary of Labor for Occupational Safety and Health[3], [4].

Standards of Relevant Consensus

The requirements governing electric power production, transmission, and distribution activities are included in the National Electrical Safety Code Standard (ANSI/IEEE C2, often known as the NESC). The whole spectrum of dangers addressed by this final regulation, however, is not covered by ANSI/IEEE C2. While it includes a few standards for the avoidance of falls and burns from electric arcs, its main focus is the prevention of electric shock.Standards for the production, transmission, and distribution of electric power have been set by the American Society for Testing and Materials. Standards for climbing gear, protective grounding gear, fiberglass rod and tube used in live-line tools, and clothing for workers exposed to electric arcs have been produced by ASTM Committee F18 on Electrical Protection Equipment for Workers.

A standard for electrical safety in the workplace, known as NFPA 70E, has been accepted by the National Fire Protection Association. The NFPA standard contains provisions addressing work near such installations carried out by unqualified employees, that is, employees who have not been trained to work on or with electric power generation, transmission, or distribution installations, even though it does not apply to electric power generation, transmission, or distribution installations. Moreover, it covers how to shield workers from arc-flash dangers and includes techniques for calculating the heat energy levels produced by electric arcs.

Electric power production, transmission, and distribution installations, as well as the work on those installations, are governed by standards created by the Institute of Electrical and Electronic Engineers (IEEE). ANSI has embraced several of these standards. IEEE Std 516 and the IEEE Handbook for Maintenance Techniques for Energized Systems are two of these IEEE standards.Power-Lines and IEEE Handbook for Safe Grounding of Power Lines (IEEE Std. 1048). OSHA is aware of how crucial consensus standards may be in protecting employee safety. The current Appendix E to 1910.269 contains a complete list of consensus standards pertaining to electric power production, transmission, and distribution activities. In developing this final rule, OSHA took into account the most recent versions of all the standards mentioned in Appendix E. OSHA proposed to add the same list as Appendix E to subpart V. Part V, Summary and Explanation of the Final Regulation, which follows this preamble, provides an explanation of any significant variances from these consensus norms.

The Construction Safety and Health Advisory Committee

While establishing standards for construction work, OSHA is required under 29 CFR sections 1911 and 1912 to confer with the Advisory Committee on Construction Safety and Health, which was created in accordance with Section 107 of the Contract Work Hours and Safety Standards Act. According to 1911.10, the Assistant Secretary must provide a draft proposed regulation to ACCSH and give the Committee a chance to offer suggestions. Furthermore, see 1912.3.OSHA has consulted with ACCSH on this regulation for a very long time. On May 25, 1995, OSHA presented the ACCSH with a draft of the proposed construction standards as well as a statement on the need to update the standards. To examine the materials, the Committee established a workgroup, and the committee gave OSHA feedback. On August 8, 1995, the Agency provided a progress update on the proposal to the Committee, and on December 10, 1999, it sent an updated draft of the proposal to ACCSH. OSHA provided ACCSH with another progress report and an overview of the significant amendments it had made to the plan on February 13, 2003. The identical draft plan that was given to the small entity representatives taking part in the Small Business Regulatory Enforcement and Fairness Act hearings, which were taking place at the time, was given to the Committee by OSHA on May 22, 2003. OSHA also addressed the main concerns expressed by the representatives of small entities on the proposed plan[5]–[7].

The ACCSH provided the Agency with official recommendations on the proposal on May 18, 2004. OSHA requested the ACCSH's opinions on the plan as a whole, as well as on details of host employer-contractor interactions and flame-resistant apparel in particular. The ACCSH unanimously agreed that employees must be protected from electric arc hazards by wearing flame-retardant clothing, that construction standards for electric power transmission and distribution work should be the same as general industry standards for the same type of work, and that some form of safety-related communication between host employers and contractors is required. The ACCSH unanimously recommended that OSHA release its proposal in accordance with these particular suggestions.

In order to construct the final rule's minimum approach-distance requirements, EEI advised OSHA to consult ACCSH further if it chose to rely on recent work of the IEEE technical committee responsible for amending IEEE Std 516. This work has not been submitted to ACCSH. EEI is in error. EEI bases their claim on the National Constructors Assn. 581 F.2d 960. The use of this case by EEI is inappropriate. The OSH Act and OSHA's procedural rules place "a'stricter' requirement on when, and how often, the agency must utilize the advisory committee procedure than does the with respect to public comment during informal rulemaking," the court stated, but that statement in the decision is nonprecedential dicta. Id. at 971 n.27. The court said that it "did not determine how much harder the threshold is" since the regulation in question did not "meet even the APA's... standard." As a result, the ruling only supports the idea that OSHA must contact ACCSH in cases when the final rule in question does not pass the APA's "logical outgrowth" standard.

In this regulation, OSHA consulted with ACCSH in accordance with the National Constructors ruling. In relation to its ground-fault circuit protection, the Nat'l Constructors court ruled that OSHA needed to engage in additional consultation with ACCSH. The OSHA Docket Office and the OSHA website both provide access to this document[8], [9].

Standard where "guaranteed equipment grounding conductor programs" were acknowledged as a means of compliance in the final regulation, but ACCSH had never had the chance to comment on that specific technique of employee protection. The D.C. Circuit came to the conclusion that the in issue compliance program was not provided to ACCSH nor "grw logically out of anything that was offered to, or heard from, the Committee."

Contrarily, in this Subpart V regulation, ACCSH was given the fundamental directive to follow minimal approach distances. In light of technology advancements since the proposal was examined by ACCSH, the Agency is just improving the process utilized to determine the minimum approach distances.In any case, ACCSH had the chance to weigh in on whether OSHA should usually rely on the work of the IEEE committee. The ACCSH was aware that OSHA may use the current 1910.269 as the basis for the minimum approach distances for subpart V. In reality, the ACCSH finally came to the conclusion in its proposal that the construction standards for work related to electric power transmission and distribution should be equivalent to those used by the general industry for similar work. The basic formula for calculating minimum approach distances in the final rule is the same as the one used in existing 1910.269, and in the draft proposal submitted to ACCSH, the minimum approach distance requirements were derived from IEEE Std 516.

It is of no relevance because ACCSH did not expressly address the issue of whether OSHA should draw its minimum approach-distance criteria from work done in the creation of an IEEE standard that had not yet been published at the time of the ACCSH consultation. As stated in Nat'l Constructors, 581 F.2d at 968, "the OSH Act and OSHA's procedural rule make plain, the Assistant Secretary need only provide whatever information he has available to him at the time he makes his recommendation to the Committee." Id. at 968 n.16 The National Constructors Court acknowledged that "by designing the Advisory Committee option as a procedural step that must precede public notice, comment, and the informal hearing, assumed that the Committee would not be provided with all information that the Labor Department eventually developed on the subject." OSHA's conduct in the final rule is in line with National Constructors as a result.

A standard is technologically practicable if the safety precautions it calls for are currently in place, can be implemented using current technology, or can be developed using technology that may fairly be anticipated to be produced. For instance, take a look at American Iron and Steel Inst. 939 F.2d 975, 980 (v. OSHA). When an industry is able to bear or transfer the costs of compliance without endangering long-term profitability or the competitive landscape, then a standard is economically viable. Take American Textile Mfrs. as an example. Inst. v. Donovan, 452 U.S. 490, 530 (n.d.). Lead II, 939 F.2d at 980; 55. A standard is cost-effective if the safety precautions it calls for are the least expensive ones that can be taken to provide the same degree of safety. For instance, take a look in Lockout/Tagout II, 37 F.3d at 668.

According to Section 6 of the OSH Act, OSHA is allowed to add labeling, monitoring, medical testing, and other measures for obtaining and transmitting information to a standard's requirements. 29 U.S.C. 655. Lastly, the OSH Act mandates that OSHA provide justification for why the rule it has adopted is a superior way to carry out the Act's objectives when it varies materially from a national consensus norm. 29 U.S.C. 655. There are explanations of deviations from pertinent consensus standards elsewhere in this prologue.

Protective gear for electrical systems

Employees are protected from this danger by the use of electrical safety equipment that has been properly designed, produced, and maintained. In order to address the design, production, and maintenance of electrical protective equipment, OSHA has released final 1926.97, Electrical protective equipment. Also, OSHA is updating current. The design, production, and maintenance of electrical protective devices are also covered in 1910.137. OSHA comes to the conclusion that the final rule will protect workers from the danger of electric shock more effectively than current OSHA requirements for the reasons that are extensively covered in this part of the preamble.

Only the building of electric power transmission and distribution lines and equipment is covered by the current standards for electrical safety equipment in construction work, found in 1926.951. But, because employers in the whole construction sector utilize electrical protective equipment, OSHA thinks that the regulations for such equipment, as laid forth in the final 1926.97, should apply to all construction work, not only work involving the transmission and distribution of electricity. Because of this, OSHA has released a new standard, 1926.97, Electrical protection equipment, which is applicable to all construction activities.

The production, testing, and design of electrical protective equipment is covered in depth by these standards. Nevertheless, since the original subpart V was published in 1971, these standards have undergone a number of modifications and are now woefully out of date. The full list of related current national consensus standards is shown below:

Standard Specification for Rubber Insulating Gloves (ASTM D120-09). Rubber Standard Specification ASTM D178-01

Matting for insulation

Standard Specification for Rubber Insulating Blankets, ASTM D1048-12. Rubber Standard Specification ASTM D1049-98

Protective Covering

Rubber Standard Specification ASTM D1050-05

Line hose that insulates

Standard Specification for Rubber Insulating Sleeves, ASTM D1051-08.

Moreover, OSHA did not include or refer to the current 1926.951.12 standard when it came to the in-service care of insulating line hose and coverings, insulating blankets, and insulating gloves and sleeves.

These national consensus standards served as the basis for OSHA's proposed revised 1926.97, which was written in terms of performance. This strategy will be continued by OSHA in the final regulation. The final regulation depends on performance-based elements from the consensus standards that are essential for employee safety, but it omits many of the standards' exhaustive details. The final regulation will thus provide more latitude for compliance.

BGE said that OSHA's performance-based approach "creates potential for harmful activities" and makes the regulations "vague." OSHA rejects this statement because of the following.

The Agency is aware of the value of consensus standards in establishing the fundamental specifications for the secure design and production of electrical protection equipment for workers. To do this, OSHA will let companies to abide by the final rule by adhering to certain requirements in the consensus standards. The applicable ASTM standards are included in the record as Exs, according to OSHA. 0048, 0049, 0050, 0051, 0066, 0067, 0068, 0069, 0070. The consensus standard version in the record is often older than the version stated in the preamble. Yet, OSHA-based final

Based on the ASTM publications and other facts in the record, see 26.97 and 1910.137. Versions of the consensus standards that are not in the record are included in the preamble because OSHA determined that they were compatible with the final rule. These more recent ASTM standards, according to OSHA, meet the criteria of final 1926.97 and 1910.137. On the relevance of this choice to adhere to these particular laws, see the discussion of the notes that follow the paragraphs and how it all relates to the commenter's worry about ambiguity.

The consensus standards, however, would not be acceptable to adopt in their entirety in this rulemaking, according to OSHA. Secondly, since OSHA issued the standards in current 1926.951, each of the standards that are now cited has undergone a number of adjustments. Any particular versions that OSHA would accept would probably be out of date in a few years due to the ongoing process through which the consensus standards development bodies regularly change their consensus standards.

Moreover, it would not be feasible for OSHA to alter its rules as often as is required to stay up with changes in the consensus standards due to the long rulemaking process at OSHA. Technology updates may be included into the final 1926.97 without the requirement for ongoing editing. In order to allow for alternate compliance strategies that provide workers an equivalent level of safety, OSHA phrased the final rule in performance terms wherever practicable.

The fact that the consensus standards include specifics that are beyond the purview of the OSHA standard and have no bearing on worker safety presents another challenge in adopting them by reference. OSHA only included features from consensus standards that are pertinent to workplace employee safety while creating final 1926.97. Additionally, OSHA used wording in the final rule that is simpler than that in the consensus standards to make the requirements easier for businesses and workers to apply and understand.

Employers will not need to consult the consensus standards to ascertain their duties under final 1926.97 since all relevant requirements are included in the rules' language. Despite the fact that OSHA no longer incorporates the consensus standards by reference, it is made clear by notes scattered throughout the rule that OSHA will still consider compliance with the consensus standards listed in the notes to be compliance with the performance requirements of the final 1926.97.

OSHA adds that it recently amended the design criteria included in numerous personal protective equipment regulations but opted against adopting a recommended performance-based approach. OSHA said in its final rule that "widespread resistance" to the plan and "misunderstanding" of it suggested "potential misapplication."

This justification is not relevant to this regulation. First, the proposed performance-based strategy in this regulation did not face significant pushback. A few commenters did ask OSHA to consider companies in compliance with the final rule if they also adhere to all future updates of the consensus standards stated. The Agency is confident that the performance-based strategy it adopts in final 1926.97 will give these commenters the flexibility they requested by allowing employers to adhere to future iterations of consensus standards provided those future iterations satisfy the performance-based criteria of the final rule. Second, OSHA adopted a performance-based strategy in 1994 when it amended the then-current 1910.137.

A performance-based strategy was supported by a number of rulemaking participants in 1994. Finally, OSHA thinks that harmonizing 1926.97 and 1910.137 would lessen erroneous application by the community it regulates and, thus, lessen the danger of electric shock. Inconsistent rules would lead to more improper application by the regulated population, which would raise the danger of electric shock. Ultimately, after enacting 1910.137 in 1994, OSHA has not had any issues doing so.

Regarding the commenters' requests that OSHA deem employers who abide by all future revisions of the listed consensus standards as complying with the final rule, OSHA lacks the justification necessary to conclude that such revisions will provide adequate guidance for compliance with the performance criteria of the final rule. The performance requirements of the final regulation may or may not be met by revised consensus standards. Nevertheless, if a new consensus standard clearly offers protection equal to or greater than the protection given by 1926.97.13, the Agency may consider compliance with that consensus standard to be a de minimis requirement even if it does not meet the performance standards of this final rule.

Any employer wishing to depend on a revised consensus standard is free to determine whether it satisfies the performance requirements set out in the final version of 1926.97. Employers may consult OSHA for advice if they are unclear whether a revised consensus standard satisfies the performance requirements of the OSHA standard. The De minimis conditions are situations where an employer implemented a measure different from one specified in a standard, but that has no direct or immediate relationship to safety or health, even though the revised consensus standard does not appear to meet the OSHA standard's performance criteria. De minimis circumstances are not subject to citations or fines from the

Agency, nor is the employer compelled to make the workplace compliant (i.e., there are no abatement requirements). A de minimis condition exists when an employer complies with a consensus standard rather than the standard in effect at the time of the inspection and the employer's action clearly provides equivalent or more effective employee protection, according to OSHA's de minimis policy, which is outlined in OSHA Instruction CPL 02-00-148.

Employers should consult OSHA for advice before assuming that the Agency would see their adherence to the updated consensus standard as a de minimis requirement.Several participants in the rule-making process requested OSHA to provide employers the relevant consensus standards for free. According to Mr. Terry Williams of the Electric Cooperatives of South Carolina, "if OSHA is to depend on processes that it does not fully detail, the agency should offer a cost-free mechanism for employers to assess these procedures to ensure they are following them." Small firms are financially burdened by the expense of procuring and assessing these voluntary standards, according to Mr. Don Adkins of Davis H. Elliot Construction Co.

These petitions are being denied by OSHA. The Agency's use of performance-based language in the rule's formulation gives businesses some leeway when it comes to adhering to the requirements. The Agency is aware that employers may need extra direction on particular steps to take or exact standards to adhere to. To give such extra advice, Final 1926.97 refers to relevant consensus standards, although such standards are not required.In any case, even when OSHA includes consensus standards by reference, the Agency does not provide the employers access to such consensus standards for free. Many consensus standards are papers that are protected by copyright, and in such situations, the copyright holder has certain legal rights regarding the public circulation of those publications. Be aware that some organizations that produce consensus standards, like NFPA, do provide

Employers may often depend on third parties to certify that test procedures or equipment adhere to the mentioned agreed standards. Secondly, OSHA anticipates that manufacturers would normally provide manufacturers' assurances to employers that electrical protective equipment can resist the necessary electrical proof tests required by final paragraphs and. An employer may simply seek for equipment that is marked as satisfying the mentioned agreed requirements in this respect. Manufacturers certify that their equipment passed the necessary testing by using a label like this, which is normally required by the applicable consensus standard.

Second, as stated in the last paragraph, OSHA understands that many firms, especially small employers, do not test their own equipment to see whether workers can use it. Instead, some businesses have the apparatus tested by an electrical laboratory. Employers can rely on the assurance of these testing laboratories that they followed the listed consensus standards in addition to the requirements of OSHA's standard to determine whether employees can use the equipment in accordance with the final paragraph. It is OSHA's understanding that such laboratories follow the test methods in the applicable consensus standards for testing a wide range of products.

When consensus standards development organizations update their consensus standards, OSHA anticipates that manufacturers' labels will attest to the equipment's compliance with the most recent consensus standards and that testing facilities will employ the most recent consensus standards' test procedures rather than those listed in the notes. OSHA understands the worries that companies, particularly small firms, lack the funding to acquire and verify that amended consensus standards adhere to the performance requirements of the final rule.

According to what was previously discussed, an employer that lacks the funds to purchase and carefully examine an updated consensus standard may ask OSHA for advice on whether compliance with an updated consensus standard would be in accordance with this final rule or put the employer within the ambit of OSHA's de minimis policy.

To clarify that the proposed paragraph only applies to rubber insulating equipment that is typically not exposed to the same quantities or kinds of flexing and, thus, is not subject to the same stress, the terminology in the proposed paragraph has been edited in the final rule.18

The proposal's paragraph, which is being implemented with one change, mandates that electrical protective equipment be tagged with its class and kind. The type designation shows whether the equipment is ozone resistant, whereas the class marking specifies the voltage at which the equipment may be operated. Employees can identify the voltages and purposes for which the equipment is suitable thanks to these indications. In compliance with this clause, equipment may also have additional pertinent marks, such as the name of the maker, the size of the item, or a statement indicating it was produced in conformity with the applicable consensus standards.

According to propose paragraphs and, rubber insulating equipment "other than matting" would have needed to be designated as Type I or Type II to show if it was ozone-resistant. The referenced terminology should be removed from these lines, according to Mr. James Thomas, President of ASTM International, since "type categorization implies the manufacture." Tensile, compression, and shear stresses are only a few of the numerous kinds of stresses that flexing may put rubber under. The most flexing is seen when rubber insulating line hose and covers are being installed on an electrical component.

Nevertheless, workers install this equipment while using rubber insulating gloves and sleeves or live-line tools. As a result, the employee is safeguarded in additional ways when seam separation is possible.

Rubber insulating matting is typically put on the ground and does not experience the kind of bending that may separate it. The maximum usage voltages for various equipment classes are listed in E-4, which is detailed under the summary and explanation for paragraph, with infrared material being either non-ozone-resistant or ozone-resistant and applying to all, including atting.OSHA has embraced the commenter's suggestion in the final rule and concurs that the ASTM standards provide for matting to include a type mark indicating whether or not it is ozone-resistant.According to Mr. Leo Muckerheide of Safety Consulting Services, OSHA should mandate that electrical protection devices have a label indicating the maximum usage voltage because:

Many electrical professionals utilize electrical safety equipment infrequently and often operate with different voltages. Hence, it might be dangerous to expect them to remember which class to use with which voltage. The solution to this issue is to clearly designate the electrical protection equipment with the maximum usage voltage. This suggestion is rejected by OSHA. Initially, training is provided to employees wearing electrical protection equipment to ensure that they are aware of the class of equipment to use at which voltage. The evidence shows that the majority of the employees protected by

Electrified lines on a regular basis, often daily, while wearing electrical protection equipment and possessing a high level of training. In addition, a number of OSHA regulations call for personnel who operate near or on exposed electrified items to get training, in cases when electrical safety equipment is also necessary. For example, final

The provisions of 1910.269 and 1926.950 mandate that competent workers engaged in the production, transmission, and distribution of electric power must get training in the use of electrical protection equipment. A comparable requirement for employees doing various kinds of general industrial electrical work is found in 1910.333.Construction employees must complete the training requirements outlined in paragraph 1926.21. The training requirement in this final standard is more specific than the one in 1926.21, which mandates training on OSHA regulations relevant to the employee's workplace.

Second, maximum use voltage labels are often not included when producing electrical protection equipment that complies with the relevant consensus standards. Employers would likely be forced to label the equipment themselves if the maximum usage voltage of electrical safety equipment had to be marked on it. According to OSHA, the manufacturer's permanent class-rating label on electrical safety equipment offers appropriate information and is less likely to fade away over the course of the equipment's useful life than any marking applied by an employer. As a result, the Agency comes to the conclusion that it is not required to require electrical protection equipment to be marked with the maximum usage voltage.

Mr. Frank Owen Brockman, who was speaking on behalf of Farmers Rural Electric Cooperative Company, suggested that OSHA make it a requirement that the marks additionally contain the name of the organization doing the testing, the date of the test, and the equipment's owners. He made no mention of how adding this extra information to the markers would increase worker safety. The final paragraph of 1926.97 addresses this issue by requiring the employer to certify that equipment has successfully passed the periodic testing required by the final rule and by requiring this certification to identify the equipment that passed the test and the date it was tested. Moreover, although requiring the employer to note the date equipment is tested does enhance worker protection, this issue is addressed by this requirement.

OSHA concurs with Mr. Brockman that improving worker protection would result from keeping employees informed of the date of the most recent testing. OSHA changed the wording in the last paragraph to include the requirement that workers or their authorized representatives be given access to the certification required by the rule.

According to the paragraph, all marks must be nonconductive and applied so as not to affect the equipment's insulating qualities. This proposal's provision was left alone in the final rule since OSHA did not receive any feedback on it. This criterion makes sure that no markings obstruct the equipment's ability to offer protection.OSHA said in the preamble to the proposed rule that marks in other locations might potentially wear out, which is why paragraph, which is being approved without modification from the proposal, requires markings on gloves to be limited to the cuff region. Furthermore, the employee will be able to quickly identify the class and type of glove thanks to the markings being in one location. The last sentence of the preamble stipulates that rubber gloves should typically be worn underneath protector gloves. This is discussed further in the preamble. The cuff of the protector glove can be easily pulled back without being removed, making markings on the rubber glove's cuff beneath visible. A protector glove is almost always shorter than the corresponding rubber glove with which it is worn. With the protector glove on, any markings provided on the rubber glove that were outside of the cuff were invisible.

The region next to the glove's reinforced edge is known as the cuff area.Electrical specifications for rubber insulating blankets, mats, line hose, gloves, and sleeves are included in final 1926.97 paragraph. As was previously mentioned, this provision employs performance language and does not go into great detail about particular test methods.

Electrical protective equipment must be able to withstand the ac proof-test voltages in E-1 or the dc proof-test voltages in E-2 of the standard, according to paragraph, which is being carried over from the proposed rule. The proof-test voltages listed in these s were derived from the current ASTM standards, which also contain comprehensive test procedures that can be used to determine whether electrical protective equipment is able to withstand these volta ges. As was previously said, these specifics were not included in the proposed rule, and the final regulation continues to take same stance. By substituting a performance-based requirement that any proof test be utilized as long as it consistently shows that the equipment can resist the associated proof-test voltage, the paragraph eliminates those specifics.

REFEERENCES

[1] A. Efendi en Y. S. Nugroho, "Has the electrical laboratory of subang state polytechnic applied occupational safety and health? Evaluation report in 2019", *Automot. Exp.*, 2019, doi: 10.31603/ae.v2i2.2697.

[2] J. E. P. Nascimento, F. R. Pinto, D. B. de Alencar, en G. de F. Lopes, "Electrical Surge Protection Device (SPD): An Alternative to Reduce Material Loss", *Int. J. Innov. Educ. Res.*, 2019, doi: 10.31686/ijier.vol7.iss11.1897.

[3] H. León, C. Montez, O. Valle, en F. Vasques, "Real-time analysis of time-critical messages in IEC 61850 electrical substation communication systems", *Energies*, 2019, doi: 10.3390/en12122272.

[4] J. Ladislau Batista, L. Da Silva Oliveira, D. Barbosa de Alencar, en R. Silva Parente, "Accident Prevention in Electrical Installations at Construction Sites in Manaus - Amazonas", *Int. J. Innov. Educ. Res.*, 2019, doi: 10.31686/ijier.vol7.iss10.1808.

[5] R. Khajjayam en S. Bhatt, "Comparative analysis of arc flash solutions - A case study", 2019. doi: 10.33313/377/311.

[6] P. Meng, Y. Zhou, J. Wu, J. Hu, en J. He, "Surge Arrester with High Performance Metal Oxide Varistors for Deeply Suppressing Overvoltage in AC UHV Systems", 2019. doi: 10.1109/ICHVE.2018.8641983.

[7] J. S. *et al.*, "Assessment of Short Circuit Power and Protection Systems for Future Low Inertia Power Systems.", *Int. Conf. Innov. Electr. Electron. Power, Smart Grids Adv. Comput. Technol.*, 2019.

[8] J. Bacotang, "Pembangunan dan kebolehgunaan indikator kemahiran literasi awal kanak-kanak", *Tesis Phd*, 2019.

[9] H. Novita, M. F. Sinambela, M. U. Pangaribuan, en L. S. Siahaan, "Pengaruh Struktur Audit, Profesionalisme dan Penerapan Teknologi Informasi Terhadap Kinerja Auditor Pada Kantor Akuntan Publik di Medan", *Akuntansi*, 2019.

CHAPTER 13

RUBBER INSULTING GLOBE FOR SAFETY

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As opposed to the 267-millimeter glove specified in E-1 in the proposed rule, Mr. Muckerheide of Safety Consulting Services said that the standard for rubber insulating gloves, ASTM D120, provides a 280-millimeter glove. He suggested that gloves should be able to pass both tests.The 60-hertz ac proof-test current may not, at any point during the test period, exceed the values stated in E-1, according to paragraph, which is being approved as suggested. From ASTM D120-09, the currents given in were taken. This clause in the final rule is crucial because, when gloves are subjected to an ac proof test, the proof-test current that results provides evidence of the reliability of the gloves' composition, the kind of material's dielectric constant, its thickness, and the whole region under test[1], [2].

The maximum current for ac voltages at frequencies other than 60 hertz is calculated from the direct ratio of the frequencies under paragraph, which is being approved without modification from the proposal. This clause guarantees that the maximum current is the same across all frequencies.According to paragraph, which is being approved as suggested, gloves to be tested must be filled with water, submerged to the depth specified in E-3, and water must be added to or subtracted from the glove as needed to maintain an even water level inside and outside. The ASTM D120-derived E-3 is appropriate for the proof-test currents indicated in E-1. A glove is filled with water and submerged during the ac proof test, and the water on the inside and outside of the glove acts as electrodes. The length of the glove's part that is above water determines the ac proof-test current. It is crucial to include the depth in the rule since the proof-test current depends on the depth of the immersion[3], [4].

During the 16-hour water soak stipulated in paragraph, the 60-hertz proof-test current must not be more than 2 milliamperes higher than the values listed in E-1. During a 16-hour water soak, gloves must have a higher permissible proof-test current because they absorb more water. The test findings might be invalidated by atmospheric conditions at the clearances listed in E-3. For instance, the air between the water within and outside of the glove, which creates the two electrodes, might flash over under certain climatic circumstances, invalidating the test findings and harming the glove. Another example is the production of excessive corona and ozone due to atmospheric conditions that ventilation is unable to effectively remove. In order to take these atmospheric conditions into account, final E-3 contains a note that states that, in the event that these clearances become impractical due to atmospheric conditions, the clearances may be increased by a maximum of 25 mm. This small amount of water causes a slight increase in current during the test. The final regulation was taken from ASTM D120, which permits a 2 milliampere increase in the proof-test current. The gloves may have absorbed too much water if the proof-test current rises by more than 2 milliamperes. To make it clearer that this clause is a requirement rather than an exemption, OSHA changed it in the final rule[5]–[7].

The proposed rule's paragraph restricts the use of electrical protective equipment that has passed a minimum breakdown voltage test to shield workers from electrical risks, and it is implemented without amendment. The insulating material being tested may get damaged by the relatively high voltages needed to test electrical protection devices for minimal breakdown voltage. Since minimum breakdown tests are harmful, the purpose of this regulation is to prohibit the use of equipment that has undergone minimum breakdown voltage testing under circumstances comparable to those in the ASTM standards. These tests are only carried out on samples of equipment that will be thrown away[8]–[10].

Ozone-resistant materials must be able to endure an ozone test that may reliably indicate that the material will resist ozone exposure in real usage, according to paragraph, which is being implemented as proposed. Standardized ozone testing are described in the ASTM standards indicated in the note that comes after the note in the previous paragraph, and adherence to these requirements will be taken as adherence to this OSHA requirement. A bright discharge known as an electric corona may develop around high-voltage cables and equipment as a result of the surrounding air being ionized by a voltage gradient that is greater than a certain critical value. Ozone and a hissing sound are also present during the blue corona discharge, and both of these elements have the potential to harm certain rubber-based insulating materials. Hence, electrical protection equipment composed of ozone-resistant material is routinely employed at work locations where there is a potential that ozone might be created. The final regulation guarantees that materials labeled as being ozone-resistant will really be able to withstand the impacts of the gas without degrading. The final regulation also states that obvious ozone degradation indicators such checking, cracking, fractures, and pitting are proof that a material does not adhere to the standards for ozone-resistant material.

The craftsmanship and polish of electrical protection devices are discussed in the paragraph. This paragraph forbids the presence of physical irregularities that can negatively affect the insulating properties of the equipment and that can be discovered by the tests or inspections required under other provisions in 1926.97. This is because physical irregularities can interfere with the insulating properties of the equipment and reduce the protection it provides. To make it clear that "harmful physical abnormalities" refers to physical flaws that potentially negatively impact the insulating qualities of the equipment, OSHA updated the wording for this section in the final rule.

OSHA acknowledges that a few small flaws are almost always present throughout the production of rubber items, and that these flaws may also exist in the insulating materials without materially impacting the insulation. The proposal is approved with no changes to paragraph, which lists the different kinds of flaws."Ozone cutting and checking" is defined by ASTM F819-10, Standard Terminology Pertaining to Electrical Protective Equipment for Workers as "cracks created by ozone in a material under mechanical stress that are authorized." Electrical protective equipment must be able to pass the electrical tests listed in paragraph even with these flaws.

OSHA has included a comment at the end of paragraph 1926.97 that states rubber insulating equipment meeting the criteria of the above ASTM standards will be considered in accordance with the performance requirements of final 1926.97 since the paragraph is written in performance-oriented language. The most recent iterations of each document are included in this list of ASTM standards. The Agency has examined the cited ASTM standards and determined that they provide sufficient direction for compliance with the performance requirements of 1926.97. 24

A paragraph. Apart than the rubber insulating equipment mentioned in paragraph, electrical protective equipment is included in final 1926.97 paragraph.This category of equipment includes plastic guards, insulating barriers, and other safety gear designed to protect workers from electrical hazards.

In order to comply with the final rule, Mr. Steven Theis of MYR Group asked that OSHA make it clear that equipment meeting the ASTM and IEEE consensus standards stated in the proposal would be considered compliant. OSHA cited ASTM F712 in the proposal. After a study by OSHA, it was determined that ASTM F712-06 provide enough guidelines for plastic protection devices that employers may utilize to comply with the final 1926.97. OSHA has added a new section to the rule to make it clearer. For more information on how to handle previous iterations of the stated consensus standards as well as future updates, see the expanded discussion above in this part of the preamble. Note added to the paragraph to clarify that if the plastic guard equipment complies with ASTM F712-06 and is utilized as directed, OSHA will consider it to fulfill the performance standards of the paragraph.

The Agency also cited IEEE Std 516, Guidance for Maintenance Techniques for Energized Power Lines, in the proposal as evidence in support of the electrical requirements. This consensus standard is not mentioned by the Agency in the final rule. Electrical protective equipment is not subject to any requirements or testing under the IEEE standard. Instead, the consensus standard includes guidelines for live-line work, as well as standards for assessing insulating tools and machinery. The Agency observes that the design standards for electrical protective equipment stated in the final rule are identical to the criteria for assessing insulating tools and equipment given in the IEEE standard.

Electrical protective equipment must be able to resist any voltage that may be placed on it, according to paragraph, which is being implemented without making any material changes to the proposed regulation. Transient overvoltages as well as the nominal voltage that is present on an energized portion of an electric circuit are included in the voltage that the equipment must be able to bear. If the equipment retains its integrity without flashover or arc through, it can sustain a voltage.

If a national consensus standard for that kind of equipment specifies proof testing criteria for the voltage in question, then equipment that complies with that standard will often be regarded as meeting this criterion. For equipment types not covered by any consensus standards, OSHA contemplated adopting electrical protective equipment that might pass a test similar to that outlined in ASTM F712 or IEEE Std 516. The question of whether these requirements include appropriate test procedures and whether equipment that passes those tests should be accepted under the OSHA standard was put out to comment.

The conventional test procedure outlined in the ASTM standards for figuring out the minimal breakdown voltage necessitates testing at voltages that are far greater than those the equipment would be utilized on. In addition, unlike impulse testing, which applies the overvoltage for a relatively little amount of time, minimum breakdown voltage testing is carried out using a constantly increasing ac voltage. The current standards for insulating tools and equipment, as indicated in IEEE Std 516-2009, do not address whether equipment that passes the ac withstand voltage testing in those standards would also resist transient voltage shocks. To convert ac withstand voltages to impulse, or transient, voltages, the IEEE standard advises using a 1.3 ratio. OSHA has concluded that, in the absence of better information, employers may rely on this ratio and multiply the ac minimum breakdown voltage for protective equipment by this value to ascertain whether that equipment can withstand the anticipated transient overvoltages on energized circuits. The IEEE standard acknowledges that research in this area is ongoing. Insulating equipment, for instance, can endure a maximum transient overvoltage of 26,000 volts with a minimum breakdown, or withstand, voltage of 20,000 volts. Employee phase-to-ground exposures on a circuit running at 15 kilovolts, phase-to-phase, with a maximum transient overvoltage of 3.0 per unit would be protected by this device. This equipment's maximum impulse voltage is 20 kilovolts multiplied by 1.3 to get 26 kilovolts. The equipment's maximum phase-to-ground usage voltage is 26 kilovolts.

The proposed regulation solicited feedback on the need of establishing precise electrical performance values in the standard as well as whether the electrical test requirements in ASTM should be divided by the maximum transient overvoltage in kilovolts, or 8.7 kilovolts. For this exposure, the phase-to-phase circuit voltage is multiplied by 8.7 kilovolts to get 15 kilovolts.The term "overvoltage," for which "transient overvoltage" is a synonym, is defined as follows.

All varieties of electrical protection equipment described by the proposed paragraph might use the F96827) standard. IBEW stated that the test values and use values in ASTM F968 are suitable for electrically insulating plastic guard equipment but that they are not suitable for other types of equipment because plastic guard equipment is made to function differently than other kinds of electrical protective equipment. OSHA decided not to include the figures from IV-1 and IV-2 in the final rule based on the IBEW's opinion. Also, because the final regulation is expressed in terms of performance, it is not required to provide values similar to those found in these s.

The characteristics of insulating equipment that reduce the amount of current to which an employee is exposed are discussed in the last paragraph. The proposal's paragraph requires electrical protective equipment used as the principal barrier separating workers from electrified items to be able to withstand a test for current at the maximum nominal voltage under which it is intended to be used. This paragraph is being approved without change. The suggested paragraph states that during the test, the equipment current may not exceed 1 microampere per kilovolt of applied phase-to-phase voltage. This guideline forbids the use of both inadequate insulating materials, so protecting workers from severe electric shock. 27 The proposal mentioned two ASTM standards that dealt with plastic guard equipment: F968 which included specifications and F712, which featured test procedures. Since then, ASTM has merged these two standards into one, F712-06, which includes both test procedures and requirements for plastic protection devices. Contamination of conductive chemicals in materials and excellent insulating materials. OSHA considers the present level, which was established from IEEE Std 516, to be fair and suitable.

The Agency requested feedback on whether another value would better safeguard workers in the preamble to the proposed rule. The following is the IBEW's response to this:

For testing equipment used for main employee isolation from electrified elements, the IEEE Standard 516 restriction of 1 microampere per kilovolt of phase-to-phase applied voltage is acceptable. It seems that this restriction has been effective in keeping subpar protective equipment off the market.One commenter expressed worry that the proposed current limit would not provide enough protection for workers in the event of a malfunction. OSHA thinks that this worry is unwarranted. During a failure, a circuit's voltage normally drops, which would cause the equipment current to drop as well. While transient overvoltages are conceivable, whether during a failure on a neighboring phase or during switching operations, they are relatively brief in duration, and the potential increase in equipment current that results should not endanger workers' lives.

The ASTM F712 standard for plastic guard equipment is the only one of its standards that specifies a 1-microampere per kilovolt requirement, according to ASTM. The group suggested that OSHA restrict this clause to this kind of machinery.The ASTM proposal is not being adopted by OSHA. The Agency points out that ASTM F712 is not the only ASTM standard that restricts the amount of equipment current to values below 1 microampere per kilovolt of test voltage. Maximum current during the dielectric testing required by ASTM F711, Standard Specification for Fiberglass-Reinforced Plastic Rod and Tube Used in Live Line Tools, is restricted to values much lower than 1 microampere per kilovolt of test voltage. 28 Also, as was already said, this restriction was determined from IEEE Std 516. OSHA deduces that the 1-microampere limit is fair and fitting in this manner. Note 1 to paragraph underlines that this paragraph pertains to equipment that provides main insulation from electrified elements, which is consistent with the plain wording of paragraph and is being accepted without material modification from the draft. The addendum also makes it clear that the paragraph does not apply to equipment utilized for brush contact alone or for secondary insulation.

For live-line barehand work, main insulation is defined by OSHA as the insulation that is positioned between an employee and the ground or directly between an employee and an electrified item. Secondary insulation is insulation that adds to the main insulation, such as an additional layer of insulation put between the worker and the ground.In accordance with Note 2 to Paragraph, which is being approved without modification from the proposal, when equipment is tested using an Ac voltage, the test current is made up of three components: The 28 2 in ASTM F711-02 establishes the maximum leakage current for several kinds of rod and tube used in live-line tools by capacitive current. This has a maximum value of 14 microamperes. The greatest accep leakage current is 28 microamperes according to a note on the, which states that for particular applications, the maximum accep leakage current is double the value given in the. This test is conducted using a 50 kilovolt voltage. A microampere per kilovolt maximum current is thus smaller than this value. 29 It should be noted that rubber insulating equipment, which is covered by paragraph, is exempt from the equipment current requirement in paragraph.

OSHA anticipates that the manufacturer will typically carry out the testing required under concluding paragraphs and at regular intervals during the production process. The Agency is aware that certain employers may desire to utilize equipment composed of insulating materials even if the manufacturer did not intend for it to be used as insulation. A barrier constructed of stiff plastic, for instance, may be used as a multipurpose barrier. The barrier described in paragraphs and may be put to the test by an employer, and if it passes, it would be approved for use as insulating electrical protective equipment.

A paragraph. While the care and use of insulating equipment is not included by current building standards, OSHA thinks that such requirements may significantly improve worker safety. Large portions of electrical protection equipment are produced in compliance with the most recent ASTM specifications. Even in the absence of OSHA regulations, this would presumably still be the situation. The level of protection provided by this technology, however, May readily be diminished or even eliminated by inappropriate usage and maintenance. As a result, OSHA suggested expanding the current design criteria included in existing 1926.951 to include additional requirements for the maintenance and usage of electrical protection equipment while in use. The adoption of these additional clauses into the final regulation will assist to guarantee that these safety goods continue to have their insulating qualities.

The proposal's paragraph, which mandates that electrical protection equipment be kept in a safe and dependable state, is being implemented without amendment. This broad, performance-based criterion, which is applicable to all of the equipment covered by final

1926.97, aids in ensuring that workers are completely safe from electric shock.The following ASTM standards include precise guidelines for the use and maintenance of several categories of electrical protection equipment:

The standard specification for in-service maintenance of insulating line hose and covers is ASTM F478-09. Standard Specification for In-Service Care of Insulating Blankets: ASTM F479-06.

The standard specification for in-service maintenance of insulating gloves and sleeves is ASTM F496-08.

These criteria serve as the foundation for the requirements in the last paragraph. Only rubber insulating blankets, covers, line hose, gloves, and sleeves are covered by the paragraph. The usage and maintenance of various kinds of electrical protection devices are not covered by any consensus standards. Although 1926.97 addresses the material design requirements for rubber insulating matting, neither 1910.137 nor any other ASTM standard address the in-service maintenance of this matting. This kind of device is often placed permanently to provide additional protection against electric shock. Workers stand on the matting, which insulates them from the floor, one of the surfaces of the work area. Phase-to-ground electric shock is somewhat mitigated by this. This sort of equipment does not need to be tested on a regular basis and does not need the same rigorous examination before use as other insulating equipment requires since it is often kept in place after installation and is not depended upon for main protection against electric shock. Nevertheless, it should be emphasized that paragraph still requires rubber insulating matting to be kept in a trustworthy, safe state.

By limiting the use of insulating equipment to voltages lower than the proof-test voltages listed in E-1 and E-2, OSHA is adopting the margins of safety recognized in the ASTM standards in final paragraph and E-4, which are being implemented without material modification from the proposal. The voltages at which the rubber insulating equipment mentioned in 1926.97 should be used are lower than the voltages that the equipment is intended to bear. The maximum usage voltage for Class 4 equipment is 36 kilovolts, despite the fact that it is presently intended to resist voltages of up to 40 kilovolts. Employee safety is increased by using insulating devices at voltages lower than the actual breakdown voltage.

The final regulation has been modified to change the maximum use voltage for class 3 equipment in E-4 to 26,500. The maximum usage voltage suggested by OSHA for this kind of equipment is 26,000 volts. OSHA intended for this cell in the proposed to read 26,500, just as it does in I-5 in the current 1910.137 and in the relevant consensus standards, however a printing mistake led to the incorrect value being inserted in the.

The maximum use voltage of electrical protective equipment changes depending on whether multiphase exposure is present, as noted in the proposed rule's Note 1 to E-4. Electrical safety equipment must generally be rated for the whole phase-to-phase voltage of the lines or equipment being worked on. By requiring it, employers guarantee that workers are shielded from the riskiest exposure scenario—contact between conductors of different phases. The electrical safety equipment, however, may be chosen based on this lower voltage level if the employee is only exposed to phase-to-ground voltage. A three-phase, securely grounded, Y-connected overhead distribution system, for instance, might be operated as three single-phase circuits, each with one phase conductor and a neutral, or as three single-phase conductor and neutral circuits. There is no multiphase exposure if a pole has only one phase conductor. If there are three phase conductors, the multiphase exposure may be eliminated by isolating or insulating two of the phases. 30 There is no multiphase exposure after the insulation is installed or while the worker is separated from the other two phase lines, therefore electrical protective equipment suitable for the phase-to-ground voltage might be employed.

To guarantee the safe use of electrical protective equipment, the Agency sought information regarding whether workers can be shielded from multiphase exposure. The note to suggested E-4 was widely supported by the commenters.

By approaching one of the outer phase conductors and working on it from a position where there is no chance of reaching too near to the other two phase conductors, an employee may potentially be separated from two of the phases on the pole depending on how the system is set up. With particular line combinations, it can be hard to isolate the employee. It should be remembered that the phase-to-phase voltage continues to be the maximum usage voltage until the multiphase exposure has truly been eliminated. Hence, the phase-to-phase voltage on the system must be more than or equal to the maximum usage voltage of any insulation used to "eliminate phase-to-phase exposure."

The IBEW cautioned that in order to ensure that a worker is isolated from contact with an energized circuit, the isolating device must both physically prevent the worker from making contact and maintain the electrical integrity of the energized circuit. The IBEW did not expressly object to the language in the note to proposed E-4. The isolating device doesn't have to be permanent, but it should be strong enough to guarantee isolation in the event of a slip, fall, or other inadvertent movements.The union said that "the equipment's insulating value would have to be rated at the phase-to-phase voltage of the circuit being serviced."

Nevertheless, one commentator opposed to the preamble clauses that allowed for the use of phase-to-ground rated insulation, claiming that "industry practice has traditionally been to utilize protective equipment rated for the phase-to-phase rms voltage."OSHA has incorporated the remark from the proposed E-4 into the final rule without making any significant changes after taking into account the rulemaking record on this subject. The suggested letter received mostly positive feedback. The note is also the same as Note 1 to I-5 of the current 1910.137. The workers are properly protected against electric shock from the remaining phase-to-ground exposure by employing phase-to-ground rated electrical safety equipment, as noted by the commentators, after multiphase exposure has been eliminated by isolating or insulating the employee. The statement that industry practice is to employ phase-to-phase rated electrical protection equipment is contradicted by how well the notice was supported. OSHA underlines that any insulation utilized to reduce multiphase exposure must effectively shield employees doing their activities from elements that might defeat the insulation's objective in order to allay the IBEW's worries. Worker actions including reaching for tools, altering clothes or personal protective equipment, and slips and falls are a few of these causes. Last but not least, OSHA concurs with IBEW that insulation used to shield workers from phase-to-phase exposure has to be graded for the exposure. Phase-to-phase exposure exists up until this protective equipment is fitted, after all.

Insulating equipment must be visually examined before operation every day and right after following any occurrence that may reasonably be suspected of causing harm, according to paragraph, which is being accepted largely as intended. This allows for the early detection of faults that are obviously wrong. Exposure to corona and direct physical harm are examples of situations that might cause damage. In addition to the visual examination, rubber gloves must undergo an air test. This test is often performed in the field by rolling the cuff toward the palm, which traps air within the glove. A mechanical inflater is generally utilized in a testing facility. Cuts and punctures are clearly visible in both scenarios. According to the comment that follows, ASTM F1236-96, Standard Guide for Visual Inspection of Electrical Protective

Rubber Products, includes instructions on how to evaluate rubber insulating equipment as well as descriptions and images of probable flaws in the equipment.

During operation, electrical protective equipment may sustain damage and lose part of its insulating effectiveness. The proposal's last paragraph specifies several sorts of damage, such as a hole, rip, puncture, or cut, as well as an implanted foreign object, that might reduce the insulating value of rubber insulating equipment. Any of the flaws described here or in paragraph, or any other flaw that compromises the equipment's insulating abilities, must be present before it may be utilized.

Further flaws beyond those mentioned in the previous sentence might appear when the equipment is being used and could have an impact on its mechanical or insulating capabilities. If such flaws are discovered, the equipment must be taken out of operation and tested in line with other criteria in paragraph, which is being implemented without modification from the proposal. If the testing show that it is safe to put the things back in use that will be decided.Foreign materials on the surface of rubber insulation equipment may cause the material to deteriorate and result in insulation damage. The suggested paragraph, which is being accepted, specifies that the equipment must be cleaned as required to get rid of any foreign objects.

Rubber insulating equipment might deteriorate over time due to certain environmental factors. The proposal's last paragraph, which requires insulating equipment to be kept in a way that protects it from harmful elements and circumstances including light, very high or low temperatures, high humidity, and ozone, is being implemented without material modification. This criterion aids in the equipment's ability to maintain its insulating qualities over time. To make it apparent that the equipment must be safeguarded against compounds and circumstances that can harm it rather than substances and conditions that might hurt employees, OSHA has substituted the proposed phrase "injurious substances and conditions" with "damaging substances and conditions."

Regarding this criterion, the Agency does not think it is safe to keep equipment on trucks for long stretches of time when it would be exposed to extremes of humidity or temperature. In some situations, it could be essential to keep equipment inside for extended periods of time while no one is utilizing it. Electrical protection equipment is required for the safety of workers, thus every conceivable precaution must be taken to prevent unneeded harm.Insulating gloves made of rubber are especially susceptible to physical harm while in use.

An employee may ruin the gloves and lose the protection they provide by handling wires and other electrical equipment. For instance, the rubber might be pierced by a conductor's sharp tip. Over the rubber gloves, protection gloves are worn to prevent harm. The paragraph acknowledges the added protection provided by leather gloves and calls for their usage instead of rubber gloves, unless specifically stated otherwise.The proposed sentence said that in limited-use circumstances, or where extremely high finger dexterity is required for handling small equipment and components, protective gloves are not required with Class 0 or Class 00 gloves. This exception is required in order to do maintenance on tiny electrified components. The proposed provision is being adopted by the Agency with one change. The maximum voltage on which Class 0 and Class 00 gloves may be used is 1,000 volts and 500 volts, respectively, according to paragraph and E-4, which are being implemented without material modification from the proposal. The usage of Class 00 rubber insulating gloves is limited to voltages of 250 volts, ac, or less when they are worn without protectors, as noted by Mr. James A Thomas, President of ASTM International. A maximum dc voltage is also specified in the consensus standard for Class 00 gloves worn without protection.

REFERENCES

[1] X. Men, F. Wang, G. Q. Chen, H. B. Zhang, en M. Xian, "Biosynthesis of natural rubber: Current state and perspectives", *International Journal of Molecular Sciences*. 2019. doi: 10.3390/ijms20010050.

[2] S. Bressi, N. Fiorentini, J. Huang, en M. Losa, "Crumb rubber modifier in road asphalt pavements: State of the art and statistics", *Coatings*. 2019. doi: 10.3390/COATINGS9060384.

[3] S. Cherian, S. B. Ryu, en K. Cornish, "Natural rubber biosynthesis in plants, the rubber transferase complex, and metabolic engineering progress and prospects", *Plant Biotechnology Journal*. 2019. doi: 10.1111/pbi.13181.

[4] D. Jendrossek en J. Birke, "Rubber oxygenases", *Applied Microbiology and Biotechnology*. 2019. doi: 10.1007/s00253-018-9453-z.

[5] S. H. Stonebloom en H. V. Scheller, "Transcriptome analysis of rubber biosynthesis in guayule (Parthenium argentatum gray)", *BMC Plant Biol.*, 2019, doi: 10.1186/s12870-019-1669-2.

[6] K. Strukar, T. Kalman Šipoš, I. Miličević, en R. Bušić, "Potential use of rubber as aggregate in structural reinforced concrete element – A review", *Engineering Structures*. 2019. doi: 10.1016/j.engstruct.2019.03.031.

[7] C. Y. Chen en M. T. Lee, "Application of crumb rubber in cement-matrix composite", *Materials (Basel).*, 2019, doi: 10.3390/ma12030529.

[8] S. Bhadra, N. Mohan, G. Parikh, en S. Nair, "Possibility of artocarpus heterophyllus latex as an alternative source for natural rubber", *Polym. Test.*, 2019, doi: 10.1016/j.polymertesting.2019.106066.

[9] M. Hidajat *et al.*, "Lifetime exposure to rubber dusts, fumes and N-nitrosamines and cancer mortality in a cohort of British rubber workers with 49 years follow-up", *Occup. Environ. Med.*, 2019, doi: 10.1136/oemed-2018-105181.

[10] W. Dong, W. Li, L. Shen, en D. Sheng, "Piezoresistive behaviours of carbon black cement-based sensors with layer-distributed conductive rubber fibres", *Mater. Des.*, 2019, doi: 10.1016/j.matdes.2019.108012.

CHAPTER 14

SPECIFICATION FOR IN-SERVICE CARE OF INSULATING GLOVES AND SLEEVES

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Protective gloves may not be used with Class 0 gloves in some situations, such as while handling tiny objects that call for very excellent finger dexterity. Class 00 gloves may be worn without protectors in the same circumstances, but only at voltages up to and including 250 V a-c or 375 V d-c. The use of other classes of gloves without protection gloves is only permitted in situations where it is unlikely that the gloves would sustain bodily harm and only when the voltage class of the employed gloves is one class higher than the voltage exposure.After being used without protectors, rubber insulating gloves must wait until they have undergone an inspection and an electrical retest before being used with protectors[1], [2].

The Agency draws the conclusion that employing Class 00 gloves without protectors on voltages exceeding 250 volts, ac, or 375 volts, DC, is deemed to be harmful by the experts on the consensus standards committee based on section 8.7.4 of ASTM F496-02a.32 As these two voltage limits apply to the use of Class 00 gloves without protectors, OSHA has included a new paragraph to the final rule that addresses their usage. As a result, OSHA renumbered proposed paragraphs and as paragraphs and is accepting them without making any significant changes[3], [4].

As previously said, there is a chance that a sharp item might pierce the rubber if protection gloves are not used. Because of the potential for leakage or current arcing through the hole to the employee's hand and exposing them to electric shock, the resultant hole might jeopardize workers handling live components. An employee is protected against electric shock as long as the live component itself does not pierce the rubber and come into contact with the employee's hand when the voltage is 250 volts, ac, or less; 375 volts, dc, or less; or 1,000 volts, or less, for Class 00 gloves. The risk still remains even though small items used in activities covered by the exemption, including tiny nuts and washers, are unlikely to cause this. Therefore, OSHA is adopting a note to the final paragraph that states that people inspecting rubber insulating gloves used under these conditions need to take extra care to visually examine them and that employees using the gloves under these conditions need to take extra care to avoid handling sharp objects. This note is being adopted without any substantive changes from the proposal[5], [6].

If the employer can show that the risk of bodily harm to the glove is low and gloves at least one class higher than necessary for the voltage are employed, classes of rubber insulating gloves other than Class 0 and Class 00 may be used without protection gloves under the. Protective gloves are not required, for instance, if a Class 2 glove is used at 7,500 volts or less and the employer can show that the risk of injury is minimal. By mandating thicker insulation as an additional measure of physical protection that will better resist puncture during use, the final rule considerably lowers the risk to the employee and guarantees that damage is unlikely within the restrictions provided by the exception. 33 Moreover, the consensus standard allows for the use of these kinds of rubber insulating gloves without guards under the same circumstances. This exemption does not apply where there is a high risk of injury, such as when a worker must handle moving items like conductors being dragged into position or when he or she must use a knife to remove insulation from a conductor.

At each level of rubber insulating glove, the thickness of the rubber rises.Without providing any justification, Mr. Brockman of Farmers Rural Electric Cooperative Company advised that there be no exemption allowing the use of rubber insulating gloves above Class 0 without protection.

This suggestion is rejected by the Agency. Under the restrictions set out in the last paragraph, OSHA has stated that it is safe to wear Class 1 and higher rubber insulating gloves without protection. OSHA does point out that there is a significant risk of bodily harm to rubber insulating gloves used without protection during the electric power production, transmission, and distribution operations covered by 1910.269 and subpart V almost constantly. So, when rubber insulating gloves are worn for that kind of task, the exception mentioned in the previous sentence won't happen very often. Nevertheless, the usage of electrical protective equipment specified by 1926.97 extends beyond the production, transmission, and distribution of electric power. In these other fields of employment, such as product manufacture or testing labs, the risk of injury is sporadic but possible.

No rubber insulating gloves used without protection gloves may be used again until they have been tested in accordance with paragraphs and, which address the necessary test voltages and the suitability of the test technique, respectively. This is done to guarantee that no insulation loss has occurred. It should be emphasized that regardless of whether the glove is Class 0 or 00, as allowed in paragraphs and, or is Class 1 or above, as allowed in paragraph, this testing is necessary.

Testing rubber insulating gloves after usage without protection was opposed by the National Electrical Contractors Association and numerous other NECAs. They claimed that the increased testing frequency would be burdensome for companies and that there was no safety advantage. For instance, according to NECA, the prologue contains no information on electrical accidents caused by insulated gloves that were worn without leather covers. As a result, mandating that insulating gloves be retested after each usage without a protector burdens the business without providing any extra protection for workers. Because of the need for manual dexterity while wearing gloves in Classes 1 through 4, protectors often need to be taken off, but since the components being worked on are rather big, the risk of injury is low. Damaged gloves may be found using the inspection and air-testing methods already in use[7]–[9].

Mr. Tom Chappell of the Southern Company was another respondent who made the case for an expedited testing schedule as an alternative to testing each time a rubber insulating glove is worn without a protection.These concerns are rejected by OSHA. First off, the consensus standard includes this provision, indicating that the majority of expert opinion thinks it adds an extra layer of protection for workers. Second, a voltage test may be able to find tiny damage that a visual check and air test may miss. Even Mr. Chappell is of the opinion that more testing is necessary to support the visual examination. Finally, expedited testing would make it possible for such damage to go unnoticed until the subsequent test, which, according to Mr. Chappell's suggested testing timetable, could take up to 89 days. Fourth, OSHA thinks that testing rubber insulating gloves used without protection would severely discourage any unnecessary use of the gloves without guards since testing gloves shortens their useful life and is expensive. Lastly, because employers are already obligated to do the majority of the testing called for under the final rule, any new burden on them will be minimal. Moreover, current 1910.137 already mandates that gloves worn without protection be tested before being utilized at a higher voltage. 34 As a result, OSHA included the proposed paragraph unchanged into the final rule.

Insulating equipment must be tested frequently at the test voltages and testing intervals defined in E-4 and E-5, respectively, according to paragraph, which is being approved as suggested. These tests will confirm if the insulating qualities of electrical protective gear hold true over time. The retest voltages for the various classes of protective equipment are listed in E-4, and E-5 includes the testing intervals for the various equipment types. These test voltages and times were calculated based on the applicable ASTM standards.

Rubber insulating line pipe was not intended to be included in planned E-4 and E-5, according to Mr. Thomas Frank of Ameren Corporation. He stated that there is no specified test procedure for this equipment in the relevant consensus standard.This protest is rejected by OSHA. Contrary to Mr. Frank's claim, test procedures for rubber insulating line hose are included in ASTM D1050, Standard Specification for Rubber Insulating Line Hose. Line hose testing is only necessary when 35 E-5, which defines test intervals for rubber insulating equipment, is used. The current 1910.137 merely mandates that gloves be examined before being used at higher voltages. The proposed change to this requirement is adopted in the final rule, requiring that rubber insulating gloves worn without protection be tested before being used again. Reuse is defined in 1926.97 and 1910.137 as any use that follows the restricted use that is allowed without protective gloves[10], [11].

The performance-oriented condition in paragraph (which is being approved without modification from the proposal) is that the testing procedures used to determine whether the electrical protective equipment can withstand the voltages involved must be reliable. OSHA does not provide specific instructions for the necessary testing since this is a performance-oriented regulation; the needed tests will, of course, vary based on the kind of equipment being evaluated.The electrical test procedures in the different mentioned ASTM standards for rubber-insulating equipment are noted to be judged to fulfill the performance criteria in the sentence that follows. This comment does not imply that OSHA is adopting the referenced ASTM standards by reference, as was previously stated. Any test technique that satisfies the OSHA standard's performance requirements shall be accepted by the Agency for the purposes of enforcing 1926.97.

Be sure that any failed equipment is not put back into service after it has completed in-service inspections and testing. The proposal's last sentence, which is being accepted unchanged, forbids the use of electrical protection equipment that failed the necessary inspections and testing. Yet, the paragraph lists the following effective ways to fix flaws and make the equipment usable once again.

The final standard allows for the removal of damaged rubber line hose and blanket sections in specified circumstances. Smaller blankets or shorter line hoses would be the outcome. According to the standard, Class 1, 2, 3, and 4 rubber insulating blankets may only be saved by cutting away the damaged areas if the remaining area is at least 560 mm by 560 mm in size. Smaller sizes for these classes cannot be examined in a reliable manner using conventional test techniques. OSHA believes that employers will be forced to similarly limit the size of these blankets when they have been repaired by cutting out a damaged portion due to practical considerations in testing and using Class 0 blankets, despite the fact that the standard does not specify a size restriction for Class 0 blankets.

While the final standard allows patching of rubber insulating gloves and sleeves if the flaws are minimal, it is obvious that gloves and sleeves cannot be mended by removing a problematic section. In certain cases, patches may even be sewn onto blankets.

Moreover, small surface imperfections on rubber insulating gloves and sleeves may be fixed using an appropriate liquid solution. The mended region must always match the material being fixed's electrical and physical characteristics.

Since the standard calls for the use of appropriate patches or liquid compounds and stipulates that the repaired area have the same electrical and physical characteristics as the surrounding material, repairs carried out in conformity with the standard are unlikely to fail. Repairs to rubber insulating gloves outside the gauntlet area are not permitted, nevertheless, to reduce the likelihood that they may fail. OSHA emphasizes that the final rule forbids repairs in the glove's working area because repeated bending of the rubber during use may cause an improperly-formed patch to come away. Injury would probably occur very soon if a patch or liquid compound in this location of the glove failed. Conversely, the gauntlet portion of rubber insulating gloves seldom comes into touch with electrically charged components. There is a significantly lower chance of a worker being hurt if a patch fails in this location.Without providing any justification, Farmers Rural Electric Cooperative Company suggested that OSHA prohibit repairing rubber insulating gloves and sleeves. This suggestion is rejected by OSHA. OSHA has said that the standards outlined in the last paragraph must be met in order to safely repair insulating gloves and sleeves.

It is necessary to check the insulating equipment once repairs have been made to make sure that any patches are successful and that no further flaws remain. Such retests are needed under paragraph, which is being accepted from the proposal without modification. The tests required by this part must be verified by a technique that may be used by employers, workers, and OSHA compliance personnel. In line with paragraph, this decision must be made by employer certification that the equipment has undergone standard-compliant testing. The certification is necessary to show which pieces of equipment passed the test and when. Logs and stamping test dates on the equipment are typical ways to comply with this requirement. The remark that follows the above paragraph clarifies that various certification methods are acceptable. The final rule, in contrast to the proposal, contains an explicit requirement that employers make this certification accessible to workers and their authorized representatives upon request. This is described under the summary and explanation for paragraph earlier in this part of the preamble. Moreover, OSHA has clarified the rule to provide that the Assistant Secretary for Occupational Safety and Health must be given access to the certification records upon request.

Subpart V, Electric Power Transmission and Distribution

Subpart V of OSHA's construction rules is being updated. To avoid fatalities and other injuries to workers undertaking construction work on electric power transmission and distribution infrastructure. The general industry standard at 1910.269, Electric power generation, transmission, and distribution, which the Agency issued in January 1994, served as the main inspiration for OSHA's reform of subpart V. Subpart V's title is changed from "Power Transmission and Distribution" to "Electric Power Transmission and Distribution" in the final standard to more clearly state that the subpart deals with "electric" power transmission and distribution and to more nearly resemble the title of 1910.269 as well.

The definition of final subpart V's scope is found in section 1926.950, which also specifies broad guidelines for training and methods for assessing working conditions. The proposed paragraph of final 1926.950, which establishes the parameters of redesigned subpart V, is approved without modification. This passage is mostly based on existing Section 1926.950 and. The building of electric power transmission and distribution installations is covered under Subpart V. According to the existing 1926.950 and 1910.12, paragraph of the final 1926.950 states that "construction" includes the installation of new electric transmission and distribution lines and equipment as well as the modifying, upgrading, and converting of already-existing electric transmission and distribution lines and equipment.

Background, earlier in this preamble, the purpose of OSHA to provide uniformity between 1910.269 and subpart V was broadly endorsed by rulemaking participants. The Agency was advised by several commentators to merge 1910.269 and subpart V into a single standard that would apply to all electric power production, transmission, and distribution activity. Several rulemaking participants asserted that integrating 1910.269 and subpart V into a single standard would have a number of advantages, including:

Reducing ambiguitya single standard would provide consistent interpretations for all generating, transmission, and distribution activities and remove issues regarding whether work is construction or maintenance;facilitating compliance and lowering costs under a single standard, firms may educate personnel in a single set of regulations as opposed to one set for building and another set for maintenance;Removing the need for ongoing maintenance and revision of two standards.

These suggestions to consolidate 1910.269 and subpart V into a single standard have been rejected by OSHA. First off, according to OSHA, companies won't be required to uphold distinct sets of regulations for construction and maintenance. OSHA anticipates that employers will be able to create a single set of regulations that are compliant with both 1910.269 and subpart V and apply regardless of the kind of work being done since the final rule incorporates standards that are basically the same for construction and maintenance. Based on basic differences between the general industry standards in part 1910 and the other construction requirements in part 1926, OSHA is adopting differing rules in a few instances in the final standard. For instance, Sections 1910.151 and 1926.50 of the General Industry and Construction Standards on Medical Services and First Aid are referred to in Sections 1910.269 and Subpart V, respectively. The criteria for medical services and first aid are somewhat different under these broad industrial and building norms. Similar to this, 1910.269 and subpart V separately pertain to the construction and general industry ladder requirements. Beyond the few instances given here, there are many more variations between construction and general industry standards that may be applicable to the production, transmission, and distribution of electric power. The goal of this regulation does not include harmonizing the many construction and general industry standards that are relevant to the production, transmission, and distribution of electric power. As a result, every employer who handles both general industry and construction work must guarantee that all relevant part 1910 and part 1926 regulations are followed. Employers would still have to deal with variations between other requirements in the general industry and construction regulations even if OSHA were to establish a single standard for the production, transmission, and distribution of electric power.

Second, the worries expressed by commentators about linguistic and interpretive discrepancies are mostly unjustified. Making the criteria for construction and maintenance uniform is one of the fundamental aims of this regulation, as stated in the preamble to the proposal. The Agency will take measures to make sure that the two standards' interpretations of requirements that are the same are consistent. To this purpose, the Agency is adding a note to the final version of Section 1926.950 to clarify that an employer that complies with Section 1910.269 will typically be regarded as complying with Subpart V requirements. A small exception applies to provisions in subpart V that integrate specifications from other subparts of part 1926 by way of reference. The employer must follow the applicable construction standards in order to comply with those requirements of subpart V; following the general industry standards listed in the analogous sections of 1910.269 will not be adequate. The updated note to Section 1926.950 ought help ease commenters' worries over perhaps divergent readings of analogous requirements under Section 1910.269 and Subpart V. Also, the note should reassure employers that they may use standard working procedures for the building, running, and maintaining electric power generating, transmission, and distribution installations in accordance with these specifications.

Ameren Company was worried OSHA would "make major and expensive modifications to the existing 1910.269 standard without appropriately allowing for utilities to evaluate and comment on the implications of these changes." The business asked the Agency to provide the utility sector a chance to comment on any changes to the current 1910.269 that weren't included in the proposal.OSHA does not think that any of the amendments to 1910.269 that are proposed in this final rule need further notice or a chance for comment. The Agency said in the preamble to the proposed rule that OSHA anticipates the final Subpart V to vary from the proposed Subpart V due to adjustments made in accordance with the rulemaking record. The Agency plans to modify 1910.269 in a similar manner when the final rule is issued, save to the extent that there are material distinctions between work in the general industry and work in the construction sector that need different standards. The Agency achieved this goal with its final regulation. Any amendments to the current 1910.269 approved in the final rule, according to OSHA, are based on the record taken as a whole and are a logical extension of the rulemaking record.

Instead of adding a new section on electrical protection equipment to the building standards, Mr. Anthony Ahern of the Ohio Rural Electric Cooperatives suggested that OSHA combine 1910.137 and 1926.97 or just mention 1910.137. This request is denied by OSHA. Not simply electrical power production, transmission, and distribution operations is covered by the new 1926.97. No extra burden on employers is imposed by the final 1926.97 over and above what would be required under 1910.137. Construction businesses and workers may easily acquire the protective equipment standards that are relevant to their activity by duplicating the 1910.137 criteria in part 1926.

The term "improvement" in the draft 1926.950 drew Ms. Salud Layton of the Virginia, Maryland & Delaware Association of Electric Cooperatives' objection. Ms. Layton also voiced worry about OSHA's usage of the word "repair" to describe construction operations in a section of the proposed rule's preamble. The regulation's definition of "construction" states that it also encompasses the "erection of new electric transmission and distribution lines and equipment, as well as the modification, conversion, and upgrading of existing electric transmission and distribution lines and equipment." While "alteration" and "conversion" might be considered construction-related operations, the word "improvement" is too inclusive. Several upkeep tasks are regarded as enhancements. The word "repair" is often used in the prologue to describe construction-related operations. This problem is further complicated by the fact that repairs are often seen as maintenance tasks in our sector.

Despite taking Ms. Layton's concerns into consideration, OSHA opted to continue categorizing "improvements" and "repairs" as construction, as it has done for many years. For many years, the definition of building activity under Subpart V has included the word "improvement." Moreover, as previously mentioned, this term is outlined in 29 CFR 1910.12.

Moreover, because all improvements are considered "alterations," a phrase she did not object to, deleting the term would have no real impact on the definition. OSHA has long considered "repairs" to be part of construction activities. See §1910.12. OSHA has clarified in multiple letters that construction was only important "f the standards are not the same" and that there may not always be a clear separation between construction repair and general industry maintenance. Hence, the proposed definition of "construction" in 1926.950 is carried over into the final rule without modification.

The American Insurance Association's Mr. Kenneth Stoller asked if the new contractor obligations contemplated by the proposal with respect to training, reporting, record-keeping, and personal protective equipment may unintentionally apply to insurance industry employees, whose only responsibility is to inspect – but not work on – some of the electrical equipment. Although neither electrical utilities nor electrical construction firms are among our members, certain of their commissioned inspectors must visit and examine equipment that is both powered and open. Moreover, certain state rules specify that particular equipment that is situated near to powered and open electrical apparatus has to undergo routine inspections.

Even though the proposal's preamble states that these obligations should only apply to entities performing maintenance and repairs, not just inspections, subjecting insurers to these new requirements would require individual companies to spend tens of thousands of dollars per year for additional training and equipment. In light of this, we suggest that the plan be changed to specifically exclude workers of the insurance business from any responsibilities it imposes on contractors.

Despite taking into account this criticism, OSHA decided not to exclude workers in the insurance sector from the final regulation. Inspections of electric power generating, transmission, and distribution facilities carried out by insurance company employees are already covered under existing 1910.269 as labor "directly related with" these installations. Existing 1910.269 in this respect reads, "Work on or directly related with installations. Since the goal of these inspections is to ensure the safety of these installations and the personnel working on or near them, OSHA interprets Section 1910.269 to apply to inspections carried out by insurance company employees. Inspections carried out by insurance companies are comparable to those carried out by power utilities and their contractors. "Inspection" was expressly mentioned in the preamble of the 1994 final rule establishing 1910.269 as an action covered by that standard. Without regard to the employer's industry or the employment of the individuals doing the inspections, Section 1910.269 is applicable to this kind of labor. 39 Hence, this job is already covered by current 1910.269 as it relates to general industry, and it will remain covered when the final rule takes effect. Nevertheless, if an insurance examination involves building work, it may come under subpart V rather than 1910.269 instead. Whether an insurance inspection qualifies as construction will depend on how the work was done.)

The insurance sector won't likely incur any significant higher expenses as a result of the final regulation, according to OSHA. Nowadays, the great majority of insurance inspections of electric power plants are covered under 1910.269. The amendments to 1910.269 made by this final rule's new provisions are anticipated to have the least substantial financial effects on inspections carried out by employees of the insurance business. First off, because insurance sector inspectors are virtually never certified staff, the minimum approach distance and arc-flash protection regulations often do not apply to the business (1926.960).

Second, the insurance business shouldn't be burdened by the host-contractor rules in 1910.269 and 1926.950. OSHA calculated the costs of the host-contractor requirements on a per-project basis, meaning that employers will incur expenses only once for each project, Final Economic Analysis and Regulatory Flexibility Analysis, further in this preamble. While OSHA usually assigned the expenses to contract employers, OSHA thinks that its estimate of the number of projects properly accounted for projects that entail inspections of electric power generating, transmission, and distribution facilities, including insurance inspections. According to OSHA, just a tiny portion of all the projects will need insurance inspections. The overall expenses associated with employers' compliance with the host-contractor arrangements for insurance inspections would be less than $20,000 per year, of which host employers would shoulder half. This assumes that 1 in every 1,000 projects includes an insurance inspection. The Agency views these expenses as minor relative to the total costs of the final regulation and as having little impact on the insurance sector.

Finally, OSHA does not anticipate that insurance inspections would often include workers using aerial lifts or on poles, towers, or other comparable structures that are subject to the requirements for personal protective equipment in final 1910.269 and 1926.954 regulations. The inspection of pressure vessels, Mr. Stoller's only example of work that may be impacted by the final rule, is not normally covered by those rules, which largely apply to work involving overhead transmission and distribution lines. OSHA isn't aware of any other insurance inspection activity that would require staff members to stand on poles, towers, or other comparable structures or operate from aerial platforms. Even if such inspections do occur, they should be few, and the Agency believes that the expenses associated with them are both irrelevant to the total costs of the final rule and irrelevant to the insurance sector.

Subpart V is not applicable to electrical safety-related work practices for untrained personnel, according to final 1926.950 paragraph. Other subparts of part 1926, such subparts K, N, and CC, provide regulations for these workers' work practices relating to electrical safety. For instance, 1926.416 in subpart K forbids employers from allowing an employee to work in close proximity to any part of an electric power circuit that the employee may contact during the course of their work, unless the employee is protected against electric shock by deenergizing and grounding the circuit, or by effectively guarding it by insulation or other means. Unqualified workers are shielded from electric shock by deactivating circuits and isolating them from personnel. Contrarily, subpart V of final 1926.960 restricts access to exposed electrified wires and equipment to certified personnel only. Unless the employee is insulated from the energized part, the energized part is insulated from the employee and from any other conductive object at a different potential, or the employee is performing live-line barehand work in accordance with final 1926.960, the employer must make sure that no employee approaches or takes any conductive object closer to exposed energized parts than the minimum approach distances, established by the employer under final 1926.960.

When using cranes or derricks close to overhead electrical lines, employers must normally make sure that workers maintain minimal clearances. As a general rule, the requirements of 1926.600 must be followed while using mechanical equipment close to overhead electricity lines. 1926.959 of this final rule generally requires mechanical equipment, including cranes and derricks, to maintain minimum approach distances that are significantly less than the minimum clearance distances in either 1926.600 or subpart CC, in part because subpart V establishes requirements for qualified employees operating mechanical equipment.

However, the preamble to the proposal made it clear that the requirements of subpart V did not apply to electrical safety-related work practices used by unqualified employees. OSHA did not explicitly propose to exempt electrical safety-related work practices used by unqualified employees from subpart V. In further detail, the Agency said: "The proposed amendment of Subpart V's general approach is to offer certified personnel with safety-related work practices to adhere to while they are executing electric power transmission and distribution work. In the proposed Subpart V, safe work practices for untrained personnel are not included. According to information in the record, the standards in subpart V do not adequately safeguard non-qualified workers from electrical dangers presented by power transmission and distribution systems. For instance, NFPA 70E has electrical safety-related work practice requirements. 41 Unqualified workers must maintain minimum approach distances that are much larger than those in Subpart V in accordance with the consensus norm. OSHA created subpart V to correspond with the specifications in 1910.269. Existing 1910.269 states that it applies to "ower generation, transmission, and distribution installations, including related equipment for the purpose of communication or metering, which are accessible only to qualified employees" and is being adopted in the final rule without any substantive changes. OSHA observes that the electrical safety-related work procedures mandated by Subpart V do not adequately safeguard inexperienced workers. As a result, Subpart V should not and does not apply to such work practices. The final regulation, in 1926.950, specifically states that electrical safety-related work practices for untrained personnel are not covered by Subpart V.

Subpart V applies in addition to all other relevant standards included in part 1926, according to paragraph of the final 1926.950, which is being implemented without modification from the proposal. This sentence also states that the use of Section 1910.5 does not exempt employers doing work covered by Subpart V from other relevant Part 1926 regulations. Moreover, the paragraph makes it clear that any particular references in subpart V to other parts of part 1926 are merely there for emphasis. According to this clause, unless there is a relevant exemption in subpart V or elsewhere in part 1926, all construction industry standards continue to apply to work covered by subpart V. For instance, 1926.959 mandates that the major safety elements of rotating and elevating mechanical equipment be visually examined prior to each shift. This clause does not take the place of 1926.1412, which specifies the criteria for a competent person to visually examine cranes every shift. OSHA finds the amendment to 1910.269 to be nonsubstantive, adding wording that is comparable to that in 1926.950.

In order to operate on electric power generating systems, Subpart V has never applied. According to proposed 1926.950, all activity, including building, involving electric power production installations would be covered under 1910.269 nevertheless. The Agency said in the introduction to the proposal that ordinary construction risks, or risks not covered by subpart V, are often the sole risks associated with building an electric power production station. The final stages of generating station construction, when electrical and other acceptance testing of the installation is being done, and during "reconstruction," when portions of the generating station not undergoing construction are still in operation, were recognized by OSHA as the two exceptions to this rule. Both of these cases involve building work at a generating station, which exposes employees to risks similar to those associated with running and maintaining a generation plant. The Agency determined that employers should adhere to 1910.269 in such circumstances because it thought that these two processes were more similar to general industry labor than construction. OSHA suggested that all work involving electric power production installations be covered by 1910.269 rather than repeating the relevant sections in subpart V.

The Agency sought feedback on whether the proposed application of 1910.269 to all work involving electric power generation installations should stand or whether the necessary provisions from 1910.269 should be included in the final subpart V for construction work involving electric power generation installations. To this request, OSHA got a large number of answers. The majority of commenters endorsed OSHA's suggested strategy and the phrase extending the application of 1910.269 to any work involving electric power production facilities. Mason County Public Utilities District 3, for instance, said in a statement that the proposed wording referencing 1910.269 for any work involving electric power production installations "should be implemented." Similar reasoning was given in response by Siemens Power Generation, who stated that "Subpart V should not apply to the electric power generation installations as maintenance in these installations is covered adequately by 1910.269 and construction is covered adequately by general construction requirements." Also, Southern Company's Mr. Tom Chappell concurred with OSHA that it would be better to use 1910.269 during the "final phase of construction" or "reconstruction work" rather than having to recreate the same criteria in Subpart V.

Nonetheless, NIOSH said that it "would be less cumbersome" for employers if the relevant specifications for building at power production facilities were included in subpart V. MYR Group also expressed worry that the OSHA's suggested strategy may generate confusion, stating that applying the Part 1910 electrical requirements would make it unclear if other general industry or construction regulations would apply to the other components of such work. As a result, the OSHA plan, which is based on a supposed simplification, is confusing in and of itself.

While taking these concerns into account, OSHA does not think that implementing 1910.269 to construction projects including generating installations would result in any significant burdens or misunderstanding. The general construction tasks carried out at generating installation sites are covered by OSHA's construction regulations. As previously stated, until the final stage of construction, many of the regulations in 1910.269 do not typically apply to the initial construction of a generating station. For instance, during the first stages of construction, the generator installation would not have any powered circuits, therefore the guidelines in 1910.269 about working near energized items would not be applicable. Similar to this, until coal is available, the criteria in 1910.269 on coal handling would not apply to the building of a coal-fired generating plant. The provisions of 1910.269 augment, but do not replace, any relevant general construction standards, to the extent that an employer is executing late-stage construction or rebuilding of a generating facility and 1910.269 applies.

The Agency is adopting proposed 1926.950 as it pertains to the building of electric power generating facilities after providing this additional explanation and receiving support from the majority of commenters who offered opinion on this matter. Line-clearance tree cutting, which is already covered in 1910.269.44, is another coverage concern brought up in the proposal.) Line-clearance tree cutting is not often carried out as part of the building of electric power transmission or distribution infrastructure, as OSHA stated in the preamble to the proposal. One exception is when trees are cut back along an existing overhead power line to make room for a newly constructed transmission or distribution line. While this sort of work by line-clearance tree trimmers is legitimately categorized as construction work, it has many parallels to the work done by line-clearance tree trimmers that is legitimately categorized as construction work.

Work in enclosed spaces rules are stated in paragraph of 1910.269. A standard for confined spaces in construction was recently suggested by OSHA, and it would address many of the same risks. While creating and announcing that final rule, OSHA will take into account how to apply these new confined space regulations to the development of power production plants.The current version of 1910.269 states that building activity is exempt from its provisions. OSHA is changing this sentence in the final rule to clarify that, with the exception of line-clearance tree-trimming operations and work involving electric power generating facilities as described in 1926.950, 1910.269 does not apply to construction work as defined in 1910.12. With this modification, subpart V's coverage of work involving electric power production installations will be consistent with how 1910.269 is applied.

REFERENCES

[1] W. A. Byrd, J. J. Kavolus, C. T. Penrose, en S. S. Wellman, “Donning Gloves Before Surgical Gown Eliminates Sleeve Contamination”, *J. Arthroplasty*, 2019, doi: 10.1016/j.arth.2019.01.015.

[2] H. C. Broding en M. Fartasch, “Automotive industry”, in *Kanerva’s Occupational Dermatology*, 2019. doi: 10.1007/978-3-319-68617-2_134.

[3] T. D. Rizky Intan, P. A. Alayyannur, D. N. Haqi, Mulyono, en F. Rizky Agung, “Risk analysis of occupational safety and health in pharmaceutical analysis laboratory in indonesia”, *Indian J. Forensic Med. Toxicol.*, 2019, doi: 10.5958/0973-9130.2019.00238.X.

[4] J. Yao, X. J. Liao, W. M. Mao, W. J. Wu, Y. Y. Yu, en G. G. Yang, “A comparison of colonoscopy - assisted transanal minimally invasive surgery via glove port and endoscopic submucosal dissection in the treatment of early rectal tumors”, *Zhonghua Wei Chang Wai Ke Za Zhi*, 2019, doi: 10.3760/cma.j.issn.1671-0274.2019.07.010.

[5] Y. Guo, F. Xu, Y. Song, X. Cao, en F. Meng, “A soft robotic glove for hand rehabilitation using pneumatic actuators with variable stiffness”, 2019. doi: 10.1007/978-3-030-27535-8_12.

[6] A. L. Urakov, K. Ammer, V. B. Dementiev, N. A. Urakova, en A. A. Gadelshina, “The contribution of infrared thermal imaging to designing a ‘winter rifle’ - An observational study”, *Thermol. Int.*, 2019.

[7] A. S. Barker, J. Law, M. Nicholson, D. Collett, en A. K. Deva, “The Reversed Glove Sleeve: A Readily Available and Cost-effective Way to Achieve ‘no Touch’ Breast Implant Insertion”, *Plast. Reconstr. Surg. - Glob. Open*, 2020, doi: 10.1097/GOX.0000000000002650.

[8] A. S. Barker, J. Law, M. Nicholson, D. Collett, en A. K. Deva, “The Reversed Glove Sleeve”, *Plast. Reconstr. Surg. - Glob. Open*, 2020, doi: 10.1097/gox.0000000000002650.

[9] M. Zohair, K. Moyer, J. Eaves-Rathert, C. Meng, J. Waugh, en C. L. Pint, “Continuous Energy Harvesting and Motion Sensing from Flexible Electrochemical Nanogenerators: Toward Smart and Multifunctional Textiles”, *ACS Nano*, 2020, doi: 10.1021/acsnano.9b09445.

[10] Elsivier Clinical Skills, “Endotracheal Tube : Closed Suctioning (Neonatal) – CE”, *Elsivier*, 2020.

[11] M. S. I. Afrad, A. A. Barau, M. E. Haque, en M. Habibullah, “Farmers’ Use of Personal Protection Equipment in Jeshore and Rajshahi Districts of Bangladesh”, *J. Educ. Soc. Behav. Sci.*, 2020, doi: 10.9734/jesbs/2020/v33i330204.

CHAPTER 15

REQUIREMENTS FOR LINE-CLEARANCE TREE-TRIMMING OPERATIONS

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When telecommunications wires are involved, 1910.268 also addresses line-clearance tree cutting, which is categorized as general industrial labor. 45 This is why planned 1926.950 stipulated that 1910.269 would apply to all line-clearance tree-trimming activities, including those that may be regarded as construction, as well as for ease of compliance and enforcement. OSHA asked feedback on the proposed application of 1910.269 to all activities requiring line-clearance tree cutting and if subpart V should instead include the relevant 1910.269 standards. Many comments were sent to the Agency on this matter. In general, these remarks agreed with OSHA's suggested strategy. The line-clearance tree-trimming criteria from 1910.269 in subpart V, for instance, were accepted by Mr. Anthony Ahern of Ohio Rural Electric Cooperatives as not needing to be repeated by OSHA. The criteria for line-clearance tree-trimming activities should only be covered under 1910.269, according to Mr. James Gartland of Duke Energy, who also added that the standards are the same whether the activity is classified as general industry or construction.

IBEW requested clarification from OSHA on whether or not Section 1910.269 would apply to tree-trimming activities that would be categorized as "construction," such as removing the area surrounding already-energized facilities to make room for a new right-of-way. In certain situations, OSHA is enforcing 1910.269 of the law. In light of this clarification, IBEW concurred that subpart V does not necessitate a repetition of the 1910.269 standards for line-clearance tree-trimming activities. OSHA is implementing 1926.950 as suggested with regard to line-clearance tree pruning in light of the support from the respondents[1], [2].

While the tree trimming industry did not object to 1910.269 encompassing all line-clearance tree trimming, industry representatives requested the Agency to enlarge the definition of that word in order to increase the range of covered line-clearance tree trimming operations. Based on the already-existing 1910.269, the proposed definition of "line-clearance tree cutting" in 1926.968 read as follows:

Any tree trimming, fixing, removing, maintaining, or clearing that occurs within 3.05 meters of electrical supply lines and equipment.According to the Utility Line Clearance Coalition, the term "line-clearance tree pruning" should not be restricted to trees that are 3.05 meters or less from an electric supply line. In order to include all vegetation management tasks performed by line-clearance tree trimmers and trainees for the installation or upkeep of electric supply lines or for electric utilities, ULCC recommended that OSHA broaden the definition of "line-clearance tree trimming." The identical modification to the term "line-clearance tree pruning" was recommended by the Tree Care Industry Association, which clarifies that 1910.269 does not apply to construction activities. OSHA is changing this sentence in the final rule to clarify that, with the exception of line-clearance tree-trimming operations and work involving electric power generating facilities as described in 1926.950, 1910.269 does not apply to construction work as defined in 1910.12. With this modification, the applicability of 1910.269 is now consistent with subpart V's coverage of line-clearance tree-trimming activities[3], [4].

0503). The following definition of "line- clearing tree cutting" was suggested by both tree trimming trade associations: The work carried out by line clearance tree trimmer/trainees for the construction or upkeep of electric supply lines and/or for electric utilities, including pruning, trimming, repairing, maintaining, removing, treating, or clearing of trees or the cutting of brush that is within 10 feet of electric supply lines and equipment.

The sector offered three key justifications for its suggestion to broaden the kind of tree-trimming operations covered by 1910.269 in its submission. OSHA is not convinced by the industry's arguments and will not be extending the definition of "line-clearance tree pruning" to include any vegetation management work for the installation or upkeep of electric supply lines or for electric utilities, for the reasons that will be discussed later.

But, OSHA is changing the definition of "line-clearance tree trimming" in a way that would narrowly expand the range of tree-trimming activities that are covered by 1910.269. Further on in this prologue, these modifications are covered.The first justification offered by the tree trimming business for its suggested definition is that other provisions of 1910.269 are in conflict with the "10-foot rule." In his testimony on behalf of the ULCC, Joe Tommasi of the Davey Tree Expert Company made the following observation: the definition states that such work is not subject to the line clearance tree trimming standard because the standard only applies to trees that are within the ten feet of overhead conductors, even though the standard requires line clearance arborists to maintain more than ten feet from some lines depending on the voltage exposures[5]–[7].

Moreover, Mr. Tommasi proposed that some regulations, such as those for applying herbicides and removing stumps, may also apply to work that is done more than 3.05 meters from power lines. This argument doesn't hold much weight in OSHA's eyes. This initial defense put up by the tree trimmers reveals a fundamental misunderstanding of how the suggested standard operated. Tree pruning work was only covered by 1910.269 under the proposed regulation if it was done on trees or bushes that were less than 3.05 meters from electrical supply wires and equipment. None of the rules in proposed 1910.269 applicable if the work was done on trees or brush that was more than 3.05 meters away from lines and equipment. In 1910.269, the proposed "10-foot rule" did not lead to any internal disputes. The planned regulations that worried the sector, such as minimum approach distances and specifications for pesticide spraying and stump grinding, did not apply to activity done outside of the 3.05-meter line.

The "10-foot rule" weakens safety by making various safety criteria for line-clearance tree trimmers apply depending on their distance from the line, according to the tree trimmers' second argument for broadening the definition of line-clearance tree cutting in 1910.269. A single set of safety regulations that are applicable to line tree arborists obtain the best percentage of compliance and, therefore, the highest level of safety, according to Mr. Tommasi's testimony. Mr. Tommasi said that during arborist activities more than 3.05 meters from power lines, Federal and State OSHA compliance officers have enforced other criteria, including as OSHA's logging standard. In addition, ULCC said that "adherence to a single predic set of safety criteria in which staff can be taught and frequently drilled is the cornerstone of worker safety in line clearing tree cutting."

Changing the definition of "line-clearance tree cutting" in 1910.269 would not necessarily accomplish the industry's purpose, but OSHA recognizes the industry's desire for a single set of safety-related work practices. As previously noted, even work covered by 1910.269 and subpart V is required to adhere to all other general industry and building standards that are relevant. In any case, the Agency does not consider it essential to address every risk that line-clearance tree trimmers experience under 1910.269 in order to ensure employee safety. Employers in every sector, including line-clearance tree trimming businesses, are required to identify all relevant OSHA standards as well as their general duty clause responsibilities. They must then develop, disseminate, and enforce a set of work rules that complies with all of the regulations. For instance, if a line-clearance tree trimming contractor completes work that is subject to the logging or site-clearing requirements, the contractor must verify that its work rules comply with those standards in addition to 1910.269. 47

The EEI-IBEW draft on which the existing 1910.269 was based included provisions on brush chippers, sprayers and related equipment, stump cutters, gasoline-engine power saws, backpack units for use in pruning and clearing, rope, and fall protection, which were "checked against the equivalent ANSI standard, ANSI Z133.1-1982 logging standard to line clearance unless so-designated." This is a false interpretation that fails to take into account existing 1910.269, which clarifies that "specific references in this section to other parts of part 1910 are included primarily for emphasis." If the work being done comes within the scope of both 1910.269 and other pertinent provisions in part 1910 at the same time, those requirements, including other elements in the logging standard, continue to apply requirements, to ensure that OSHA's rules would promote safety more effectively than the national consensus norm. OSHA did not, however, include in 1910.269 a thorough tree-trimming requirement. Hence, 1910.269 does not include several crucial safety requirements found in relevant consensus standards and other OSHA standards, and it does not address certain crucial safety risks encountered by employees engaged in tree care activities. For instance, there are no explicit protection provisions in 1910.269 for employees who are felling trees. The OSHA logging standard includes such standards. Additionally, the OSHA rules do not address nonelectrical dangers as thoroughly as the current version of ANSI Z133.1.48, or even the 1982 version, even though such risks are included by the 1910.269 tree-trimming requirements. For instance, both the new and old consensus standards have rules on hand tools like axes, pruners, and saws that are not found in 1910.269 as well as extra criteria for brush chippers. These factors make it unlikely that following the industry's suggestion to make 1910.269 the only source of standards for tree-trimming activity will increase worker safety. Instead, it would put the personnel carrying out such procedures in danger. For instance, an employer could carry out a logging operation next to an overhead power line as part of a deal with an electric company to cut down trees encroaching on the power line's right-of-way. The protection offered by the tree-felling rules of the logging standard would be eliminated if the advice and reasoning of the tree care business were applied to this activity[8], [9].

To collect data for use in creating a thorough standard on tree care operations, the Agency released an advance notice of proposed rulemaking. OSHA will evaluate whether and to what degree any new standard on tree care activities should include line-clearance tree pruning throughout that rulemaking process.

The final rationale offered by the tree trimmers for broadening the scope of what qualifies as line-clearance tree pruning under Section 1910.269 is the fact that the electrical risks covered by that section occur at distances greater than 3.05 meters from the line. In many situations, according to ULCC, line-clearance tree trimmers are exposed to electrical dangers at distances more than 3.05 meters from the line. For instance, a tree or part of a tree may fall onto the line even if the tree itself is further away than 3.05 meters. Mr. Tommasi used the example of a 15.2-meter-tall oak tree that was situated 4.6 meters away from an overhead power line to demonstrate his argument.The 3.05-meter regulation is largely fair and compatible with rules in 29 CFR section 1910, subpart S, OSHA's general industrial electrical standards, after OSHA has given this point some thought. The necessity to establish a locus within which 1910.269 should apply will become clearer when we examine the various standards that apply to the electrical risks created by tree-trimming activities.

There are various criteria to safeguard line-clearance tree trimmers from electrical dangers under the current 1910.269 standards for line-clearance tree cutting. Employees must first be acquainted with the unique procedures and risks associated with line-clearance tree trimming via training or experience in order to be deemed line-clearance tree trimmers under 1910.269 of the OSHA code 49 and the current 1910.269 definition of "line-clearance tree trimmer"). In addition, if a line-clearance tree trimmer is going to get closer than 3.05 meters to any conductor or electric apparatus that is energized at more than 750 volts, if the branches or limbs being cut are getting closer than the required minimum approach distances to lines that are energized at more than 750 volts, or if roping is required to cut the branches or limbs from such conductors, at least two line-clearance tree trim Finally, at least two personnel must be trained in first aid, including cardiac resuscitation, when there are two or more employees present and the line voltage is 50 volts or higher. Employees are required to maintain minimal approach distances that are adequate for competent personnel. Finally, personnel engaged in tree-trimming activities must utilize insulating equipment to cut away branches that are in touch with exposed, electrified wires or equipment or that are closer than the required minimum approach distances from such items. Employees engaged in tree-related activity who do not meet the requirements of 1910.269 are referred to by OSHA as "ordinary tree trimmers" or "tree workers who are not line-clearance tree trimmers." Note also the summary and justification for Section 1926.950, further down in this Preamble.

Subpart S of the general industry standards in part 1910 contains the requirements for "ordinary tree trimmers," or tree trimmers who do not do line-clearance tree trimming. For the purposes of Subpart S, tree trimmers fall into two categories: line-clearance tree trimmers, who OSHA classifies as qualified individuals under subpart S, and normal tree trimmers, who OSHA regards as unqualified persons. Under 1910.269, line-clearance tree trimmers are excluded from the subpart S standards for electrical safety-related work practices and must adhere to the

Line-clearance tree trimmers, on the other hand, are classified in 1910.269 as qualified workers for the purposes of the electrical safety-related work practices in Subpart S. According to paragraph of 1910.331 1910.331 through 1910.335 do not apply to work done on or in close proximity to generating, transmission, and distribution installations by certified individuals, including line-clearance tree trimmers as defined in 1910.269. In addition, Note 3 to 1910.331 makes it clear that the agency views tree removal for line clearance as activity directly related to such installations.Regular tree trimmers are not covered by 1910.269.52 but are subject to the subpart S regulations, which include certain fundamental standards. First, normal tree trimmers must have the proper training, even if this training is not as intensive for regular tree trimmers as it is for line-clearance tree trimmers. Second, ordinary tree trimmers must typically keep a distance of 3.05 meters or more between themselves and overhead power lines. Lastly, except in limited circumstances, conventional tree trimmers operating on the ground are not permitted to come into touch with mechanical equipment or vehicles whose components may be raised close to electrified overhead power wires.

According to existing 1910.269, line-clearance tree-trimming operations typically call for the presence of at least two workers. Currently, an employee must meet the definition of "line-clearance tree trimmer" in existing 1910.269 and have training that complies with 1910.269 in order to perform line-clearance tree-trimming operations. (See also the summary and explanation for 1926.950 and 1910.269, later in this section of the preamble, which states that a person must have the training required by that paragraph in order to be considered a qualified person.) OSHA added to 1910.269 appropriate training requirements for line-clearance tree trimmers. As a result, in accordance with this final rule, in order to be regarded as a qualified employee for the purposes of subpart S, an employee must fulfill the definition of "line-clearance tree trimmer" and receive training that complies with 1910.269. Each particular tree trimmer is either a line-clearance tree trimmer, who is regarded as a qualified employee under subpart S, or a normal tree trimmer, who is regarded as an unqualified employee under both the current standards and the final rule.

Line-clearance tree trimmers who are certified in first aid are also trained in CPR. There's nothing analogous in Subpart S. The current 1910.269 prohibits line-clearance tree-trimming activities where hazardous weather makes labor risky. Weather is not a topic covered in Subpart S.However, as compared to subpart S, current 1910.269 includes stronger protections for employees in the event that mechanical equipment comes into contact with an electrical line. As opposed to ULCC's assertion that electrical dangers should be present at all times, OSHA thinks that these crucial precautions in the current 1910.269 must only be mandated when tree-trimming activities expose workers to the most significant electrical hazards.

According to OSHA, the electrical risks that cutting trees poses depend on how near the tree is to the power line. The worker has greater trouble maintaining minimal approach distances the closer the tree is near the power line. For instance, roping can be needed to maintain the requisite minimum approach distances. Also, a worker cutting trees from an aerial lift must pay closer attention to the distances between the power line and the tree, the aerial lift, and themselves when the tree is near to the power line. The more space an employee has to operate the aerial lift, the farther the tree is from the power line.

Hence, the sole decision the Agency must make is how near the tree must be to a power line in order for the 1910.269 measures to be necessary. According to the Agency, such safeguards must begin as soon as a tree is 3.05 meters away from a power line. Unqualified workers are not allowed to work in conformity with Subpart S within that distance, but they are allowed to do so outside of it (plus an additional distance of 10 kilovolts for every 50 kilovolts). OSHA considers it to be inconsistent to broaden the definition of "line-clearance tree trimming" to the point where line-clearance tree trimmers working on trees or brush more than 3.05 meters from the lines would be eligible for the enhanced protections of 1910.269, while workers performing other types of work closer to the lines would be subject to the more restricted protections provided by subpart S. The Agency usually thinks that subpart S sufficiently addresses any electrical dangers that may exist when a tree is further away from power lines than 3.05 meters.

Nevertheless, to establish conformity with the 3.05-meter limit that applies to untrained personnel under 1910.331, revisions to the current definition of "line-clearance tree cutting" in 1910.269 are required. As previously mentioned, the minimum separation required between an untrained personnel and overhead electrical wires under 1910.333 is 3.05 meters. When the voltage exceeds 50 kilovolts, the necessary distance under. For every 10 kilovolts of electricity over 50 kilovolts, 1910.333 rises by 100 millimeters. OSHA thinks that the link between voltage and electrical hazard severity is adequately captured by the increase in distance. As a result, OSHA opted to add this additional distance to the definition of "line-clearance tree cutting" in order to comply with 1910.333, even though this is not to the degree that the tree trimming industry has suggested.

The updated definition is mentioned in both 1926.968 and 1910.269.The final 1926.950's paragraph on staff training. There are presently no general rules in Subpart V that deal with educating staff members on the safety procedures required to carry out transmission and distribution operations on electric power. It is generally acknowledged that the job types covered by this standard call for certain knowledge and abilities. The protection of workers is further ensured by the many safety-related work practice standards included in final subpart V. Employees must get proper training in order to acquire the necessary information and abilities to apply these work methods. Hence, with a few modifications and additions, OSHA incorporated training requirements that were similar to those found in 1910.269 in the proposed amendment of subpart V. Editorial modifications are being made, according to OSHA, to make it clear that employers are responsible for ensuring that "any" employee covered by a particular training requirement obtains the training mandated by that provision.53

All workers conducting work covered by subpart V are subject to the training requirements in the paragraph. Siemens Power Generation and ORC Worldwide advised removing the phrase "All employees" from the proposed paragraph. They raised worry that the clause would be interpreted as requiring training for workers doing jobs not covered by subpart V, such as office workers. Siemens' response:

The Agency implies that training is required for all personnel, regardless of the breadth of their responsibilities, by adding the term "ALL." That suggests, for instance, that even for administrative staff who pose little risk, some recorded training must be undertaken to meet this obligation. OSHA is aware of these issues, but has chosen to keep the proposed title in the paragraph. OSHA stated in the proposal, and is reiterating here, that paragraph does not impose training requirements on employees who are not performing work covered by subpart V. The text of paragraph is self-limiting employees are not required to complete the training described in paragraph unless they are performing work covered by subpart V. The Agency believes it is important to distinguish between the training requirements in paragraph, which are broadly applicable to workers doing work covered by subpart V, and the requirements in paragraph, which are applicable

In order to comply with this requirement, employers are not required to provide training to clerical workers in live-line barehand or any other work methods covered by this final rule since they do not undertake the kinds of hazardous work covered by subpart V. The same electrical safety training needed for personnel participating in the installation of transmission and distribution lines and equipment would not be necessary for employees doing clerical work or other jobs not covered by subpart V. Nonetheless, employers are required to provide clerical employees doing tasks covered by subpart V with the necessary training about any potential dangers.

The proposed paragraphs and mostly used elements from the existing 1910.269 as their models. Every employee must get training in and familiarize themselves with the safety-related work practices, safety procedures, and other safety standards in subpart V that apply to their specific job assignments, according to paragraph. It should be noted that this provision requires employers to train employees not only in the content of the applicable requirements of the final rule but also in how to comply with those requirements. OSHA considers this training necessary to ensure that employees use the safety-related work practices outlined in subpart V. OSHA included the proposed paragraph into the final rule without making any significant changes since it did not receive any comments.

Moreover, the proposed sentence mandated that staff members get training in and familiarize themselves with any extra safety procedures relevant to their line of work and essential for their safety, including any applicable emergency protocols like pole-top and manhole rescue. The proposed sentence mandated that safety training be given in subjects relevant to the employee's employment but not specifically covered by subpart V. This training fills in the gaps created by the final rule's failure to include standards for every danger an employee can face while doing work related to the production, transmission, or distribution of electric power. OSHA said in the preamble to the proposal that an employee would only need to be instructed in the work techniques to be employed if more than one set of work practices may be used to complete a job safely. A personnel operating without electrical protective equipment or utilizing live-line tools or rubber insulating equipment, for instance, may replace an insulator on a power line after deenergizing and grounding the line. Just the procedure actually utilized to replace that insulator would need to be taught to the employee.

Many submissions to the Agency suggested that the suggested training requirement in the preceding paragraph was overly broad. This proposed clause, according to Mr. Don Adkins of the electrical contractor Davis H. Elliot Company, is "impermissibly wide" and provides "no direction as to what safety procedures are'related' to the job of those covered by the standard," for instance. The sentence, in the opinion of Mr. Robert Matuga of the National Association of Home Builders, was "overly broad" and may require businesses to teach their employees on "virtually any danger that might reasonably be faced on a construction workplace." Additionally, he claimed that the proposed sentence duplicates the requirements of 1926.21, which states that "the employer shall instruct each employee in the recognition and avoidance of unsafe conditions and the regulations applicable to his work environment to control or eliminate any hazards or other exposure to illness or injury." U.S.A. is another. The Office of Advocacy of the Small Business Administration stated:

These recommended electrical standards' work practices are just one aspect of the mandated employee training; other safety procedures that are relevant to their jobs and essential for their safety are also included. The SBREFA panel expressed worry that this terminology was extremely general and may be interpreted to encompass other, less-specific workplace dangers, such as ergonomic injuries from overhead work. The proposed training wording is still ambiguous, and OSHA needs to specify what training is required to meet the standard's requirements.Notwithstanding these criticisms, OSHA is still certain that the proposed paragraph's requirement is crucial for the wellbeing and safety of workers and is adopting it in its final rule without making any substantial changes. Mr. Brian Erga of Electrical Safety Consultants International endorsed the suggested training requirements and said that adding these clauses to the current 1910.269 will boost worker competency and create safer workplaces. He clarified:

It has been repeatedly shown that investing in high-quality training and retraining not only makes the workplace safer but also benefits the employer in terms of financial contributions and long-term productivity. If the proposed 950 and related language in the preamble are implemented, the industry will, in our judgment, transition to a safer working environment. The new training requirements and the existing training standards in 1910.269 are not too demanding and will result in a more knowledgeable and experienced workforce. Additionally, Mr. Donald Hartley from the IBEW stated during the 2006 public hearing that it is crucial to "ensure that... employees are trained in the safety-related work practices, procedures, and requirements that pertain to their... assignments" in order to ensure that they are prepared to handle any potential risks related to this dangerous work. Several rulemaking participants acknowledged that subpart V does not specifically address all hazards faced by employees performing covered work and suggested that training is an important factor in employee safety. He did not suggest that this training be restricted to the safety practices and other safety requirements in subpart V. For instance, Mr. Lee Marchessault said during his testimony that "you should perform rescue training from substation structures" to emphasize the need of training in substation rescue techniques. Energy United EMC said that in order to avoid workers in insulated aerial lifts from contacting wires, "adequate training is important." Moreover, the record shows that employers provide training to workers to protect them from heat-stress dangers, to guarantee appropriate care of protective apparel, and to augment the line-clearance tree-trimming obligations under the law as it stands (1910.269).

The requirement suggested in 1926.950 is already included in existing 1910.269, and OSHA has had success enforcing this rule. First, the Agency does not believe that the requirement is as ambiguous as the commenters claim because it has not received any letters asking for interpretation or clarification of this provision, with the exception of two inquiries addressing who needs to be trained in emergency and rescue procedures. Second, in 362 inspections of electric utilities, OSHA only issued a few citations under the current 1910.269, which supports OSHA's judgment that workers conducting work under the existing

1910.269 typically get the necessary training. Finally, even EEI acknowledges that "usually, EEI members have considered the training requirements of paragraph 1910.269 to be practical for their staff." Consequently, it seems that electric companies have had little trouble adhering to the same rule in the current 1910.269.The Agency, on the other hand, concurs with these commenters that the final rule's 1926.950 establishes a wide, general need for training personnel. This method of writing an OSHA standard is not unusual. Employers are required to provide and ensure the use of protective equipment whenever it is necessary due to process or environmental hazards, chemical hazards, radiological hazards, or mechanical irritants encountered in a way that is capable of inflicting harm or impairing the function of any part of the body through absorption, inhalation, or physical contact under OSHA's personal protective equipment standards in 1910.132 and 1926.95. When an employer fails to supply PPE despite having actual or constructive knowledge of a danger at its facility for which protective equipment is required, it is termed a breach of the PPE rules. Similar in scope, the general construction training requirement in 1926.21 mandates that employers train every employee in the identification and avoidance of unsafe conditions as well as the rules that apply to their workplace in order to control or eliminate any hazards or other exposure to illness or injury.

Pressure Concrete Constr. Co., 15 BNA OSHC 2011, has been cited as another example of how this standard has been interpreted to require employers to give workers "the instructions that a reasonably prudent employer would have given in the same circumstances." Although the Commission and the courts have not stated specifically what instruction must be given to employees, they have held that an employer must teach workers how to recognize and avoid those hazards of which a reasonably pruden

The last paragraph is being applied by OSHA in the same way. Hence, each employee exposed to the danger must get training if the employer has actual knowledge of the hazard or constructive awareness of the hazard. The training must be enough for the employee to identify the danger and take prudent precautions to avoid or appropriately control it in order for it to be in compliance with this clause.Moreover, OSHA concurs with Mr. Matuga that paragraph needs the same training as 1926.21 except to the extent that it only applies to Subpart V work. Employers that satisfy 1926.21 also satisfy 1926.950's final requirements.

The Agency is adopting the paragraph in order to retain consistency with current 1910.269, even though the final rule repeats the general construction training requirement.

It was suggested by Mr. Lee Marchessault of Workplace Safety Solutions that the paragraph providing examples of possibly relevant emergency methods in the parentheses apply to rescues at heights generally rather than only pole-top rescue. He pointed out that rescue operations are carried out from utility poles, towers, and substation buildings in addition to wind turbines.OSHA has chosen not to follow this advice since no changes are required. The sorts of emergency measures specified in the final rule's paragraph are simply samples. Since it is a frequently utilized and known emergency operation, pole-top rescue is included. The Agency does point out that if it is important for employee safety during the relevant task, training in these other sorts of emergency measures is necessary.

OSHA intended to add a new clause emphasizing that the level of training necessary is dependent on the risk to the employee for the relevant work to both subpart V and 1910.269. According to OSHA, under this proposed clause, the employee's training would need to be appropriate for the risk the employee confronts. While 1910.332 does not include the "for the work involved" phrase, the two sections, proposed 1910.269 and 1926.950, are based on it. These additional training clauses were included to make sure that workers received the proper amount of instruction. Workers who do duties that carry low risk need less training than those whose occupations carry more risk.

According to OSHA, this requirement would guarantee that businesses focus their training efforts where they would yield the highest returns while also ensuring that all workers get sufficient training to safeguard them against the risks they experience at work. OSHA said in the proposal's preamble that current training offered in accordance with 1910.269 would be deemed adequate for compliance with these provisions. The provisions would provide companies the choice to customize their training programs and resources to workers with especially high-risk professions rather than requiring them to alter current training programs that abide by 1910.269 in any way.

EEI went on to say that the additional requirement would likely lead to confusion among many companies that lack access to or don't often examine the preambles to OSHA rules, saying: "EEI's fear is that the new wording would certainly lead to confusion among many employers." Most readers, save the most knowledgeable, will probably conclude that the updated standard mandates the modification of current training programs. The proposition is also ambiguous: The definition of "degree of training" is elusive since it is unclear how OSHA would categorize and assess such a qualification.

A lot of the feedback on the suggested paragraph was negative, mostly due to the phrasing linking training to "the work involved." For instance, Mr. Mark Spence from Dow Industries said that although he generally agreed with the proposed clause, the comparable requirement in 1910.332, which omits the phrase "for the work involved," "has been in existence since 1990 without posing substantial issues for businesses." The plan refers to training "for the work involved," which raised worries for Mr. Spence regarding the added phrasing. In contrast to task-specific training programs, broad programs are more common. The current language might be seen as requiring overwhelming training for impacted personnel on the specifics of each job. OSHA should think about rephrasing this clause or making it clearer that it states that, if necessary, extra training may be needed for a specific activity. Similar to Mr. Tom Chappell of Southern Company, he said that "it would be impossible to assess each work and define the amount of training that would be necessary" due to the "huge number of diverse activities that an employee may need to accomplish." According to Consumers

Energy, "workers can safely accomplish hundreds of distinct duties" without the need for specialized training in each one, in its experience. According to Mr. Donald Hartley of the IBEW, it is both impractical and improper to "connect the degree of training to the danger to the employee for the duty involved." It's not quite apparent what, by definition, the degree of training must be established by the danger to the employee for the activity involved, according to Mr. William Mattiford of Henkels& McCoy. And that's when we realize how perplexing it is.

Wilson Yancey is present. Measure Services endorsed the following remarks:

Bill and I both concur on his points. I believe that much of it has been discussed today. We won't finish it and it will be too expensive for the contractor if we have to go down and replicate it and make lesson plans for everything.

OSHA continues to hold that it's critical that workers get training that is appropriate for the danger they face. The advantages that may be attained are maximized by focusing training where the danger is the highest. Also, limiting the amount of training provided for risks that provide a low risk helps preserve precious and often scarce safety and health resources. This broad strategy was effectively employed by OSHA in 1910.332, giving businesses flexibility in employee training while ensuring that those workers who are most at risk get the greatest training. The agency's article "Training Requirements in OSHA Rules and Training Recommendations" acknowledges this strategy. On the other hand, the Agency is aware of the concerns raised by the rulemaking participants.The majority of comments were against setting training levels based on "the job required." While personnel are taught to undertake the many duties associated with their occupations, as highlighted by Mr. Mattiford, Mr. Hartley asserts that it may appear intimidating and impossible to examine each duty to establish the proportional risk.

But, employers must be able to assess the relative risk associated with the many risks that their staff may face. OSHA changed the wording "for the job involved" from the proposal with the language "for the danger involved" in the final rule to make this requirement clearer.Employers are urged to abide by the recommendations in OSHA's publication "Training Requirements in OSHA Rules and Training Guidelines," Voluntary Training Guidelines, Part III, in order to assess the relative risk faced by workers. In any case, as long as every impacted employee obtains the minimal training required by subpart V, businesses are free to distribute training resources based on their own assessment of relative risk.

Further guidelines for educating competent staff are provided in the paragraph. It is crucial that competent staff get specialized training since they may operate very near to electric power lines and equipment and, as a result, run a significant danger of electrocution. To this end, the standard stipulates that these workers must receive training in the following areas: differentiating exposed live parts from other electrical equipment components; figuring out exposed live parts' nominal voltages; maintaining applicable minimum approach distances; knowing the proper techniques for identifying electrical hazards; and working on or near exposed live parts. The terminology used here roughly corresponds to the wording used in existing 1910.269. But, the current 1910.269 does not include a parallel to paragraph, which calls for instruction in how to identify and manage or prevent electrical dangers. Also, OSHA amended the final rule to include language requiring employers to provide competent workers with the knowledge and abilities required to maintain minimum approach distances. For a description of this modification, see the summary and explanation of final 1926.960, which is located further in this part of the preamble.

According to NIOSH, both certified and unqualified staff should get the same training since they are both exposed to the same electrical risks. Once competent staff are taught, NIOSH recommended that "all workers potentially exposed to electrocution threats should be educated in hazard awareness and the identification and control of these hazards." Line-clearance tree trimmers and ground workers confront electrical dangers that are equivalent to those experienced by skilled professionals, according to NIOSH.

The training of ground workers on tree crews or other tree workers who are neither qualified employees under 1910.269 nor line-clearance tree trimmers should not be subject to the adoption of requirements in this final rule, according to OSHA. Electrical safety-related work practices of ground workers on tree crews and other tree workers who are not line-clearance tree trimmers are subject to subpart S, not 1910.269 or subpart V.) This is made very obvious in the preamble of the 1994 1910.269 final rule as follows:

Some arborists lack the education required to qualify as "qualified personnel" or "line-clearance tree trimmers," as those terms are defined in 1910.269. These workers are in no way protected by 1910.269 at al. Subpart S of Part 1910 specifies the work procedures that these personnel must follow.As required by Subpart S, tree workers must keep a minimum of 10 feet between themselves and overhead power wires. Tree trimmers for line clearance operate near to but away from live power lines. As a result, the Agency considers that these workers need different training than other qualified workers covered by 1910.269. OSHA has addressed the training for line-clearance tree trimmers within the terms of existing 1910.269 in the definition of "line-clearance tree trimmer" and the comments to that definition. The notes and definition may be found in existing 1910.269. Line clearance tree trimmers are not qualified workers for the purposes of 1910.269, but they are qualified employees exempt from the electrical safety-related work practice standards in subpart S, according to Note 2 to that definition. According to the note that follows 1910.332, in order for OSHA to deem a person competent for the purposes of 1910.331 through 1910.335, that person must have completed the training specified by 1910.332 in order to do so. Thus, a tree trimmer must complete the training required by 1910.332 in order to be designated a line-clearance tree trimmer under 1910.269 and, therefore, a qualified person under subpart S. Without such training, a tree trimmer is not deemed qualified under subpart S, and as previously stated, the electrical safety-related work practices in that standard take precedence over those in 1910.269 for the purpose of determining what activities are required.

OSHA suggested adding requirements for supervision and additional training in paragraphs and to the training requirements in paragraphs and. These specifications were extracted from from the text of existing 1910.269 and. The Agency clarified in the proposal that providing new hires with initial training in safe procedures does not guarantee that they would consistently follow safe work practices. To guarantee that the employee follows the instructions he or she has been taught, ongoing reinforcement of this first training must be given. Supervision, safety meetings, pre-job briefings or conferences, and retraining are all examples of ways to reinforce behavior.The proposal's paragraph, which is being approved unchanged, mandates that the employer verify each employee's compliance with the safety-related work practices specified in subpart V by ongoing supervision and inspections carried out at least once a year. Further training is necessary according to paragraph, which is also approved without alteration from the proposal, whenever: Frequent supervision or an annual inspection required by paragraph shows that the employee is not adhering to the safety-related work practices required by subpart V,when compared to the employee's usual work practices, new technology, equipment, or procedural changes require the employment of safety-related work practices that are different from those practices, or

The employee is required to utilize safety-related work procedures that are beyond the scope of their typical responsibilities.Before an employee performs a duty that is carried out less often than once a year, retraining must be given, according to a note to the previous sentence. Pre-job briefing instruction is acceptable as long as it is thorough enough to completely educate the employee of the steps involved in the task and to guarantee that he or she can complete them safely.The criteria for retraining in the proposed paragraph, according to Mr. Leo Muckerheide of Safety Consulting Services, were reactive rather than proactive. He advocated for the need of 4 to 8 hours of refresher training every 2 to 3 years, contending that employees adhere to good safety procedures right initially but start to stray from them with time.

OSHA disagrees that the retraining requirements in the preceding sentence are solely reactive. The safety-related work practices required by the standard are frequently used on a daily or other regular basis by employees conducting work covered by the final regulation. The Agency has no evidence that a lack of regularly scheduled retraining relates to a failure to follow safe work practices that are often utilized, and it assumes that employees will typically continue to follow these practices over time. OSHA does acknowledge the significance of retraining for seldom used work practices, however. In order to apply new or different safety-related work practices or safety-related work practices that are not part of their usual job tasks, personnel must get extra training, according to paragraphs and. For instance, under paragraph, a worker who is required to provide CPR in an emergency situation requires retraining if they haven't performed such emergency procedures in the preceding year. If an employee has to climb a pole and it has been more than a year since they last employed pole-climbing techniques, they would also need to undergo retraining. 58 OSHA is accepting this paragraph from the proposal without making any modifications because it does not think they are required.

According to clause, the training needed by clause may be given in a classroom, on the job, or both. This sentence comes straight from the current section 1910.269. The Agency has found that these kinds of training, which give employees a chance to raise questions and get employer responses, are most beneficial. This clause is being implemented as proposed since OSHA did not receive any feedback on it.According to the paragraph, training provided in accordance with 1926.950 must make employees proficient in the tasks they must do and introduce the processes needed for subpart V compliance. This sentence, which OSHA adopted without making any changes from the draft since it was lifted from the already-existing 1910.269, did not receive any comments. There is no guarantee that an employee will work safely until a training program develops that employee's expertise in safe work practices and that person subsequently proves that employee's capacity to undertake the appropriate work practices. An person won't often be considered competent in a difficult technique after taking only one training session on it, such as the lockout and tagging procedures employed in an electric generating facility. The demonstration of competency required in paragraph and paragraph will prevent companies from trying to comply with 1926.950 by only giving staff training materials. These clauses necessitate that employers take measures to ensure that staff members understand what they have been taught and are competent to carry out the work practices specified by the standard. OSHA considers that doing this optimizes the advantages of the instruction mandated by the final rule.

Employers are obliged by current 1910.269 to confirm that each employee has undergone the necessary training. When the employee exhibits competence in the relevant work procedures, the certification must be produced and kept up during the employee's employment. With passages in both 1910.269) and subpart that just call for the employer to decide that each employee has shown competency in the essential work practices, OSHA proposed to abolish this certification requirement. The Agency sought to relieve businesses of needless bureaucratic burdens when it proposed this adjustment. OSHA said in the preamble to the proposal that, in the absence of training certificates, employee interviews might be used to assess compliance with training standards. This proposed paragraph had a comment that, while not necessary, employers may continue to keep track of employee training records to determine when workers exhibit competency. OSHA particularly asked for feedback on the need of the current certification requirement and the suitability of the proposed standard without one.

On this subject, OSHA got a lot of input. The suggestion made by OSHA received support from several rulemakers. For instance, Mr. Brian Skeahan of Cowlitz County's Public Utilities District No. 1 stated that the switch from the certification requirement to the need to show competency was an "accep adjustment," noting that keeping track of on-the-job training might be cumbersome. Similar remarks were made by Mr. Wilson Yancey of Quanta Services, who said that he "supports OSHA's proposal to require just that the employer verify that the employee is able to show competency." The certification requirement, he said, "would not materially benefit employee safety and health" and "is an unnecessary recordkeeping burden that would be impossible to execute in reality due to the fact that crews are spread out." The National Electrical Contractors Association, represented by Mr. Brooke Stauffer, endorsed the plan as well: "NECA supports the proposed shift from certification of training to demonstration of ability. Because of the significant turnover in the line construction business, we oppose a mandate to preserve records of employee training. Moreover, it is impossible to document on-the-job training with such record-keeping. The present training certification requirement in paragraph 1910.269, according to EEI, "has shown to be of no use, is superfluous, and should be abolished." Moreover, Southern Company informed OSHA that it would be difficult or impossible to keep records for this kind of training since it is accepted as a way for teaching personnel. We agree that records of training that are typically kept should be accepted as a way to assess whether an employee has received training. Yet, the best indicator of a worker's capacity for safe employment is whether or not they can show their competence. Some commentators criticized the idea of doing rid of the certification requirement and emphasized the need of recordkeeping. For instance, Mr. Tommy Lucas of TVA stated: "Training should be recorded to guarantee that workers have been instructed and showed competency." Managers and supervisors need documented training in order to determine if an employee is skilled in the abilities needed for the job they are being given. Employee protection will be improved if managers and supervisors have access to training records. IBEW concurred and supported a training recording requirement, saying as follows:

Employers should be required by law to keep track of employee training. The issue that has to be addressed is how an employer can adhere to initial and continuing training obligations if training records are not retained. The majority of training programs in this field are organized utilizing topics and techniques that are fairly general. The majority of employers that use this sort of training record both the original instruction and any further training they may provide. Employers will not be subjected to any extraneous or expensive requirements as a result of recording employee training. In his statement at the 2006 public hearing, Mr. Donald Hartley from IBEW further clarified the union's position:

Employers should be required by OSHA to certify that their staff members are competent in the jobs they are given, and to keep records of their proven competence. If paperwork is not needed, there is simply no way to verify that businesses are truly certifying workers. Also, over time, the information may be utilized to assess whether personnel have previously met the training requirements and whether further training or recertification is required.

REFERENCES

[1] M. Graziano, P. Gunther, A. Gallaher, F. V. Carstensen, en B. Becker, “The wider regional benefits of power grids improved resilience through tree-trimming operations evidences from Connecticut, USA”, *Energy Policy*, 2020, doi: 10.1016/j.enpol.2020.111293.

[2] A. B. Mitchell, G. K. Norwood, en C. D. Bartlett, “Vxte deepwater tree development-cost and risk reduction through newand advanced technology”, 2020. doi: 10.4043/30519-ms.

[3] Y. Lin, H. Zheng, en L. Dong, “Enhanced ethanol production from tree trimmings via microbial consortium pretreatment with selective degradation of lignin”, *Biomass and Bioenergy*, 2020, doi: 10.1016/j.biombioe.2020.105787.

[4] E. D. Cahyono *et al.*, “Agroforestry innovation through planned farmer behavior: Trimming in pine–coffee systems”, *Land*, 2020, doi: 10.3390/land9100363.

[5] R. H. Cruz-Estrada, J. Guillén-Mallette, C. V. Cupul-Manzano, en J. I. Balam-Hernández, “Potential use of waste from tree pruning and recovered plastic to obtain a building material: Case study of Merida, Mexico”, *Waste Manag. Res.*, 2020, doi: 10.1177/0734242X20928404.

[6] B. Brenner, J. C. Cawley, en D. Majano, “Electrically Hazardous Jobs in the U.S.”, 2020. doi: 10.1109/TIA.2020.2980221.

[7] I. Stavi, “On-site use of plant litter and yard waste as mulch in gardening and landscaping systems”, *Sustain.*, 2020, doi: 10.3390/su12187521.

[8] S. Tapper, J. J. Nocera, en G. Burness, “Experimental evidence that hyperthermia limits offspring provisioning in a temperate-breeding bird: Hyperthermia influences parental care”, *R. Soc. Open Sci.*, 2020, doi: 10.1098/rsos.201589.

[9] S. A. Tormoehlen, W. E. Field, S. G. Ehlers, en K. F. Ferraro, “Indiana farm occasional wood cutter fatalities involving individuals 55 years and older”, *J. Agric. Saf. Health*, 2020, doi: 10.13031/JASH.13690.