IEET - International Electrical Engineering Transactions, Vol. 10 No.1 (18) January - June, 2024

Corrosion in Electrical Distribution Board: Occurrences, Effects, and Prevention

Somsak Sanmuang, Hanwei Li, Zhuoran Yang, and Jun Lin*

School of New Energy,
North China Electric Power University,
Beijing, China 102206

ABSTRACT: As an essential part of the electrical infrastructure, electrical distribution boards (EDBs) play an important role in efficient power management and distribution. However, they are facing a widespread and significant challenge by the corrosion problem. Understanding and preventing corrosion in EDBs is crucial for maintaining the reliability, performance, and safety of electrical power systems. This paper reviews the different types of corrosion in EDBs, as well as the influential factors that can contribute to the occurrence of corrosion. The detrimental effects that corrosion poses on the safety, electrical failures, and associated losses of EDBs are also discussed. Finally, measures are proposed to prevent the corrosion and ensure the normal function of EDBs.

***Keywords*—Corrosion, Effects, Electrical Distribution Board, Prevention.**

I. INTRODUCTION

Corrosion is a natural process that causes the degradation of a metal when it reacts with its environment[1-3]. Environmental elements such as humidity, ions, pH, and oxygen content can all affect corrosion[4-8]. Corrosion occurrences cause enormous issues in the energy industry, including coal mining, fossil fuel, oil and gas industry, and electric power systems[5-7, 9-12]. In electrical power systems as illustrated in Fig. 1, the three major sectors including the electrical generation, transmission, and distribution sectors all contain large amounts of metal components in many equipment and accessories such as conductors, connectors, terminal bars, cable towers, transformers, ground electrodes, conduits, and enclosures. Corrosion can take place in any part of such a huge electrical power system and needs to be paid careful attention to prevent any possible damages, that may lead to equipment failures, energy losses, and safety hazards.

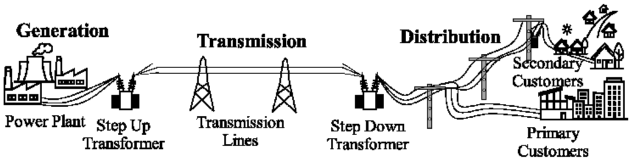


Fig. 1. Schematic diagram of the electrical power systems

The initial corrosion in electrical systems might not create many problems in the beginning when the systems are still able to supply their loads as normal. This may cause some technical inspectors to neglect the investigation of the developing problem due to a lack of awareness of long-term consequences [13-15]. However, the corrosion reactions will slowly develop and eventually damage the systems, as there are many cases reported of the corrosion attack in different parts of the power systems resulting in the loss of reliability and performance of the systems [16-27].

The current paper limits the discussion only to the corrosion that appears on the electrical distribution boards (EDBs) installed on the customers' side, particularly, residential customers. Usually, the electrical systems installed in factories and office buildings are regularly inspected and maintained by professional engineering teams and thus corrosion can be suppressed to a large extent. However, in the case of residential buildings or houses where they do not have professional teams to regularly monitor the systems, corrosion can easily develop on unprotected metal surfaces of the electrical system after a certain period. In a study on the electrical inspection of 1,052 residential electrical service panels in which the age of equipment ranged between brand new and over 50 years old [11], D. J. Friedman revealed that 126 cases or 12% of all panels showed corrosion or corrosion-

The manuscript received April 25, 2024; revised May 31, 2024; accepted June 1, 2024; Date of publication June 30, 2024

*Correspondence: Jun Lin, School of New Energy, North China Electric Power University, Beijing China 10226, (E-mail: jun.lin@ncepu.edu.cn)

related defects in different parts of the electrical distribution boards, including the panel surface, entrance cables and their connectors, circuit breaker terminals, connector bars, and other metal parts. In a report by R. Williams [28], a service panel installed in the garage of one resident's house was fully occupied by rust and corrosion for only a year, especially at its connector bar. The technical inspector in charge of this case found the concentrated air salt in the garage as evidence to affect the corrosion. It was discovered that the salt was brought into the garage by two cars when they came back from outside during the snowy winter season, during which the salt was mixed with melted snow, and then accumulated in the garage after water evaporation. In another case that was related to a ground-level indoor electrical panel [29], as the cables connected to the panel were directly buried underground without protection the temperature difference between underground and room temperature resulted in the condensation of water vapor on the panel, causing the corrosion occurrence in many parts of the panel in only four years.

Corrosion in the distribution system not only causes damage to the electrical parts but also can cause further issues. The occurrences, effects, and prevention of corrosion occurring in electrical distribution boards in residential units are discussed in this paper.

II. CORROSION OCCURRENCE IN ELECTRICAL DISTRIBUTION BOARD

EDB is the central distribution point in an electrical system of a building or facility, dividing the incoming electrical power into separate circuits, each of which feeds a different area of the building. The EDBs can provide either single-phase or three-phase panels to supply electric power as customers demand. An EDB may consist of a variety of components, some of which are displayed in Fig. 2[30-39]. Because these components mostly comprise metals as mentioned previously, corrosion can develop throughout the EDBs.

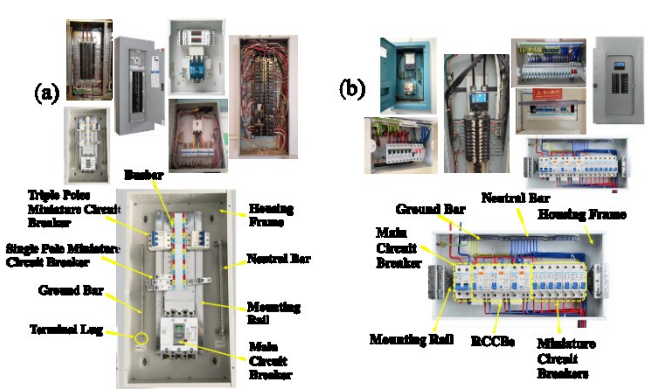


Fig. 2. (a) Examples of three-phase EDBs[30-34], and (b) examples of single-phase EDBs[35-39]

A. Corrosion Mechanism

The natural electrochemical process conducts corrosion into metal surfaces and converts metal into corrosion products, which involves the oxidation of the metal (anode) and the reduction of an oxidant (cathode), as shown in Fig. 3.

1) Corrosion Reaction

In general, the following conditions are required to promote the corrosion reaction on a corrosion cell [40]:

a. On a metal surface, there must be a difference in the chemical potentials between nearby areas (or among alloys of different contents).

b. An electrolyte must exist to provide ion conduction.

c. An electrical channel through the metal or between the metals must be accessible to allow electrons transport.

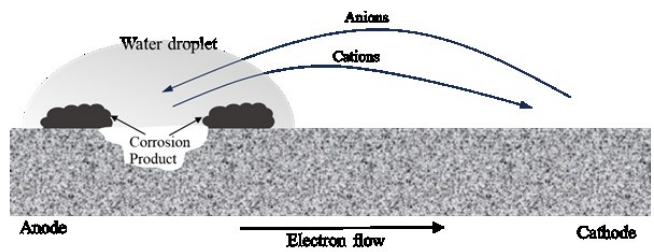


Fig. 3. Reaction on a corrosion cell

Anodic Reaction (Oxidation)

At the anode, metal atoms, here iron (Fe) atom is used as an example, lose electrons, and become ions. This process is represented by the following equation:

$$Fe \rightarrow Fe^{++} + 2e^{-} \tag{1}$$

Cathodic Reaction (Reduction)

The released electrons flow through an external circuit or directly to the cathode, where they participate in the reduction of an oxidant. The most common cathodic reactions involve the reduction of oxygen or water:

Oxygen reduction:

$$O_2 + 4H^{+} + 4e^{-} \rightarrow 2H_2O \tag{2}$$

Water reduction:

$$2H_2O + 2e^{-} \rightarrow H_2 + 2OH^{-} \tag{3}$$

When metal ions, such as Fe^{++}, encounter hydroxyl ions (OH^{--}), they can form insoluble corrosion products, such as rust ($Fe_2O_3{\cdot}H_2O$). These corrosion products can accumulate on the metal surface and prevent the formation of a protective oxide layer, leading to further corrosion.

2) Types of Corrosion

The type of corrosion depends on the specific conditions and mechanisms involved. The following is a brief characterization of common types of corrosion that can take place in the EDBs when they face an electrolyte such as water from condensed moisture in its environment.

a) Uniform Corrosion

Uniform corrosion, also known as general corrosion, is characterized by the even spreading of corrosion attack over a metal surface[41]. This type of corrosion is typically caused by exposure to an aggressive agent in the surrounding environment, such as moisture, humidity, corrosive gases, or other chemicals. These agents facilitate the formation of the metal ions and the release of electrons, which combine with oxygen to form hydroxyl ions. These hydroxyl ions then react with the metal ions to form corrosion products.

b) Galvanic Corrosion

Galvanic corrosion occurs when two metals with different electrode potentials contact with each other in an electrolyte. The more active or less noble metal, known as the anode, corrodes and releases electrons which flow to the less active or more noble metal, known as the cathode, where they combine with oxygen to form hydroxyl ions. Then, the corrosion products can be formed by the reaction between the hydroxyl ions and the metal ions from the anode. As a result, the anode dissolves into the electrolyte. The rate of galvanic corrosion is affected by several factors, including the difference in electrode potential between the two metals, the area ratio of the cathode to the anode, the different types of metals or alloys that are in contact, and the conductivity of the electrolyte[42-46].

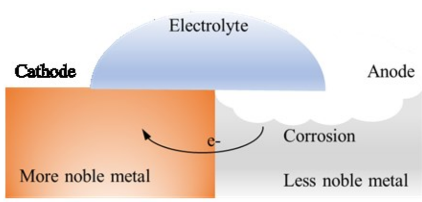


Fig. 4. Schematics of galvanic corrosion

c) Crevice Corrosion

Crevice corrosion occurs in tight spaces or crevices when a crevice is formed between two metal surfaces. The electrolyte in the crevice becomes more concentrated than that in the surrounding region. This concentration difference creates a concentration cell, with the metal inside the crevice acting as the anode and the metal outside the crevice acting as the cathode[47-51]. The corrosion mechanism begins when the reaction with the metal consumes the dissolved oxygen in the liquid deep in the crevice[41, 52] as shown in Fig. 5(a). Therefore, oxygen transport into the crevice becomes limited, and a differential aeration cell is typically established between the crevice microenvironment and the exterior surface. Corrosion reactions preferentially occur in crevices (anode) and on surfaces that are more accessible to ambient air (cathode) (Fig. 5(b)).

The cathodic oxygen reduction reaction cannot be sustained in the crevice area due to the restriction of the oxygen diffusion, giving it an anodic character in the differential aeration cell. This anodic imbalance results in the formation of highly corrosive microenvironmental conditions in the fissure, which promotes further metal breakdown as indicated in Fig. 5(c).

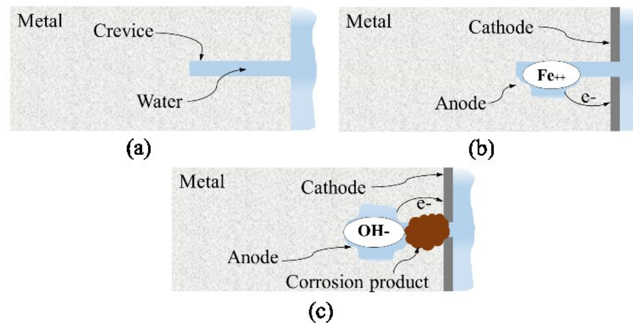


Fig. 5. Crevice corrosion process: (a) initial stage, (b) releasing electrons, (c) forming corrosion product

d) Pitting Corrosion

Pitting corrosion is a type of localized corrosion that occurs in small pits or cavities on the surface of a metal[53-56]. Initially, these pits can be deep or narrow, and they can cause serious damage to the metal after being occupied by the corrosion. Pitting corrosion occurs due to the formation of a localized corrosion cell on the metal surface. This cell is typically created by a combination of several factors[52, 57-60], such as the impurities or metallurgical defects in the metal, the stress or strain in the metal or mechanical damage, a corrosive electrolyte or chemical damage, and oxygen. This localized corrosion cell causes the metal to corrode preferentially. Later, the pit can grow in different shapes (Fig. 6), making the corroded pit deeper and wider as the corrosion reaction continues. Eventually, the pit may collapse, causing the metal to crack or fracture.

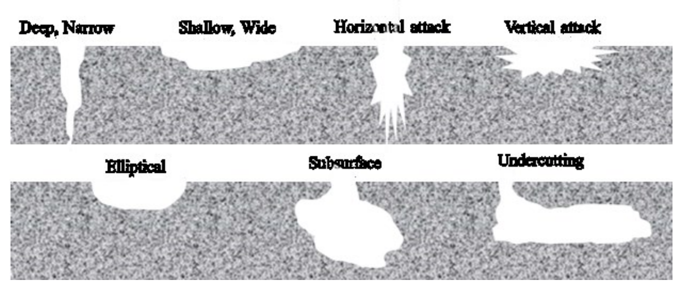


Fig. 6. Different cross-sectional shapes of pitting corrosion

e) Erosion Corrosion

Erosion corrosion is one form of corrosion that occurs when a solid surface is subjected to the simultaneous action of erosion and corrosion. Erosion is the removal of materials by a fluid or gas, while corrosion is the chemical or electrochemical attack on a metal surface. When these two processes occur together, they can accelerate the rate of material loss and lead to premature failure of components. Erosion corrosion is influenced by material properties like hardness, corrosion resistance, conductivity, thermal diffusivity, arc parameters, melting temperature, and heat resistance[61]. In the case of the electrical distribution system, erosion corrosion can be often observed after a period of arc takes place between two contact surfaces of a circuit breaker or other switching devices.

B. Factors Contributing to Corrosion Occurrence in EDB

The main factors that contribute to rust and corrosion occurrence in the EDBs include impurities on metal surfaces, moisture, corrosive agents in its environment, electric arc on the surfaces of electrical contacts, and lack of maintenance. These factors are described as follows:

1) Metal Impurities

The purity of metal is one of the most important factors that affect metal corrosion[62]. Carbon steel sheet is widely used to assemble enclosures or EDB frames. Despite its several advantages such as high strength and low cost[63-69], the vulnerability to corrosion is also a negative characteristic that poses engineering problems for carbon steels[69, 70]. In the steelmaking process, some elements such as sulfur, nitrogen, and phosphorus may be integrated in the process. These contaminated elements create metal impurities and increase the risk of corrosion. When carbon steel is exposed to atmospheric compounds such as moisture, CO_2, and H_2S, it can be corroded easily and lead to mass loss on the metal surface [66-68].

2) Moisture

Moisture is formed from various sources in the atmosphere such as rain, dew, snow, evaporated water, and fog. It acts as an electrolyte that facilitates the electrochemical reactions and causes significant corrosion to metal[71-73]. Even though the metal is covered under an insulation layer, whenever the moisture penetrates through insulation and is trapped between the metal surface and the insulation layer, the corrosion can be accelerated. Therefore, moisture plays a crucial role in the process of corrosion under insulation [70, 74]. When the moisture encounters metals, it forms a thin layer of water on the metal surface, enabling the flow of electrons between the metal and the surrounding environment. This electron transfer results in the formation of corrosion products, which weaken and ultimately destroy the metal. As a result, the moisture that builds up on the EDBs and the related equipment ultimately compromises the performance and reliability of these equipment.

Moisture can enter the EDBs through various pathways as follows. The temperature fluctuations can cause the moisture in the air to condense on the cooler surfaces of the EDBs components[28]. The moisture could also be formed due to the infiltration of water through the gaps or cracks of the building[75], leakage of roofs or pipes from structural defects or plumbing issues[11, 15]. After this moisture seeps into the EDBs and reaches the components, the corrosion reaction will be facilitated to damage the board. Animals and insects represent another pathway that could lead the moisture to enter the power distribution board. For example, ants bring humid soil into the distribution board to build nests and this can cause corrosion to the board[76].

3) Corrosive Gases

When the EDBs are exposed to the corrosive gases and surrounding area as well as the industrial gases or pollutants, they are susceptible to degradation. Corrosive gases, such as sulfur dioxide (SO_2), nitrogen dioxide (NO_2), chlorine (Cl_2), and ammonia (NH_3) can react with the metals used in the EDB components, leading to the formation of corrosion products that can lower the electrical conductivity, reduce the mechanical strength, and ultimately cause the equipment failure at an alarming rate. So, these gases pose a significant threat to the integrity and functionality of the EDBs. Moreover, the burnt cable insulation caused by overheating at around the connection point in the EDBs can also generate corrosive acidic gases such as hydrogen chloride (HCl), hydrogen bromide (HBr), and hydrogen fluoride (HF) [77, 78]. These corrosive gases from the burnt insulation can lead to the corrosion of the cable[77, 79-82]. If these corrosive gases incorporate moisture, it is unavoidable that corrosion will occur on the wires and connectors in the EDBs. Table 1 displays the examples of metal susceptibilities to a variety of the corrosive gases and corresponding acid ions[83].

Table I Metal sensitivities to atmospheric gaseous corrosive species[83]

Corrosive Species	Ag	Al	Cu	Fe	Ni	Pb	Sn	Zn
CO_2/CO_3^{2-}	L			M	L	M		M
NH_3/NH_4^+	M	L	M	L	L	L	L	L
NO_2/NO_3^-	N	L	M	M	M	M	L	M
H_2S	H	L	H	L	L	L	L	L
SO_2/SO_4^{2-}	L	M	H	H	H	M	L	H
HCl/Cl^-	M	H	M	H	M	M	M	M
$RCOOH/COOH^-$	L	L	M	M	M	H	L	M
O_3	M	N	M	M	M	M	L	M

L, M, H, and N mean low, moderate, high, and no sensitivity on metals respectively

Sulfur Dioxide (SO_2)

SO_2 is a common air pollutant primarily generated from the combustion of fossil fuels. It reacts with the moisture in the air to form sulfuric acid, which can corrode metals, especially copper, aluminum, zinc, and iron, commonly used in the EDBs.

Nitrogen Dioxide (NO_2)

NO_2, another air pollutant primarily from the combustion processes, can also contribute to corrosion. It reacts with moisture to form nitric acid, which can corrode various metals, including copper, zinc, and nickel, often found in the EDB components.

Chlorine (Cl_2)

Cl_2 is a highly reactive gas commonly used in industrial processes and water treatment. It can directly corrode metals, particularly aluminum, and copper, leading to pitting and weakening of the EDB components.

Ammonia (NH_3)

NH_3, commonly used in fertilizers and refrigeration systems, can also initiate corrosion. It reacts with moisture and carbon dioxide to form ammonium bicarbonate, which can corrode copper and its alloys, usually found in the EDBs.

Carbon Dioxide (CO_2)

CO_2 is a naturally occurring component of the atmosphere and is also emitted by human activity. CO2 is rather weakly soluble in water, forming the mildly corrosive carbonate ion (CO_3^{2-}) and corroding iron and zinc.

Hydrogen Sulfide (H_2S)

H_2S corrosion is mostly electrochemical in nature. In the presence of moisture, H_2S is oxidized to create sulfuric acid, which poses a corrosive threat to metals including copper and iron as described above.

4) Electric Arc

Electric arc or flash, characterized by high-energy sparks, can cause significant corrosion on the EDB equipment, leading to premature failure and safety hazards. The arc on various positions in the EDBs, including the contact surface of circuit breakers, other switching devices, and even the loose tightening between cables, can lead to wear and pitting corrosion. Arcing occurs when an electrical current jumps across an air gap between two conductive surfaces. The intensive heat and light generated during arcing can vaporize the surrounding metal, creating the plasma containing ionized gas[61, 84-87]. This plasma conducts electricity, sustaining the arc until the current is interrupted or the air gap becomes larger than the intensive electric field. The high temperatures and reactive environment created by arcing can initiate corrosion on the surrounding metal surfaces. The vaporized metal can react with moisture, oxygen, and other gases to form corrosion products. These corrosion products can weaken the metal structure, increase electrical resistance, and lead to equipment failure[88].

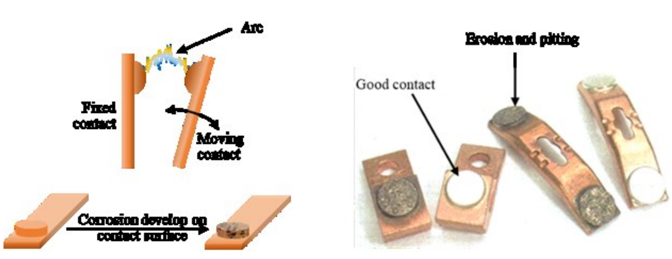


Fig. 7. Electric arc causes corrosion on contacts[89, 90]

Several factors can contribute to arcing in circuit breakers and other switching devices, mainly including voltage level, loose connection, dust or small particles in the contact area, and frequency of switching on/off, which may be adjusted to mitigate the corrosion caused by the arc.

5) Lack of Maintenance

Neglecting proper maintenance can also lead to corrosion problems, which can significantly impact the reliability and safety of the electrical system. Maintenance plays a pivotal role in preventing corrosion in the EDBs, as regular inspections and maintenance procedures, such as cleaning and removing contaminants, tightening the loose connections, and addressing deteriorated or damaged insulation, allows for early detection of corrosion signs and elimination of factors that contribute to the corrosion development.

III. EFFECTS OF CORROSION IN ELECTRICAL DISTRIBUTION BOARD

The EDB is the backbone of modern infrastructure, this critical board is prone to corrosion due to many factors as described in the above section. The natural electrochemical process can significantly compromise the performance and safety of the EDBs. This section provides the intricate relationship between corrosion and EDBs, focusing on the detrimental effects that corrosion poses on the safety, electrical failures, and associated losses of EDBs.

A. Corrosion and Damages on EDB's Components

Corrosion in the EDBs primarily occurs via electrochemical reactions, where metal atoms lose electrons and become cations, dissolving into the surrounding electrolyte. This process is facilitated by the presence of moisture, which acts as the electrolyte, and corrosive agents, such as chlorides, sulfates, and acids. Additionally, temperature fluctuations can cause condensation, promoting corrosion, and can also induce stress corrosion cracking to form the corrosion that occurs under tensile stress in specific environments. The following lists the different parts of an EDB in which the corrosion incidences may fall.

1) Enclosure

An enclosure or housing frame is widely made from thin carbon steel sheets folded into the shape of a closed box all around except on the cover side. There is primary corrosion protection by spraying rust-proof paint. The frame may also have an aluminum or alloy metal rail that is used to hold the breakers or other equipment. When installing the distribution board, drilling is made on the back of the board to secure the board to the wall. Holes can be also drilled at the different sides of the board to carry electrical conductors in and out of the board. Drilling holes make the distribution board vulnerable due to the possible damage to the painting protection layer around the drilled edges. Also, moisture and corrosive agents can enter the board through the holes and result in corrosion.

A variety of corrosion forms could occur on the housing frame. Uniform or general corrosion occurs across the entire surface of the frame where the moisture can penetrate the protective layer. Crevice corrosion can appear in tight crevices or gaps between two metal surfaces where they face an electrolyte. Galvanic corrosion is likely to arise at the contact areas of two dissimilar metals between the housing and the mounting rail in the presence of an electrolyte, while Pitting corrosion can start on the metal surface where the passive film (oxide film) is chemically or mechanically damaged and cannot instantly recover

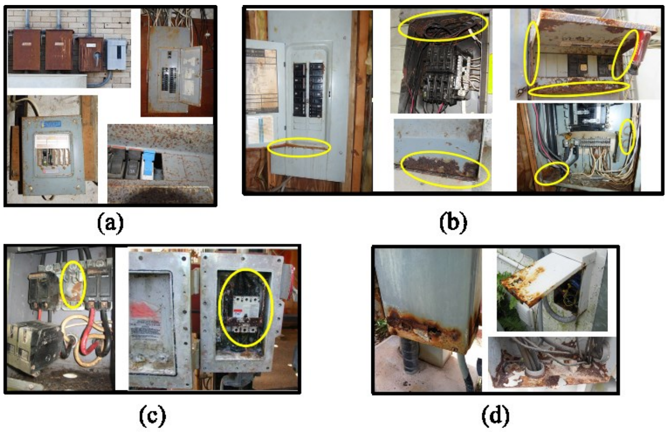


Fig. 8. (a) Uniform or general corrosion attacks on the entire surface of EDBs[91-93], (b) crevice corrosion occurs in tight space between two surfaces[93-96], (c) galvanic attack on different metals between the mounting bracket and encloser[19, 97], (d) pitting corrosion causes the metal surface to wear and tear[98-100]

2) Conductors and Connector Bars

Conductors

Conductors are one of the main players in the EDBs. Two types of conductors are widely used in electrical systems, aluminum, and copper. They conduct electric current from power sources to electrical protective or switching devices and supply the current to electrical loads. Both aluminum and copper are naturally more corrosion-resistant than many other metals, such as iron and steel. This is because a thin layer of oxide film can be formed on the surface of aluminum and copper when they are exposed to air[20, 101-103]. This oxide film or passive layer acts as a protective barrier and prevents further corrosion from occurring[57, 102, 104]. However, several environmental factors can contribute to the damage of the aluminum oxide and copper oxide layer and lead to further corrosion, such as the existence of sulfuric acid, phosphoric acid, hydrochloric acid, nitric acid, hydrogen sulfide, and chloride ions [102, 104-109]. In addition, numerous cases of crevice, galvanic, and pitting corrosion have been reported that they were found on aluminum and copper surfaces [14, 60, 83, 102, 104, 110-113].

Fig. 9 shows the image of a corroded copper wire connected to a circuit in a terminal box[107]. The result from Energy Dispersive X-ray Spectroscopy (EDS) analysis revealed that the chloride ions (Cl^-) play a key role in the corrosion process. The Cl^- accumulated between the insulation and the wire in an outdoor terminal box slowly reacts with the Cu_2O film on the copper wire surface to produce $CuCl_2$. Later, $Cu_2Cl(OH)_3$ is formed by coordination reaction and redeposition process (4)[107, 114], and this results in the acceleration of the corrosion process caused by Cl^-.

$$Cu_2O + Cl^- + 2H_2O + \frac{1}{2}O_2 \rightarrow Cu_2Cl(OH)_3 + OH^- \quad (4)$$

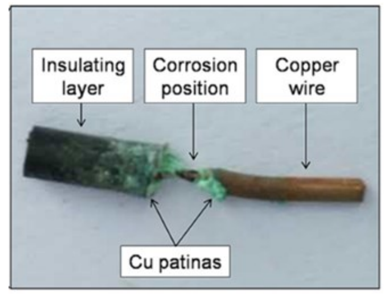


Fig. 9. Corrosion damaged a copper wire in an outdoor terminal box[107]

B. Valdez Salas et al.[108] investigated copper corrosion caused by atmospheric pollutants, which include SO_X, NO_X, CO, and H_2S. As one of the most corrosive agents, H_2S reacts with copper as shown in (5):

$$Cu + H_2S \rightarrow CuS + H_2 \quad (5)$$

Such copper sulfidation is a rapid process that occurs at the metal-gas phase interface and can reduce Cu corrosion resistance[115]. Because copper sulfide (CuS) is a very stable compound and is difficult to remove from copper surfaces, this can lead to the accumulation of CuS, which can eventually flake off, exposing the underlying copper to further corrosion. The results of a three-season year evaluation revealed the corrosion rate caused by the H_2S can damage the surface of copper at the maximum of 255, 265, and 382 mg/m^2·year in spring, summer, and winter, respectively[108].

Another study conducted by K. Kreislova et al. showed that sulfur dioxide (SO_2) in the air caused pitting corrosion to aluminum cables at 5 µm/year[110]. SO_2 reacts with water in the presence of oxygen to form sulfuric acid, which then reacts with aluminum to form aluminum sulfate to cause the corrosion of aluminum, according to the following equation:

$$2Al + 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 6H_2 \quad (6)$$

When aluminum sulfate is exposed to elevated temperatures or moisture, it can decompose into aluminum hydroxide and sulfuric acid as shown in (7):

$$Al_2(SO_4)_3 + 6H_2O \rightarrow 2Al(OH)_3 + 3H_2SO_4 \quad (7)$$

Aluminum hydroxide forms a thin protective layer on the surface of the aluminum, which can help to slow down the corrosion process. However, the sulfuric acid can also break down this protective layer, allowing the corrosion process to continue.

Connecting Equipment

Terminal lugs, cable lugs, busbars, neutral bars, ground/ earth bars, and connector bars are essential components of EDBs, made from many different metals such as brass, aluminum alloy, copper, copper-clad aluminum, and tin-plated copper. They are responsible for making reliable electrical connections between conductors and/or equipment. These metal alloys have a well-designed metal proportion to pose high conductivity, mechanical tolerance, and high corrosion resistance. However, in a harsh environment, these critical components could be also susceptible to corrosion, which can significantly degrade their performance and establish various issues. These connecting equipment can be attacked by different corrosion types such as crevice corrosion between the bar and screws, and galvanic corrosion between the bar and conductors (Fig. 10)[112].

As the bars and lugs can be found in several different types of metals in markets, this can lead to corrosion problems because the conductors connected to these parts may be different. For example, for a connector bar made from brass connected to copper or aluminum conductors that are exposed to electrolytes, the galvanic corrosion can occur (Fig. 10 (b)).

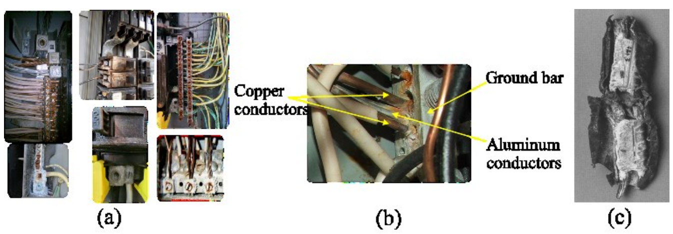


Fig. 10. (a) Corrosion attacks on terminal lugs, busbars, and connector bars of EDBs[15, 28, 93, 116, 117], (b) galvanic corrosion at a ground connector bar[118], (c) corrosion on Al-Cu connector[61]

3) Electrical Contact Points

Molded case circuit breaker (MCCB), miniature circuit breaker (MCB), residual current device (RCD), residual current operated circuit breaker with overcurrent protection (RCBO), surge protection device (SPD), and auxiliary devices such as magnetic relays and other switching equipment can be found as fitted devices in the EDBs. They are utilized to close and open electrical circuits, enhance functionality, and protect circuits or equipment in the distribution boards. One major part of these devices is the metal contact surface which is used for bridging circuits and allows current to flow from an electrical source to drive electrical appliances. Even though these devices are shielded by encapsulation, an electric arc or flash can appear on the contact surfaces when they connect or disconnect to a circuit. Besides the increased electrical resistance on the contact surface[61], damage to devices' contacts [119], and fire hazards [120], the electric arcs can cause erosion and pitting corrosion on device contacts, resulting in additional heat and vaporized metal[84].

A study conducted by G. Vogel[119, 121] revealed that nitrogen oxides, phosphorus, and silicone dioxide were generated after the arc occurred in a contact region, which caused rust and corrosion to occur on contacts. Due to the existence of nitrogen oxides and the presence of moisture, nitric acid was formed in this area and later resulted in significant corrosion after some period of time, as seen in Fig. 11.

A similar case study handled by Omron Corporation [122] found that the arc generated nitric acid from nitrogen and moisture in the atmosphere, causing the corrosion of contacts. Then the corrosion process was accelerated by the arc, resulting in damage to the switching contact. Furthermore, other connections in the EDBs, such as those between terminals and wires or between wires and devices, can also be corroded when these connections are not connected tightly enough. The electric arc can appear at these points and cause them to be corroded. In addition, the more frequently contacts switch on and off, creating the greater possibility of corrosion occurrence and eventually resulting in a shorter lifetime of contact.

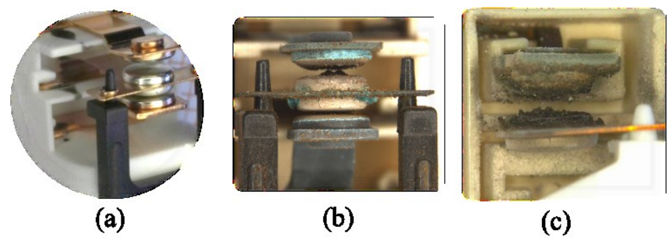


Fig. 11. (a) Initial stage of contact[123], (b) deformation and rust [119, 123], (c) corrosion on contacts' surface[123]

B. Safety Issues

Corrosion poses a silent and frightening threat to the safety of electrical systems. Accumulation of corrosion products on electrical joints such as breakers and connectors can reduce surface area and electrical conductivity. This results in higher electrical resistance and overheating [102, 109, 112]. Additionally, corrosion on the enclosure can reduce the integrity of the protection layer and create a hazard from accidental access to electrical current flowing through unprotected surfaces. This can trigger electrical faults and increase the risk, including short circuits, electric arc, leakage current, and electric shock. Thus, failure to take appropriate precautions in the use of corroded electrical equipment creates conditions that could result in safety issues like injury, fatality, or property damage[19, 124].

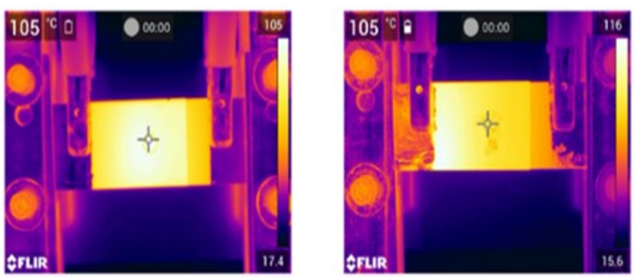
1) Health Hazard

There have been many statistical reports investigating the injuries and deaths from electrical current exposure[125-131]. To prevent accidental access to electric current or electrical equipment in the EDBs, well-maintained enclosures are extremely crucial. When the corrosion damages the enclosures, it certainly increases the chance of electrical current exposure and ensuing danger to residents.

2) Equipment Damage and Fire Hazard

Corrosion can create sharp edges or exposed wires, which pose a fire hazard. Also, the formation of an electric arc at the electrical contact surface or the electrical connection point leads to a series of events that reinforce each other between the arc and corrosion. As mentioned earlier, arc formation leads to corrosion. On the other hand, corrosion can also cause the arc[131]. The co-occurrence of these two processes exacerbates the situation of damaged equipment and fire hazards, resulting in the buildup of heat that can destroy the insulation of the electrical systems, leading to a short circuit and ultimately a fire. A study showed that 16% (82,500 cases) of building fires between 2002 and 2005 were caused by electricity in the U.S., in which more than half (8.8% of total building fires) originated from electrical distribution devices[120]. Among these incidents, corrosion was indicated to be involved with or accelerate poor connection, arcing across carbonized paths and arcing in the air, causing electrical fires[77, 84, 109, 120, 131-133].

A fascinating experiment was carried out by R. F. V. Sampaio et al. [112] presented a comparison of the heat buildup between uncorroded and corroded conductors after a current of 600 amperes was applied to the conductors. By using FLIR thermal imaging camera, it was found that the corroded conductors accumulated heat very fast, reaching the threshold temperature at 105 ^{0}C in only 300 seconds (Fig. 12), three times faster than the uncorroded sample.



$\Delta t \cong 900\,s$ (a) $\Delta t \cong 300\,s$ (b)

Fig. 12. (a) Uncorroded conductors, (b) corroded conductors[112]

C. Electric Failures

Studies have shown that corrosion-affected components may reduce the current carrying capacity, leading to the failure of equipment[19, 20, 108], disruptions to critical operations[15, 78], and degradation of the equipment's operating lifetime[134]. These would ultimately result in a decrease in the reliability and performance of the electrical system. When a corroded electrical distribution system fails in operation, residents may face difficult issues as listed below:

a. A reliable electrical system ensures consistent and uninterrupted power supply to residents, ensuring the operation of essential appliances like kitchen stuff, lighting, heating/cooling, and security systems. Interruptions can cause inconvenience, food spoilage, data loss, and safety concerns. Thus, the lack of a reliable system cannot keep residents' comfort and well-being[135].

b. A high-performance electrical distribution system can reduce energy consumption without compromising power supply quality, reducing costs and safety impact. Inefficient systems like outdated equipment, leakage current, intermittent connectivity[78], heat generation, higher electrical resistance caused by corrosion[61], and lack of maintenance can lead to increased energy bills and the safety of residents.

D. Losses

Corrosion can also result in electrical losses and financial losses. As the financial losses related to the repairing, medical expenses for injuries, and energy wasted costs are beyond the scope of the current paper, we will be focused on the electrical losses resulting from the corrosion of residential electrical systems. In technical terms, electrical losses are mostly stated to the losses in the iron core due to hysteresis and eddy currents, and the losses in winding coils or transmission lines due to several possible issues, such as increasing resistance, deterioration of old equipment, leakage current, phase imbalance, harmonics distortion, and friction from moving parts of generators or motors.[136-141].

One experiment investigating the influence of corrosion on the performance of electrical hybrid busbars was conducted by R. F. V. Sampaio et al.[112]. The result showed that, after salt spray tests, the electrical resistance of the busbars was increased. Especially, the least fastened force busbar with the tightening torque of 1 Nm is the weakest sample due to the easier penetration of the salt spray between the gap of the hybrid busbar. This resulted in the increase of electrical resistance from ~50 μΩ up to more than 1,000 μΩ within only 100 hours of testing. Other studies [142, 143] investigated the effect of corrosion on the electrical resistances of the joint surface using different combinations of materials as conductors and connectors. After 2,000 hours of cycling salt spray test, 40% of samples made from aluminum conductors and aluminum connectors were considered to fail to maintain the resistance because the resistance was changed by more than 10%. In the case of copper conductor joint to aluminum connectors, 40% of samples had a 5-10% increase in resistance. Meanwhile, the copper connectors bond to copper conductors showed a relatively small increase of resistance in 70% of samples.

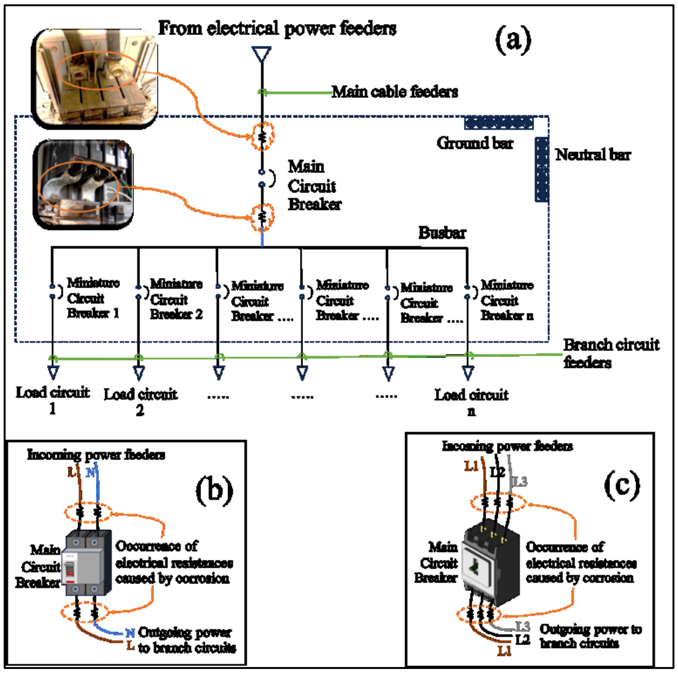


Fig. 13. (a) Single line diagram of EDB and chances of electrical resistance occurrence caused by corrosion at (b) 2-pole MCB, (c) 3-pole MCB

In practice, when the corrosion occurs at the EDBs and attacks the equipment, the resistance of the conductors and connectors increases. Even though the resistance increase on a single conductive part could be quite small (around a few μΩ), there are many conductive points in an EDB that can be corroded if poorly maintained, leading to a possibly large increase in overall resistance and huge electrical power loss. Fig. 13(a) shows a single-line diagram of an EDB consisting of a main circuit breaker, miniature circuit breakers, busbar, neutral bar, and ground bar as its components.

If the corrosion takes place on a 2-pole MCB in a single-phase system, the chance of corrosion attack can occur in the four junction points (two above and two under the MCB) as shown in Fig. 13(b). Likewise, in a 3-pole MCB in a three-phase system (Fig. 13(c)), there are a total of six connections, and thus more risky to be corroded. Additionally, other electrically conductive parts such as busbars, connector bars, and contact surfaces are also likely to be corroded when exposed to the corrosive agents as illustrated in Fig. 10 and 11. Adding up all these components, if corroded, could suggest a significant issue of energy loss.

IV. CORROSION PREVENTION

To reduce or eliminate the corrosion risk factors indicated in the above sections, proper corrosion prevention strategies are needed so that, corrosion prevention and mitigation can be implemented, which will lead to increased reliability, performance, and safety, conserve energy, and reduce costs[19, 144].

A. Corrosion-Resistant Materials

Choosing corrosion-resistant materials for electrical panels can significantly reduce the risk of corrosion problems and extend their life span. Metals like carbon steel, stainless steel, and aluminum are usually found in electrical enclosures[145, 146]. Carbon steel is a relatively cheap material, which however needs to be galvanized, painted, or coated to increase corrosion resistance so that it can be applied to the electrical enclosures. In comparison, stainless steel and aluminum have higher corrosion resistance but are more costly and harder to modify [146]. Non-metal materials like thermoplastics and thermosets are also used for electrical enclosures. They are more resistant to moisture and corrosion, but heat transfer is much more difficult in these materials compared to that in metal[147]. The limited heat transfer inside the distribution board could cause insulation damage or fire, which should not be neglected.

As for the electrical conductors and connectors, the use of dissimilar metals under the contamination of an electrolyte can result in galvanic corrosion to the less noble metal[42-46]. This type of corrosion can be prevented by using the same type of materials for the conductors and connectors[17].

B. Installation Location

The location chosen to install the power distribution panel plays an important role in slowing the corrosion process and maintaining the power distribution panel's durability. Outdoor installation undergoes the most risk for corrosion attack because it is more directly affected by the environment, including humidity, heat, and corrosive gases than indoor installation. There is an additional risk, if installation takes place at a relatively low level or the panel is mounted on the ground, due to the possibility of flooding[148, 149], ground moisture, and infestation by insects or other animals[150, 151]. Meanwhile, if factors that promote or accelerate corrosion are neglected, installation inside a building could also be at higher risk of corrosion, e.g., the installation on a wall that is the outermost part of a building or next to a bathroom or washing area, because these areas are easily exposed to moisture or corrosive chemicals.

Therefore, if the installation area is available to be selected without any reserved conditions for use, it would be better to choose to install the distribution panel in a common area inside the building, which is easily accessible for maintenance. It should not be installed near humidity sources or corrosive agents, such as the shared wall with bathrooms, basements, and chemical storage rooms. In cases where external installation cannot be avoided, a high ingress protection (IP) rating is preferred when choosing an outdoor-type EDB. If the EDB is required to be installed on the ground, the mounting base of the cabinet should be set up at a level high enough to prevent flooding or water awaiting to be drained after rain.

C. Coating and Sealing

Applying a protective coating to the materials or sealing the electric panels can provide several advantages including protecting against moisture and chemicals, extending the lifespan of the panel, reducing maintenance costs, and improving safety.

1) Coating

The coating is an applying layer of deposited materials onto a surface to protect from corrosion. Several techniques are applied to prevent the metal surfaces from corrosion such as dip coating, electroplating, thermal spraying, and polymer coatings[152-155]. EDB metal surfaces are typically coated or sprayed to prevent corrosion during the production process from factories. However, it should be noted that, during installation, EDB can be physically damaged due to transportation scratches, drilling for the mounting holes, and drilling for electrical conductors. Heat accumulation, moisture exposure, and corrosive substances can also cause damage while the electric system is operating. These factors increase the possibility of EDB corroding over time. The spray coating is a simple and cost-effective protection method for damaged panel parts after installation, sometimes using a small amount of additives to enhance adhesion and corrosion resistance.

2) Sealing

Even with the well-applied coating, corrosive substances can still possibly reach the equipment inside the board, via opened gaps such as the gap between the enclosure and its cover, or the drilled holes where the electrical conductors are carried into or out of the panel. Therefore, sealing is an important solution to enhance corrosion protection and block corrosive chemicals so as not to accumulate and react with the metals inside the board. The common sealing method used in the board is to apply silicone sealant to seal along the inside edges of the welding or folding metal joints. The gap sealing between the cabinet and cover is usually performed by using a sealing rubber attached along the cover edge. To prevent moisture and corrosive agents from entering the joint between the board and conduits connected to the board, gaskets or rubber O-rings are generally used.

In addition, there is a protection standard named IP rating, an IEC 60529 international standard used to indicate the level of sealing effectiveness in electrical cabinets against incursion of objects, dust, water, or accidental contact[156]. Normally, the sealing degree is indicated in the IP $\underline{X}_1\underline{X}_2$ form, where X_1 and X_2 indicate the capability of protection against the ingress of solid foreign objects and water, respectively[156, 157]. The number of X_1 ranges from 0 to 6 while the number of X_2 starts from 0 to 9, with the smaller number suggesting less protection provided. For example, IP 69 represents the strongest ability to protect against dust and high-temperature steam-jet water, while IP 34 can only protect against solid objects with a diameter larger than 2.5 mm and splashed water from all directions. Such a sealing indicator is especially useful for choosing the suitable outdoor cabinet.

D. Arc Mitigation

Arc mitigation helps to minimize the effects that cause wear and erosion on the contacts of switching devices, as well as the connection points between cables and terminal bars. To reduce or eliminate the possible arc-generating risks that were discussed in Section II, the following procedures can be taken to realize the electric arc mitigation and reduce the corrosion of equipment in the EDBs.

a. Tighten screws to fit conductor cables onto the busbar, terminal lugs, etc.

b. Keep clean the area in which EDBs are installed, to avoid dust, small particles, and corrosive gases.

c. Lower the resistance or make the switching current zero[158] on electrical circuits by cutting off all electrical load before connecting contacts to supply electric power to the load so that the arc can be reduced.

d. Reduce the on/off switching frequency of contacts, if possible, this will help to reduce the number of electric arc occurrences. If not, a solid-state relay (SSR), a semiconductor switching device with no mechanical contact movement[159-161], could be used as an alternative switching contact to eliminate the arc.

e. Use individual disconnect switches for large electrical loads, so that individual loads can be isolated from the circuit without having to cut off power to the entire circuit.

E. Inspections and Maintenance

Regular inspections and maintenance of EDBs are essential for preventing corrosion and maintaining the integrity of these critical components. By implementing inspections and maintenance regularly, technicians, residents, and building owners can identify any early signs of corrosion to their electrical systems and safeguard them from the damaging effects. The following lists some measures that could be used to keep EDBs away from corrosion.

a. Visual Examination

A thorough visual examination is the first step to identify any corrosion signs. It is easily conducted by examining the metal surfaces of the EDBs for rust, pitting, and flaking, with special attention paid to any spots where moisture can accumulate, such as welds, crevices, and gaskets.

b. Inspection Frequency

The inspection frequency should be determined based on the environmental conditions and the risk level associated with the EDBs. More regular inspections are required for the EDBs located in harsh environments, such as those under high humidity or more exposure to corrosive substances. Inspections should be performed at least once a year, and more frequently for the critical EDBs.

c. Environmental Control

This measure can be implemented by evaluating the environmental conditions around the EDBs and minimizing moisture and exposure to corrosive substances. Proper ventilation, humidity control, and temperature regulation are effective methodologies that can help to reduce the risk of corrosion.

d. Changing Parts

Corroded and damaged parts need to be repaired or changed right after they are discovered, to maintain the normal operation of EDBs.

V. CONCLUSION

Corrosion is an electrochemical process that occurs naturally when metals are subjected to the elements of moisture and corrosive substances that act as electrolytes. Such electrochemical reactions can occur on any part or equipment in an EDB because most of the EDB components are made from metals or alloys. Different types of corrosion can be formed throughout the EDB equipment owing to those metallic parts. The uniform corrosion can occupy the entire surface of the enclosure if the corrosive medium can penetrate the protective layer of the metal. The crevice corrosion can attack the areas between the folded or welded joint of the enclosure, or the gaps between any two metal surfaces where they face an electrolyte. The galvanic corrosion is possible to arise at the contact of two dissimilar metals in the presence of an electrolyte such as the area between the housing and the mounting rail, and the joint between connector bars and conductors. Meanwhile pitting corrosion can start on the metal surface where the passive film is chemically or mechanically damaged. Erosion corrosion also creates issues with the function of switching devices in the EDBs because of the arc generated between the electrical contacts.

These different types of corrosion and the damages that take place in the EDBs can be caused by a variety of factors. Metal impurities with contaminated elements occurred during the production process leading to metal vulnerability and increasing the risk of corrosion. Moisture formed by various sources in the atmosphere according to the location or the installed sites of the EDBs can function as an electrolyte to promote electrochemical reactions and cause significant corrosion of metals. Corrosive gases from the surrounding area can also easily cause metal degradation. The generation of electric arcs could initiate the vaporization of metal contacts which could easily react with moisture, oxygen, and other gases to form corrosion products, resulting in the damage of the contacts or causing electric failures. Ignoring routine maintenance can also result in the continuous development of corrosion, which can seriously compromise the electrical system's security, reliability, and performance.

Whenever corrosion occurs at an EDB it can lead to a sequence of issues. The safety issue like catching on fire due to the heat and arc generated by corrosion is a primary serious issue. Other incidences such as electrical loss caused by increasing electrical resistance, equipment damage, and electrical failures also affect the residents.

To ensure the normal function of the EDBs, the measures have been proposed to prevent the corrosion, which consists of selecting a suitable corrosion-resistant material for use in the electrical panels such as metallic or non-metallic EDBs, considering the proper location for the EDB installation to avoid humidity and corrosive agents, coating the damaged surface and sealing the gaps of the cabinet to prevent moisture and chemicals, reducing the electric arcs to minimize the effects that cause wear and erosion on the electrical devices, and regularly monitoring and maintaining the EDBs to prevent the corrosion occurrence. Carrying out these preventive measures into practice will improve resident safety as well as the reliability and performance of the residential electrical distribution systems.

REFERENCES

[1] S. A. Bradford and J. E. Bringas, Corrosion control. Springer, 1993.

[2] B. Shaw and R. Kelly, "What is corrosion?," The Electrochemical Society Interface, vol. 15, no. 1, p. 24, 2006.

[3] G. A. Cragnolino, "2 - Corrosion fundamentals and characterization techniques," in Techniques for Corrosion Monitoring (Second Edition), L. Yang Ed.: Woodhead Publishing, 2021, pp. 7-42.

[4] Z. Ahmad, "Introduction to corrosion," Principles of corrosion engineering and corrosion control. Oxford: Butterworth-Heinemann, vol. 1, pp. 1-8, 2006.

[5] D. MacDonald et al., "Aqueous corrosion problems in energy systems," Materials Science and Engineering, vol. 50, no. 1, pp. 19-42, 1981.

[6] B. Craig, "Some corrosion and metallurgy issues in coal mines," Mater. Perform, vol. 57, pp. 44-46, 2018.

[7] A. Groysman, "Corrosion problems and solutions in oil, gas, refining and petrochemical industry," KOM–Corrosion and Material Protection Journal, vol. 61, no. 3, pp. 100-117, 2017.

[8] B. N. Popov, "Chapter 10 - Atmospheric Corrosion," in Corrosion Engineering, B. N. Popov Ed. Amsterdam: Elsevier, 2015, pp. 451-480.

[9] H. Bai, "Mechanism analysis, anti-corrosion techniques and numerical modeling of corrosion in energy industry," Oil & Gas Science and Technology–Revue d'IFP Energies nouvelles, vol. 75, p. 42, 2020.

[10] L. T. Popoola, A. S. Grema, G. K. Latinwo, B. Gutti, and A. S. Balogun, "Corrosion problems during oil and gas production and its mitigation," International Journal of Industrial Chemistry, vol. 4, pp. 1-15, 2013.

[11] D. J. Friedman, "Field observations of residential service panel connections and components," Electrical Contacts - 1992 Proceedings of the Thirty-Eighth IEEE Holm Conference on Electrical Contacts, pp. 113- 118, 18- 21 Oct. 1992 1992, doi: 10.1109/HOLM.1992.246926.

[12] G. Koch, M. Brongers, N. Thompson, Y. Virmani, and J. Payer, "Chapter 1- Cost of corrosion in the United States Handbook of Environmental Degradation of Materials," Norwich, NY: William Andrew Publishing, 2005.

[13] N. Hise, "Small amount of rust in panel (no holes)," in General Inspection Discuusion, ed. Online: InterNACHI Inspection Community, 2021.

[14] L. A. Luiz, C. M. Gobi, J. de Andrade, E. Peres, and O. Paro, "Failure analysis of corroded 500 kV connectors made of silver plated ASTM 356 aluminum alloy," Engineering Failure Analysis, vol. 136, p. 106229, 2022/ 06/ 01/ 2022, doi: https://doi.org/10.1016/j.engfailanal.2022.106229.

[15] D. Friedman, "Field Observations of Residential Service Panel Connections and Components," in Rust & Corrosion in Electrical Panels, ed: InspectAPedia, 2015.

[16] H. Chen, X. Yu, X. Liu, and F. Tian, "Corrosion Failure Analysis of Fittings Used for Electrical Equipment in 220 kV Substation," Journal of Physics: Conference Series, vol. 1676, no. 1, p. 012146, 2020.

[17] E. S. Ibrahim, "Corrosion control in electric power systems," Electric Power Systems Research, vol. 52, no. 1, pp. 9-17, 1999/10/01/ 1999, doi: https://doi.org/10.1016/S0378-7796(98)00133-3.

[18] M. B. Z. Ramay, S. Amin, Y. Butt, and M. Sohail, "Corrosion Effect in Underground LV Distribution Networks in Domestic and Commercial Buildings," Engineering Proceedings, vol. 22, no. 1, p. 16, 2022.

[19] J. W. Taylor, K. W. McFarland, and S. Ellis, "Corrosion reduction in power distribution," 2017 Petroleum and Chemical Industry Technical Conference (PCIC), pp. 253-262, 2017.

[20] R. Vera, D. Delgado, and B. M. Rosales, "Effect of atmospheric pollutants on the corrosion of high power electrical conductors: Part 1. Aluminium and AA6201 alloy," Corrosion Science, vol. 48, no. 10, pp. 2882- 2900, 2006/ 10/ 01/ 2006, doi: https://doi.org/10.1016/j.corsci.2005.11.012.

[21] C. O. Muller, "Control of corrosive gases to avoid electrical equipment failure," Purafil, Inc., webpage: www. purafil. com/literature/control-of-corrosive-gases. pdf, pp. 1-13, 1999.

[22] D. Lauria, M. Pagano, C. Petrarca, and C. Pisani, "A Novel Approach to Design Cathodic Protection System for High-Voltage Transmission Cables," IEEE Transactions on Industry Applications, vol. 51, no. 6, pp. 5415-5420, 2015, doi: 10.1109/TIA.2015.2411735.

[23] Z. Huang, C. Feng, J. Wang, W. Liu, and Y. Xie, "Research on metal corrosion mechanism and inhibition measures of transmission and distribution equipment in Hunan," IOP Conference Series: Earth and Environmental Science, vol. 621, no. 1, p. 012035, 2021/01/01 2021, doi: 10.1088/1755-1315/621/1/012035.

[24] C. Jinbing, W. Guogang, and L. Huijun, "Mechanisms analysis and countermeasure of electrical contact overheating of overhead line," in 2014 International Conference on Power System Technology, 2014: IEEE, pp. 1503-1508.

[25] E. Sadeghi, N. Markocsan, and S. Joshi, "Advances in corrosion-resistant thermal spray coatings for renewable energy power plants. Part I: Effect of composition and microstructure," Journal of Thermal Spray Technology, vol. 28, pp. 1749-1788, 2019.

[26] K. Szymański, A. Hernas, G. Moskal, and H. Myalska, "Thermally sprayed coatings resistant to erosion and corrosion for power plant boilers - A review," Surface and Coatings Technology, vol. 268, pp. 153- 164, 2015/ 04/ 25/ 2015, doi: https://doi.org/10.1016/j.surfcoat.2014.10.046.

[27] B. Radojković et al., "Corrosion of metal parts in the power plant," Materials and Corrosion, vol. 74, no. 10, pp. 1499-1513, 2023.

[28] R. Williams. "Building Diagnostic-Service Panel Corrosion." Northern Built. https: / / www. northernbuilt. pro/ building- diagnostic- service-panel-corrosion/ (accessed 22 November, 2023).

[29] R. R. Pierre, Corrosion Engineering- Principles and Practice. TheMcGraw-Hill Companies Inc. USA, 2008.

[30] Eaton. "Panelboards: fundamentals of electrical panelboards." https: / / www. eaton. com/ us/ en- us/ products/ low- voltage- power-distribution-control-systems/panelboards/panelboard-vs--loadcenter---eaton.html (accessed 1st December, 2023).

[31] L. Chen. "Distribution Board Busbar MCB Pan Assembly 100A 200A." Singi Electric. https: / / usune- electric. en. made- in-china. com/ productimage/ aFNGRPmEVBYU-2f1j00jdrWuKJhkGpN/China-Distribution-Board-Busbar-MCB-Pan-Assembly-100A-200A.html (accessed 2nd December, 2023).

[32] H. Junlang. "12 Way Three Phase Distribution Board." Junon Electrical. https://www.junonelectrical.com/product/12-way-three-phase-distribution-board.html (accessed 2nd December, 2023).

[33] D. Horton, "3 phase, residential," ed. Online: Inter NACHI Inspection Community, 2021.

[34] J. P, "US Electrical Panel," ed. Online: Reddit r/electricians, 2020.

[35] Eaton. "Load centers: Fundamentals of electrical load centers." https: / / www. eaton. com/ us/ en- us/ products/ low- voltage- power-distribution- control- systems/ loadcenters/ load- center-fundamentals.html (accessed 1st December, 2023).

[36] Panny. "MCB CE Approved Singi Electric Price Mini Miniature Circuit Breaker Dz47-63." Singi Electric https://singielectric.en.made-in- china. com/ productimage/ nwCaWTyxXskR-2f1j00QJvWUSikMwbe/China-Hot-Sale-MCB-CE-Approved-Singi-Electric- Price- Mini- Miniature- Circuit- Breaker- Dz47- 63. html (accessed 2nd December, 2023).

[37] Pettett. "Replacement of Old Breaker Panel in Plano, TX." Pettett Electric. https: / / www. pettettelectric. com/ about- us/ Case-Studies/replacement-panel (accessed 1st December, 2023).

[38] Pat. "Consumer Unit / Fuseboard Replacement & Installation in Hertfordshire." PAT Testing &EICR. https://www.pattestingherts.co.uk/consumer-unit-replacement.html (accessed 2nd December, 2023).

[39] SES. "Fusebox Consumer Unit Upgrades." Stones Electrical Solutions. https://stoneselectricalsolutions.co.uk/domestic-electrician/fusebox-consumer-unit/ (accessed 2nd December, 2023).

[40] T. Charng and F. Lansing, "Review of corrosion causes and corrosion control in a technical facility," TDA progress report, vol. 42, no. 69, pp. 145-156, 1982.

[41] P. R. Roberge, Handbook of Corrosion Engineering. McGraw-Hill, 2000.

[42] S. C. Dexter, "Galvanic Corrosion," 1999.

[43] K. Sotoodeh, "Chapter 8 - Galvanic corrosion," in Case Studies of Material Corrosion Prevention for Oil and Gas Valves, K. Sotoodeh Ed.: Gulf Professional Publishing, 2022, pp. 271-286.

[44] F. Khoshnaw and R. Gubner, "Part II: Corrosion Topics," in Corrosion Atlas Case Studies: Elsevier, 2020, pp. xliii-lxviii.

[45] S. V. Yadla, V. S. , M. V. V. C. L. , and S. P. K. K. , "A REVIEW ON CORROSION OF METALS AND PROTECTION," INTERNATIONAL JOURNAL OF ENGINEERING SCIENCE & ADVANCED TECHNOLOGY [IJESAT] vol. 2, no. 3, pp. 637-644, 2012.

[46] C. Vargel, "Chapter B.3 - Galvanic Corrosion," in Corrosion of Aluminium, C. Vargel Ed. Amsterdam: Elsevier, 2004, pp. 149-164.

[47] I. Rosenfeld and I. Marshakov, "Mechanism of crevice corrosion," Corrosion, vol. 20, no. 4, pp. 115t-125t, 1964.

[48] Z. Chen, F. Cui, and R. Kelly, "Calculations of the cathodic current delivery capacity and stability of crevice corrosion under atmospheric environments," Journal of the Electrochemical Society, vol. 155, no. 7, p. C360, 2008.

[49] A. Lazareva, J. Owen, S. Vargas, R. Barker, and A. Neville, "Investigation of the evolution of an iron carbonate layer and its effect on localized corrosion of X65 carbon steel in CO2 corrosion environments," Corrosion Science, vol. 192, p. 109849, 2021.

[50] Y. Li, N. Xu, G. Liu, X. Guo, and G. Zhang, "Crevice corrosion of N80 carbon steel in CO2-saturated environment containing acetic acid," Corrosion Science, vol. 112, pp. 426-437, 2016.

[51] Q. Hu, G. Zhang, Y. Qiu, and X. Guo, "The crevice corrosion behaviour of stainless steel in sodium chloride solution," Corrosion science, vol. 53, no. 12, pp. 4065-4072, 2011.

[52] P. R. Roberge, "Corrosion engineering," Principles and Practice, vol. 1, 2005.

[53] G. S. Frankel, "Pitting Corrosion of Metals: A Review of the Critical Factors," Journal of The Electrochemical Society, vol. 145, no. 6, p. 2186, 1998/06/01 1998, doi: 10.1149/1.1838615.

[54] G. T. Burstein, C. Liu, R. M. Souto, and S. P. Vines, "Origins of pitting corrosion," Corrosion Engineering, Science and Technology, vol. 39, no. 1, pp. 25- 30, 2004/ 03/ 01 2004, doi: 10.1179/147842204225016859.

[55] G. Frankel, "Pitting corrosion of metals: a review of the critical factors," Journal of the Electrochemical society, vol. 145, no. 6, p. 2186, 1998.

[56] S. M. Sharland, "A review of the theoretical modelling of crevice and pitting corrosion," Corrosion Science, vol. 27, no. 3, pp. 289-323, 1987/01/01/ 1987, doi: https://doi.org/10.1016/0010-938X(87)90024-2.

[57] Z. Szklarska-Smialowska, "Pitting corrosion of aluminum," Corrosion science, vol. 41, no. 9, pp. 1743-1767, 1999.

[58] G. Burstein, C. Liu, R. Souto, and S. Vines, "Origins of pitting corrosion," Corrosion Engineering, Science and Technology, vol. 39, no. 1, pp. 25-30, 2004.

[59] N. U. Obeyesekere, "Pitting corrosion," Trends in Oil and Gas Corrosion Research and Technologies, pp. 215-248, 2017.

[60] K. Akpanyung and R. Loto, "Pitting corrosion evaluation: a review," Journal of Physics: Conference Series, vol. 1378, no. 2, p. 022088, 2019.

[61] M. Braunovic, N. K. Myshkin, and V. V. Konchits, Electrical contacts: fundamentals, applications and technology. CRC press, 2017.

[62] S. Harsimran, K. Santosh, and K. Rakesh, "Overview of corrosion and its control: A critical review," Proc. Eng. Sci, vol. 3, no. 1, pp. 13-24, 2021.

[63] M. Stewart, "2 - History and organization of codes," in Surface Production Operations, M. Stewart Ed. Boston: Gulf Professional Publishing, 2021, pp. 19-60.

[64] R. D. Pehlke, "Steel Plants: Size, Location, and Design," in Encyclopedia of Materials: Science and Technology, K. H. J. Buschow et al. Eds. Oxford: Elsevier, 2001, pp. 8824-8832.

[65] N. Bailey, "1 - Factors influencing weldability," in Weldability of Ferritic Steels, N. Bailey Ed.: Woodhead Publishing, 1994, pp. 1-44.

[66] M. Stewart, "4 - Materials selection for pressure vessels," in Surface Production Operations, M. Stewart Ed. Boston: Gulf Professional Publishing, 2021, pp. 93-116.
[67] K. Sotoodeh, "Chapter Four - Corrosion study and material selection for cryogenic valves in an LNG plant," in Cryogenic Valves for Liquefied Natural Gas Plants, K. Sotoodeh Ed.: Gulf Professional Publishing, 2022, pp. 175-211.
[68] K. Sotoodeh, "Chapter Twelve - Material selection and corrosion," in Subsea Valves and Actuators for the Oil and Gas Industry, K. Sotoodeh Ed.: Gulf Professional Publishing, 2021, pp. 421-457.
[69] F. Mutahhar, G. Aithan, E. V. Iski, M. W. Keller, S. Shirazi, and K. P. Roberts, "31 - Mechanistic modeling of erosion–corrosion for carbon steel," in Trends in Oil and Gas Corrosion Research and Technologies, A. M. El-Sherik Ed. Boston: Woodhead Publishing, 2017, pp. 749-763.
[70] S. Winnik, "8 - Design for the prevention of corrosion-under-insulation," in Corrosion Under Insulation (CUI) Guidelines, S. Winnik Ed.: Woodhead Publishing, 2008, pp. 63-69.
[71] Z. Ahmad, "CHAPTER 10 - ATMOSPHERIC CORROSION," in Principles of Corrosion Engineering and Corrosion Control, Z. Ahmad Ed. Oxford: Butterworth-Heinemann, 2006, pp. 550-575.
[72] B. G. Koushik, N. Van den Steen, M. H. Mamme, Y. Van Ingelgem, and H. Terryn, "Review on modelling of corrosion under droplet electrolyte for predicting atmospheric corrosion rate," Journal of Materials Science & Technology, vol. 62, pp. 254-267, 2021/01/30/ 2021, doi: https://doi.org/10.1016/j.jmst.2020.04.061.
[73] M. I. Hussain et al., "Chapter 5 - Corrosion resistance of nanostructured metals and alloys," in Corrosion Protection at the Nanoscale, S. Rajendran, T. A. N. H. Nguyen, S. Kakooei, M. Yeganeh, and Y. Li Eds.: Elsevier, 2020, pp. 63-87.
[74] Q. Cao et al., "A Review of Corrosion under Insulation: A Critical Issue in the Oil and Gas Industry," Metals, vol. 12, no. 4, p. 561, 2022. [Online]. Available: https://www.mdpi.com/2075-4701/12/4/561.
[75] J. S. G. Elizalde and Y.-S. Chiou, "Improving the detectability and confirmation of hidden surface corrosion on metal sheets using active infrared thermography," Journal of Building Engineering, vol. 66, p. 105931, 2023/05/01/ 2023, doi: https://doi.org/10.1016/j.jobe.2023.105931.
[76] B. M. Drees et al., "Managing imported fire ants in urban areas," 2009.
[77] D. Zeng, P. P. Su, R. Madan, and Y. Wang, "Evaluation of flammability and smoke corrosivity of data/power cables used in data centers," Fire Safety Journal, vol. 120, p. 103094, 2021/03/01/ 2021, doi: https://doi.org/10.1016/j.firesaf.2020.103094.
[78] J. S. Newman, P. Su, G. G. Yee, and S. Chivukula, "Development of smoke corrosion and leakage current damage functions," Fire safety journal, vol. 61, pp. 92-99, 2013.
[79] B. T. Reagor, "Smoke corrosivity: Generation, impact, detection, and protection," Journal of fire sciences, vol. 10, no. 2, pp. 169-179, 1992.
[80] T. J. Tanaka, "Measurements of the effects of smoke on active circuits," Fire and materials, vol. 23, no. 3, pp. 103-108, 1999.
[81] L. Gay, R. Gracia, S. Mongruel, and E. Wizenne, "Effects of cable fire smoke on electronic boards," Fire Saf. Sci, vol. 11, pp. 1035-1048, 2014.
[82] J. Gibbons and G. Stevens, "Limiting the corrosion hazard from electrical cables involved in fires," Fire safety journal, vol. 15, no. 2, pp. 183-190, 1989.
[83] C. Leygraf, I. O. Wallinder, J. Tidblad, and T. Graedel, Atmospheric corrosion. John Wiley & Sons, 2016.
[84] J. C. Das, Arc flash hazard analysis and mitigation, 2nd ed. John Wiley & Sons, 2020.
[85] S. Hwang, D. Hwang, H. Baek, and C. Shin, "Effect of copper-based spring alloy selection on arc erosion of electrical contacts in a miniature electrical switch," Metals and Materials International, vol. 27, pp. 2369-2377, 2021.
[86] J. McBride and P. Weaver, "Review of arcing phenomena in low voltage current limiting circuit breakers," IEE Proceedings-Science, Measurement and Technology, vol. 148, no. 1, pp. 1-7, 2001.
[87] M. Kesim, H. Yu, Y. Sun, M. Aindow, and S. Alpay, "Corrosion, oxidation, erosion and performance of Ag/W-based circuit breaker contacts: A review," Corrosion Science, vol. 135, pp. 12-34, 2018.
[88] Tyco, "Contact Life: Unsuppressed vs. Suppressed Arcing," Arc Suppression Technologies, LLC, 2013. [Online]. Available: https://www.arcsuppressiontechnologies.com/wp-content/uploads/2016/07/Arc_Supression_Lab_Note_105_Contact_Life.pdf
[89] B. Johnson. "Btu Buddy 147: Low Performance Commercial Unit." The NEWS. https://www.achrnews.com/articles/129926-btu-buddy-147-low-performance-commercial-unit (accessed 17th December, 2023).
[90] J. Moore, "Basic Electrical Contactors," ed: Slide Player, 2015.
[91] D. Bradshaw. "How to Prevent Rust and Damage to Your Electrical Panel." All Seasons https://www.wantheat.com/how-to-prevent-rust-and-damage-to-your-electrical-panel/ (accessed 9th December, 2023).
[92] "Specially selected historic real estate for old house enthusiasts." Old House Dreams. https://www.oldhousedreams.com/2020/10/26/c-1875-gothic-revival-italianate-in-le-raysville-pa/ (accessed 9th December, 2023).
[93] D. Jones. "Rusted and Corroded Electrical Panels." Buyers Ask. https://buyersask.com/electrical/electrical-panels/rusted-panels/ (accessed 10th December, 2023).
[94] J. Markanich. "How Much Rust In An Electric Panel Box And Its Components Is Too Much?" Jay Markanich Real Estate Inspections, LLC. https://activerain.com/blogsview/4331126/how-much-rust-in-an-electric-panel-box-and-its-components-is-too-much- (accessed 10th December, 2023).
[95] R. SALTZMAN. "Challenger panels are fine." Structure Tech. https://structuretech.com/challenger-panels-are-fine/ (accessed 10th December, 2023).
[96] J. Grabowski. "Rusted Circuit Breaker Cover." DIY Chatroom. https://www.diychatroom.com/media/rusted-circuit-breaker-cover.38655/ (accessed 10th December, 2023).
[97] "ELECTRICAL SERVICES." Abacoore Electric. http://www.abacooreelectric.com/residential/ (accessed 10th December, 2023).
[98] Carrie. "Do You Need an electrical panel Upgrade." Eagle Plumbing Services. https://eagleplumbing.net/thinking-of-replacing-your-electrical-panel/ (accessed 9th December, 2023).
[99] R. McGarry and G. Madsen. "When should a corroded or damaged electric panel cabinet or disconnect box be replaced?" McGarry and Madsen Inspection. https://www.howtolookatahouse.com/Blog/Entries/2018/6/when-should-a-corroded-or-damaged-electric-panel-cabinet-or-disconnect-box-be-replaced.html (accessed 10th December, 2023).
[100] "Rusted Electrical Box - Exterior." Home Repair. http://homerepair.gregvan.com/electrical_repair/rusted_electrical_box__exterior.htm (accessed 10th December, 2023).
[101] A. Van Deursen, B. Kruizinga, P. Wouters, and E. Steennis, "Impact of corrosion on the reliability of low voltage cables with aluminium conductors," in 2017 52nd International Universities Power Engineering Conference (UPEC), 2017: IEEE, pp. 1-6.
[102] A. Fateh, M. Aliofkhazraei, and A. Rezvanian, "Review of corrosive environments for copper and its corrosion inhibitors," Arabian journal of Chemistry, vol. 13, no. 1, pp. 481-544, 2020.
[103] J. J. Shim and J. G. Kim, "Copper corrosion in potable water distribution systems: influence of copper products on the corrosion behavior," Materials Letters, vol. 58, no. 14, pp. 2002-2006, 2004/05/01/ 2004, doi: https://doi.org/10.1016/j.matlet.2003.12.017.
[104] R. E. Melchers, "Time dependent development of aluminium pitting corrosion," Advances in Materials Science and Engineering, vol. 2015, 2015.
[105] K. Habib, "In-situ monitoring of pitting corrosion of copper alloys by holographic interferometry," Corrosion science, vol. 40, no. 8, pp. 1435-1440, 1998.
[106] R. Souto, M. P. Sánchez, M. Barrera, S. González, R. Salvarezza, and A. Arvia, "The kinetics of pitting corrosion of copper in alkaline solutions containing sodium perchlorate," Electrochimica acta, vol. 37, no. 8, pp. 1437-1443, 1992.
[107] T. Wu, Z. Zhou, S. Xu, Y. Xie, L. Huang, and F. Yin, "A corrosion failure analysis of copper wires used in outdoor terminal boxes in substation," Engineering Failure Analysis, vol. 98, pp. 83-94, 2019.
[108] B. Valdez Salas et al., "Copper corrosion by atmospheric pollutants in the electronics industry," International Scholarly Research Notices, vol. 2013, 2013.
[109] M. Benfer and D. Gottuk, "Electrical receptacles—Overheating, arcing, and melting," Fire Safety Science, vol. 11, pp. 1010-1023, 2014.
[110] K. Kreislova, M. Jaglova, L. Turek, and A. Koukalova, "Evaluation of corrosion of long-term exposed aluminium conductor/Hodnocení

korozního napadení hliníkových vodičù po dlouhodobé expozici," KOM– Corrosion and Material Protection Journal, vol. 57, no. 1, pp. 25-34, 2013.
[111] M. Winnicki et al., "Corrosion protection and electrical conductivity of copper coatings deposited by low-pressure cold spraying," Surface and Coatings Technology, vol. 318, pp. 90-98, 2017.
[112] R. F. V. Sampaio, J. P. M. Pragana, I. M. F. Bragança, C. M. A. Silva, J. C. S. Fernandes, and P. A. F. Martins, "Influence of corrosion on the electrical and mechanical performance of hybrid busbars," International Journal of Lightweight Materials and Manufacture, vol. 5, no. 4, pp. 510- 519, 2022/ 12/ 01/ 2022, doi: https://doi.org/10.1016/j.ijlmm.2022.06.005.
[113] C. Vargel, "Chapter H.5 - Resistance of aluminium to atmospheric corrosion," in Corrosion of Aluminium (Second Edition), C. Vargel Ed. Amsterdam: Elsevier, 2020, pp. 575-589.
[114] Q. Dongmei, C. Ruoyi, D. Xiaoqing, C. Yu, Z. Zhao, and Z. Jianqing, "Review on atmospheric corrosion of copper and copper alloys," Journal of Chinese Society for Corrosion and protection, vol. 34, no. 5, pp. 389-398, 2014.
[115] L. Veleva, B. Valdez, G. Lopez, L. Vargas, and J. Flores, "Atmospheric corrosion of electro-electronics metals in urban desert simulated indoor environment," Corrosion Engineering, Science and Technology, vol. 43, no. 2, pp. 149-155, 2008.
[116] R. McGarry and G. Madsen. "How dangerous is rust and corrosion inside an electrical panel?" McGarry and Madsen Inspection. https: / / www. howtolookatahouse. com/ Blog/ Entries/ 2020/ 1/ how-dangerous- is- rust- and- corrosion- inside- an- electrical- panel. html (accessed 11st December, 2023).
[117] GPintheMitten, " Corrosion in Electric Panel," ed. Online: GPintheMitten, 2009.
[118] C. Buell, "corrosion at CU & AL," ed. Online: Inter Nachi Inspection Community, 2007.
[119] G. Vogel, "FAILURE MECHANISMS OF ELECTROMECHANICAL RELAYS ON PCBAs: PART II," ELECTRONIC DEVICE FAILURE ANALYS, vol. 20, no. 2, pp. 4-8, 2018.
[120] V. Babrauskas, "Research on electrical fires: The state of the art," Fire Saf. Sci, vol. 9, pp. 3-18, 2008.
[121] G. Vogel, "FAILURE MECHANISMS OF ELECTROMECHANICAL RELAYS ON PCBAs: PART I," ELECTRONIC DEVICE FAILURE ANALYS, vol. 20, no. 1, pp. 4-8, 2018.
[122] Omron, The solusions: Relay Defects. OMRON Corporation, 2016.
[123] G. Vogel, Contact failures on electromechanical relays. 2017.
[124] R. W. McLay and R. D. Brugger, "Engineering Standards in Electric Shock," in Engineering Standards for Forensic Application: Elsevier, 2019, pp. 79-94.
[125] V. Volberg, T. Fordyce, M. Leonhard, G. Mezei, X. Vergara, and L. Krishen, "Injuries among electric power industry workers, 1995–2013," Journal of Safety Research, vol. 60, pp. 9-16, 2017/02/01/ 2017, doi: https://doi.org/10.1016/j.jsr.2016.11.001.
[126] A. D. Baka and A. D. Bakas, "Preventing electric shock accidents in workplaces," Ain Shams Engineering Journal, vol. 13, no. 6, p. 101702, 2022/11/01/ 2022, doi: https://doi.org/10.1016/j.asej.2022.101702.
[127] M. A. Kelsh, E. T. Lu, K. Ramachandran, C. Jesser, T. Fordyce, and J. W. Yager, "Occupational injury surveillance among electric utility employees," Journal of occupational and environmental medicine, pp. 974-984, 2004.
[128] A. Piotrowski et al., "Outcome of occupational electrical injuries among French electric company workers: A retrospective report of 311 cases, 1996–2005," Burns, vol. 40, no. 3, pp. 480-488, 2014/05/01/ 2014, doi: https://doi.org/10.1016/j.burns.2013.08.008.
[129] H. Maghsoudi, Y. Adyani, and N. Ahmadian, "Electrical and Lightning Injuries," Journal of Burn Care & Research, vol. 28, no. 2, pp. 255-261, 2007, doi: 10.1097/bcr.0b013e318031a11c.
[130] T. A. Fordyce, M. Kelsh, E. T. Lu, J. D. Sahl, and J. W. Yager, "Thermal burn and electrical injuries among electric utility workers, 1995–2004," Burns, vol. 33, no. 2, pp. 209-220, 2007.
[131] K. Kowalski-Trakofler and E. Barrett, "Reducing non-contact electric arc injuries: An investigation of behavioral and organizational issues," Journal of Safety Research, vol. 38, no. 5, pp. 597-608, 2007/01/01/ 2007, doi: https://doi.org/10.1016/j.jsr.2007.06.004.
[132] J. Li, Z. He, L. Bao, and L. Yang, "Influences of corrosive sulfur on copper wires and oil-paper insulation in transformers," Energies, vol. 4, no. 10, pp. 1563-1573, 2011.
[133] X. Shi, Q. Ke, J. Lei, and Z. Yuan, "Test and Analysis of Accelerated Corrosion of Electrical Equipment in Distribution Power System," in Journal of Physics: Conference Series, 2020, vol. 1578, no. 1: IOP Publishing, p. 012203.
[134] A. Stoppato, A. Mirandola, G. Meneghetti, and E. L. Casto, "On the operation strategy of steam power plants working at variable load: Technical and economic issues," Energy, vol. 37, no. 1, pp. 228-236, 2012.
[135] D. Abi Ghanem, S. Mander, and C. Gough, "“I think we need to get a better generator”: Household resilience to disruption to power supply during storm events," Energy Policy, vol. 92, pp. 171-180, 2016.
[136] J. P. Navani, N. K. Sharma, and S. Sapra, "Technical and non-technical losses in power system and its economic consequence in Indian economy," International journal of electronics and computer science engineering, vol. 1, no. 2, pp. 757-761, 2012.
[137] H. E. Kassem, M. Badr, and S. A. Ahmed, "Reduction of energy losses in electrical distribution systems," 2013.
[138] S. S. Mustafa, M. H. Yasen, H. H. Abdullah, and H. K. Hazaa, "Evaluation of electric energy losses in kirkuk distribution electric system area," Iraq J. Electrical and Electronic Engineering, vol. 7, no. 2, pp. 144-150, 2011.
[139] S. M. Plotnikov, "Determination of Eddy-Current and Hysteresis Losses in the Magnetic Circuits of Electrical Machines," Measurement Techniques, vol. 63, no. 11, pp. 904-909, 2021/02/01 2021, doi: 10.1007/s11018-021-01866-9.
[140] W. Geng et al., "Rotor Air-Friction Loss and Thermal Analysis of IPM Rotors for High Speed Axial-Flux Machine," IEEE Transactions on Industry Applications, vol. 59, no. 1, pp. 779-788, 2023, doi: 10.1109/TIA.2022.3210896.
[141] M. M. Znidarich, "Hydro generator stator cores part 2 - core losses, degradation mechanisms, testing and specification," in 2008 Australasian Universities Power Engineering Conference, 14-17 Dec. 2008 2008, pp. 1-9.
[142] R. Frank and C. Morton, "Comparative corrosion and current burst testing of copper and aluminum electrical power connectors," in Fourtieth IAS Annual Meeting. Conference Record of the 2005 Industry Applications Conference, 2005., 2005, vol. 1: IEEE, pp. 442-447.
[143] V. Buchholz, R. Frank, and C. Morton, "Corrosion and Current Burst Testing of Copper and Aluminum Electrical Power Connectors," in 2005/2006 IEEE/PES Transmission and Distribution Conference and Exhibition, 2006: IEEE, pp. 996-1001.
[144] J. H. Payer and R. Latanision, "Preventive Strategies," ed, 2017.
[145] "Electrical Enclosure Materials." NEMA Enclosures. https: / / www. nemaenclosures. com/ materials. html (accessed 28th December, 2023).
[146] M. Szemanski. "Electrical Enclosures: Know Your Materials." Panel Shop. https://info.panelshop.com/blog/electrical-enclosures-know-your-materials#:~:text=The%20Main%203%20Materials&text=The%20three%20most%20common%20metals,fabrication%20for%20installation%20or%20expansion. (accessed 28th December, 2023).
[147] M. Szymiczek and D. Buła, "Polyester and Epoxy Resins with Increased Thermal Conductivity and Reduced Surface Resistivity for Applications in Explosion-Proof Enclosures of Electrical Devices," Materials, vol. 15, no. 6, p. 2171, 2022. [Online]. Available: https://www.mdpi.com/1996-1944/15/6/2171.
[148] E. I. Chisolm and J. C. Matthews, "Impact of hurricanes and flooding on buried infrastructure," Leadership and Management in Engineering, vol. 12, no. 3, pp. 151-156, 2012.
[149] N. Abi-Samra and W. Henry, "Actions before… and after a flood," IEEE Power and Energy Magazine, vol. 9, no. 2, pp. 52-58, 2011.
[150] B. M. Drees, "Managing Red Imported Fire Ant in Electrical Equipment and Utility Housings," Texas fire ant research and management project, 1998.
[151] H. C. Reed and P. J. Landolt, "Chapter 22 - Ants, Wasps, and Bees (Hymenoptera)," in Medical and Veterinary Entomology (Third Edition), G. R. Mullen and L. A. Durden Eds.: Academic Press, 2019, pp. 459-488.
[152] B. Fotovvati, N. Namdari, and A. Dehghanghadikolaei, "On coating techniques for surface protection: A review," Journal of Manufacturing and Materials processing, vol. 3, no. 1, p. 28, 2019.
[153] P. C. Innocenzi, M. Guglielmi, M. Gobbin, and P. Colombo, "Coating of metals by the sol-gel dip-coating method," Journal of the European

Ceramic Society, vol. 10, no. 6, pp. 431-436, 1992/01/01/ 1992, doi: https://doi.org/10.1016/0955-2219(92)90018-9.

[154] Y. Zhai, K. Pan, and E. Zhang, "Anti-corrosive coating of carbon-steel assisted by polymer- camphorsulfonic acid embedded within graphene," Coatings, vol. 10, no. 9, p. 879, 2020.

[155] L. Barchi, U. Bardi, S. Caporali, M. Fantini, A. Scrivani, and A. Scrivani, "Electroplated bright aluminium coatings for anticorrosion and decorative purposes," Progress in Organic Coatings, vol. 67, no. 2, pp. 146-151, 2010.

[156] A. A. Date, "ANSI/IEC 60529-2004," 2004.

[157] IEC. "IP ratings." International Electrotechnical Commission. https://www.iec.ch/ip-ratings (accessed 31st December, 2023).

[158] M. Brown, J. Rawtani, and D. Patil, "5 - Switches, circuit breakers and switchboards," in Practical Troubleshooting of Electrical Equipment and Control Circuits, M. Brown, J. Rawtani, and D. Patil Eds. Oxford: Newnes, 2004, pp. 112-120.

[159] V. Gurevich, "The International Standard on Solid-State Relays (IEC 62314, Ed. 1) Critical Review," 8th January 2024. [Online]. Available: https://www.gurevich-publications.com/reviews/iec_62314.pdf. Israel Electric Corporation.

[160] Technical Explanation for Solid-state Relays: Omron. [Online]. Available: https://www.ia.omron.com/data_pdf/guide/18/ssr_tg_e_9_2.pdf. Accessed on: 8th January 2024.

[161] Allen-Bradley, Solid-State Relays 700-SA -SC, -SE, -SF, -SH, -SK: Rockwell Automation, 2002. [Online]. Available: https://literature.rockwellautomation.com/idc/groups/literature/documents/at/700-at001_-en-e.pdf. Accessed on: 8th January 2024.