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# Unraveling The Complexity: Root Cause Analysis Of Electrical Faults In Industry & Other Facility

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**Abstract -** The sole purpose of this analysis was to discuss the broader picture of fire incidents that occurred in industry due to electrical faults. Nowadays, fire incidents in industries as well as in residential and commercial buildings are a common case. Local and international print & electronic media report fire incidents every day. The fatalities are remarkable and also caused extensive property damage, and undoubtedly, it can be mitigated upon consideration of a few factors. This article identifies the exact causes of electrical faults, investigating previous fire incident reports in various industries and other possible reasons. During the past decades, there has been a noticeable change in infrastructure and industrial development worldwide. Because of land shortage and improper planning, the number of high-rise buildings in the industry sector increases without maintaining electrical standards, increasing fire incidents, fatality rates, and substantial property damages. Though strong laws, national and international standards, and regulatory measures existed, accidents occurred regularly. Also, there is no significant guideline for electrical product quality, run time, and materials selection, which plays a major role in fire incidents. This report anticipates understanding the lack in the existing system, considerable findings for installations, and extending to further studies to find out proper remediation.

**Keywords:** Electrical Fault, Fire Safety, Risk Analysis, Sustainability, Short-Circuit.

## 1. INTRODUCTION

The whole world is in a transition of fast modernization in the industry. Modern technology is a blessing for business development; fire incidents and fatality rates have increased proportionally. Fire incidents are boosted with flammable materials and chemicals, and it is also difficult to save life and property once it starts. So the analysis is taken part for no fire start or less in number. Electrical short circuit is a very common problem in the industry. Although the adequacy of fire safety arrangements is considerable, it wasn't worth it in some cases. Considering previous fire incident reports in Bangladesh, the fire service authority concluded that there were more than 21,000 fire incidents annually, and about 40% were caused by electrical short circuits (The Business Standard, 2022). According to the National Fire Protection Association report, nearly 50,000 home fires are involved by electrical problems each year in the US, resulting in more than 500 deaths and property damage worth $1.4 billion, besides 24% of structure fire incidents caused by electrical distribution systems (Campbell, 2018). Some unacceptable electrical hazards are found upon field visits and report analysis of various industries in Bangladesh. Standard design considering safety factors before electrical installation and component selection is crucial to avoid malfunction (Aronstein, 2022). So far, most of the electrical installations have been conducted by the local contractor without maintaining compliance standards, and the customer selected cheap equipment without prioritizing the safety factor. As considered, the electrical fault is the main culprit for most of the fire incidents; the results conclude that incorrectly refurbished circuit breaker from local rebuilder, higher rated circuit breaker compared to cable and load capacity, loose connection, insulation damage, compromised overload protection, exposed live cable, non-standard cable joints and usage of old, outdated electrical equipment's are the main cause for electrical fire occurrence (Kumar & Kalappan, 2023). Material selection does not take place when designing and installing electrical systems according to the power quality, ambient temperature, humidity, and environment as it defers in areas. Besides these, low-skilled electricians/operators are similarly responsible for hazardous workplaces.

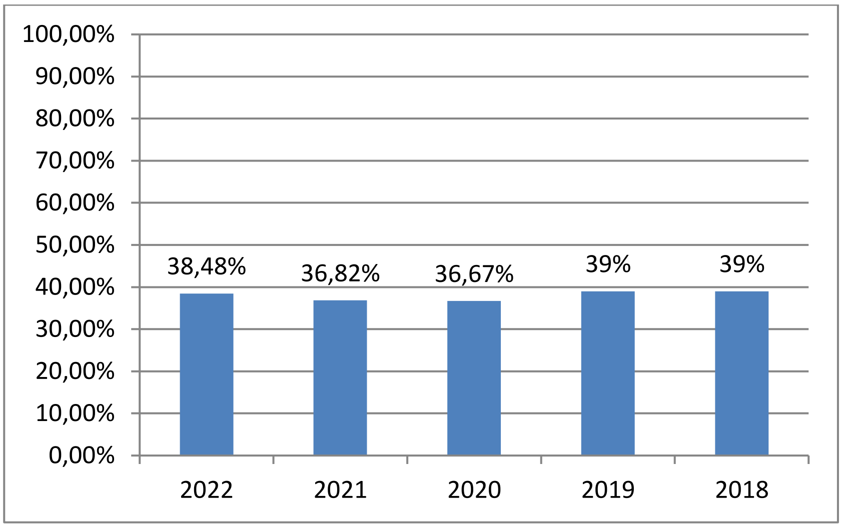


**Figure 1.** Fire Incident by Electrical Fault in Bangladesh (Fire Service & Civil Defense).

According to the yearly database of Fire Service and Civil Defense Bangladesh, there were no significant changes in the number of electrical fires in the last five years. The statistic shows that nearly 40% of fires in industry and other facilities are caused yearly by electrical hazards (Fire Service & Civil Defense).

## 2. LITERATURE REVIEW: MAJOR FINDINGS FOR ELECTRICAL FIRES

### 2.1 Incorrectly Refurbished Circuit Breaker

An incorrectly refurbished circuit breaker is a circuit breaker that has been fixed or rebuilt in a way that does not meet the original manufacturer's specifications. These breakers were sold by the third-party rebuilder either directly to users or indirectly through the local market. Also, it can happen if the work is performed by a company that is not qualified to repair circuit breakers or if the company employs inappropriate parts or processes. Circuit breakers that have been improperly refurbished is defective and can be harmful since they may not perform properly in the case of an overload or short circuit (Aronstein, 2022), which can result in a variety of risks, including:

The arc flash: When an electric arc is exposed to air, it can cause an arc flash, which is a rapid and intense burst of light and heat. These rapid releases of energy are due to an arcing fault between a phase conductor with another phase conductor, or with a neutral or ground conductor (Pham & Jones, 2009). Arc flashes have the potential to cause severe burns, blindness, and even death.

Shock and electrocution: When a circuit breaker fails to trip when it should, it can allow too much electricity to pass through a circuit, resulting in shock or electrocution. There are two factors involved in electrocution: the nature of electric supply like voltage, amperage and form of current; and the victim’s body tissues resistance absorb capacity, area of contact of the body, duration of contact, earthing and insulation (Vij, 2011).

Fire: If a circuit breaker that has been improperly reconditioned or due to temperature, it fails to trip when it should, it might overheat and spark a fire (Wang et al., 2023).

The breakers may have an actual rating of 600 volts AC (alternating current) (VAC) or less but are labeled as 1,000 VAC and may contain incorrect parts that can cause the breaker to malfunction. The hazardous condition may affect circuit breakers of any size and capacity. The

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circuit breakers may appear new, but a third-party rebuilder changed them from the manufacturer's original design. The third-party rebuilder reproduced and affixed a product label to the front of the breakers to make the circuit breakers look new and legitimate to their new duplicate capacity. These covers do not meet manufacturer specifications; the breakers may lack safety features and specifications, and possible threats such as phase-to-phase fault protection or proper grounding, circuit overload, fires, and power surges. In addition, the label used in front of the covers labeled 200A TP MCCB may be a 400A TP MCCB originally or less in rating, as shown in Figure 2. Also, there is a high chance that short circuit protection will be compromised due to not tripping during an overload. Typical failures of circuit breaker include spring failure, loose component, jammed cores & operating mechanism faults (Chen et al., 2023).

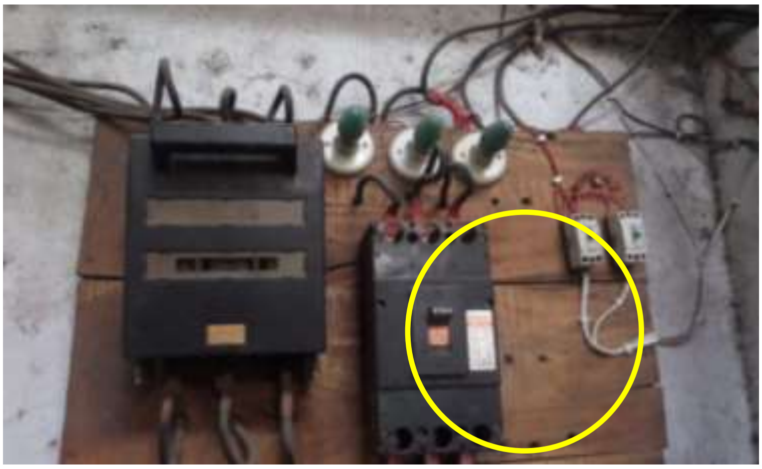
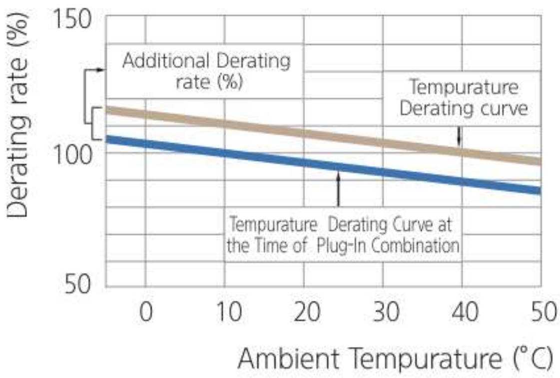


**Figure 2.** Snapshot taken during factory visit (Breaker capacity unknown due to altered label)

**2.2 Circuit breaker selection considering wires capacity, loads & ambient temperature**

A circuit breaker is intended to trip during an overload or short circuit, cutting off the power flow and averting a fire. However, if the breaker does not trip, the excess current might cause the wires to overheat and potentially catch fire. Connecting a higher-rated circuit breaker to lower-capacity cables may result in a fire. This is because a circuit breaker is designed to trip and stop the electricity flow if the circuit's current exceeds the circuit breaker's rating (Roybal, 2004). However, if the wires are not rated to handle the current that the circuit breaker allows, they will overheat, causing the insulation to melt and a fire to start.




In (Rated Current): Circuit breaker's rating at about ambient temperature 40 ℃

Ir (Real Current): Circuit breaker's rating at about ambient temperature

Ir = Correction ratio (%) x In

**Figure 3.** Sourced from Hyundai circuit breaker technical specification brochure

For illustration, if 20-amp circuits with 12 gauge wire operate by a 32-amp circuit breaker, the circuit breaker will not trip until the current on the circuit reaches 32 amps. However, the 12 gauge wire can carry 20 amps safely. This means the cables will overheat when plugging in a load that draws more than 20 amps, which can cause a fire. Another potential threat is that if the insulation on the wires melts down, the exposed wires could come into contact with each other or with other conductive materials (Svare et al., 2023), such as metal pipes or boxes, or cable trays. This could create a short circuit, which could cause a spark and ignite flammable materials nearby.

Various brand circuit breakers were manufactured with a variety of ambient temperatures. The industry does not practice circuit breaker adjustment according to load and ambient temperature. For instance, an overcurrent characteristic of MCCB has been set to the ambient temperature of 40 degrees Celsius in Hyundai circuit breakers. The overcurrent features can be changed if the ambient temperature (40 degrees Celsius) is less or more (Hyundai Electric), (Aronstein, 2022).

If the ambient temperature is less than 40 degrees Celsius, to ensure that the circuit breaker's overcurrent meets the derating curve [Figure: 2] at the given ambient temperature, the real current (Ir) should be adjusted as it can pass more than the rated current.

On the other side, if the ambient temperature is more than 40 degrees Celsius, thermal damage to the insulating material occurs inside the MCCB, causing the breaker to trip at an early stage. When applying ambient temperatures higher than 40 degrees Celsius, the circuit breaker must adjust [Table: 1] the rated current as per manufacturer guidelines more (Hyundai Electric), (Aronstein, 2022).

Rated Current Derating Table: HG Type / Standard Mounting (Fixed) (Hyundai Electric)

**Table 1.** Current carrying capacity of a circuit breaker changes with ambient temperature (Hyundai Electric)

| Model | Rated Current (A) | Ambient Temperature (degree Celsius) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 10 | 20 | 30 | 40 | 45 | 50 | 55 | 60 | 65 | 70 |
| HGP 160D | 16 | 18 | 17 | 17 | 16 | 16 | 15 | 15 | 14 | 14 | 13 |
| | 20 | 22 | 22 | 21 | 20 | 19 | 19 | 18 | 18 | 17 | 16 |
| | 25 | 28 | 27 | 26 | 25 | 24 | 24 | 23 | 22 | 22 | 21 |
| | 32 | 36 | 35 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 |
| | 40 | 45 | 43 | 42 | 40 | 39 | 38 | 36 | 35 | 34 | 33 |
| | 50 | 56 | 54 | 52 | 50 | 49 | 47 | 46 | 44 | 43 | 41 |
| | 63 | 71 | 68 | 66 | 63 | 61 | 59 | 57 | 55 | 53 | 51 |
| | 80 | 90 | 87 | 83 | 80 | 78 | 75 | 73 | 70 | 68 | 65 |
| | 100 | 112 | 108 | 104 | 100 | 97 | 94 | 91 | 88 | 85 | 82 |
| | 125 | 141 | 135 | 130 | 125 | 121 | 117 | 113 | 109 | 105 | 101 |
| | 150 | 169 | 162 | 156 | 150 | 145 | 140 | 135 | 130 | 125 | 120 |
| | 160 | 180 | 173 | 166 | 160 | 155 | 150 | 145 | 140 | 135 | 130 |

### 2.3 Non-standard cable joints in an electrical circuit

A cable joint is a connection between two or more electrical cables. Non-standard cable joints are those that do not meet the requirements of the relevant electrical code (BNBC- 2020) including wrong materials, joints that are not properly insulated, and joints that are not properly enclosed (Aronstein, 2022). Using PVC tape to insulate a twisting joint is a widely used practice in the industry. Using a crimp connector that is improper in size for the designated wire and not using of heat shrink sleeve to insulate a soldered joint are also common.

Fire hazards can be created by non-standard cable joints, including:

Overheating: Non-standard cable joints can overheat due to poor electrical contact or inadequate insulation, which can cause the wires to melt, creating a spark or arc that can ignite nearby materials. The higher the cable temperature is, the bigger the cable resistance is (Xishan & Peng, 2005).

Arcing: Non-standard cable joints can also cause arcing, a type of electrical discharge that can create sparks and heat. Arcing can ignite nearby materials or cause the wires to melt, leading to a fire (Svare et al., 2023).

Corrosion: Non-standard cable joints are more likely to corrode, weakening the connection and increasing the risk of overheating and arcing which leads to flow current in human body. In general, electric current flow is directly proportional to water content of tissue. For example, heart and blood give allow more flow i.e. give less resistance than skin (Tyagi et al. 2019)

**Figure 4.** Snapshot taken during factory visit (PVC tape wrapping to insulate twisting joint)

Short circuits: A short circuit is an electrical fault that occurs when two live conductors come into direct contact (Yang et al., 2022). Short circuits can cause an unexpected surge of current, which can overheat the cables and start a fire. Non-standard cable joints are more likely to cause short circuits than properly made joints.

**2.4 Loose or Poor Connection**

A loose connection can create electrical resistance. When electricity flows through a resistant material, it heats up (Gore & Gore, 2018). If the resistance is high enough, at a certain stage, it heats up, becomes glowing, and starts a fire (BNBC- 2020) (Vytenis, 2001).

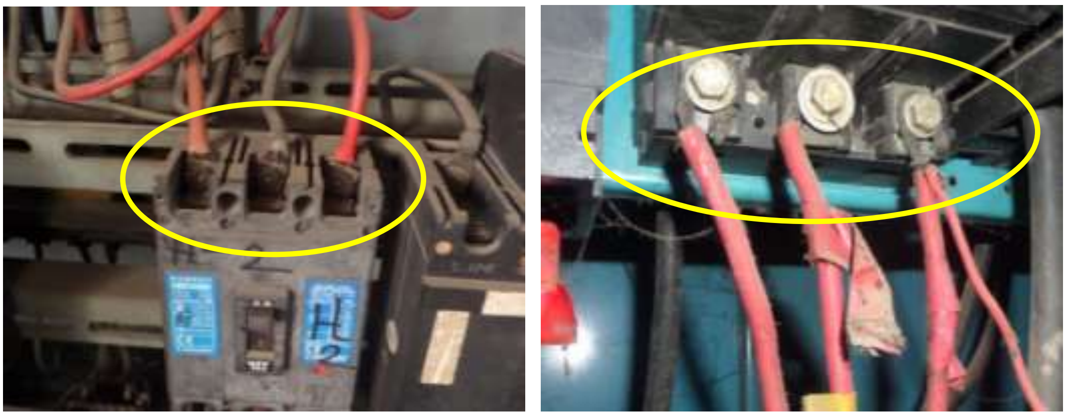


**Figure 5.** Snapshot taken during factory visit (Connection without lugs in the circuit breaker terminal causes heat)

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Loose connections can also cause arcing. Arcing occurs when the current jumps across the gap between the loose wires or terminals, which create sparks, can ignite flammable materials such as wood or insulation or cause electrocution. A loose connection was established by reducing the tightening torque of the bolt below the specified value close or equal to zero (Xin & Schoepf, 2011).

For instance, loose connections in electrical circuits can be a loose screw on a terminal block, a loose wire in a crimp connector or screw connector, a damaged or corroded electrical outlet or plug, or a loose wire nut in a bus bar. Loose connections can occur in any electrical circuit, including residential, commercial, and industrial circuits. They can be caused by various factors, such as vibrations, corrosion, improper installation, and wear and tear. The effects of loose connections on the contact inductance and revealed that loose electrical contact connections significantly increase the inductance and resistance at the contacting points that can lead to electromagnetic radiations. (Sato et al., 2020)

**2.5 Oil Leakage in liquid filled transformer & insulation failure**

Transformers are often filled with petroleum-based oil, referred to as the insulating liquid or dielectric liquid, for insulation (Lewand & Koehler, 2003) to prevent electrical arcing and work as a coolant. This oil is flammable and similar to mineral oil. If the transformer oil quality is degraded, or the oil tank is lacking or leaking oil, it affects the oil's thermal cycle so that the oil's heat dissipation capability is lowered. Cooling efficiency is compromised, leading to short circuits or insulation failure and resulting in overheating and fire (Janic et al., 2023).

There are several reasons why a transformer may experience oil leakage. Age and wear are primary factors, as transformers deteriorate over time due to prolonged use and environmental conditions. Mechanical failures, such as a loose cover, broken tank, faulty gasket, or cracked insulation, can lead to oil leakage (Gray, 2009). When the internal temperature of a transformer reaches 150–300 °C under abnormal conditions, the mineral oils produce hydrogen and methane gases via chemical decomposition (Harbawi & Mubaddel, 2020), which causes corona & arching. At temperatures above 300 °C, ethylene is formed, which causes severe overheating, and above 700 °C, large amounts of hydrogen and ethylene are produced [12]. The gases containing both the elements carbon (C) and hydrogen (H2) are called hydrocarbons and are combustible. It has been reported that 70% to 80% of all transformer failures are due to internal winding insulation failure (Gajić et al., 2005).

**Figure 6.** Snapshot taken during factory visit (Oil leaking in an old transformer)

**2.6 Periodical inspection, testing, and poor maintenance of electrical equipment**

Due to a lack of periodic inspection and testing of electrical circuits, fire risk remains high in the industry sector. Electrical fires caused by faulty wiring and PVC insulated power cable damage (Wang et al., 2013) lead to arching sparks and remain unknown if not testing the continuity and insulation resistance. A thermography (thermal imaging) survey was not done regularly in the factory (Accord & DIFE factory inspection report) to detect overheating caused by electrical faults such as loose connections and overloaded circuits, transformer cooling faults, motor winding faults, and induced currents before they become apparent to the naked eye.

Faulty electrical outlets and aging appliances can include faults in appliance cords, receptacles, and switches, as there is no restriction on equipment fitness. The consumers always decide run time. An appliance with a damaged or frayed cord can generate dangerous heat levels, igniting surfaces like rugs and curtains and starting a fire. Another way to start a fire with an electrical cord is to take off the grounding plug before plugging it into a two-prong socket. Appliances can only be used in outlets designed to withstand the excess current these devices consume, which is why they have an additional prong. Detection of hotspots in equipment or installations could become quite a challenge using the conventional methods of temperature measurements because they could become time consuming, costly, and unsafe for personnel and equipment (Bach et al., 2015).

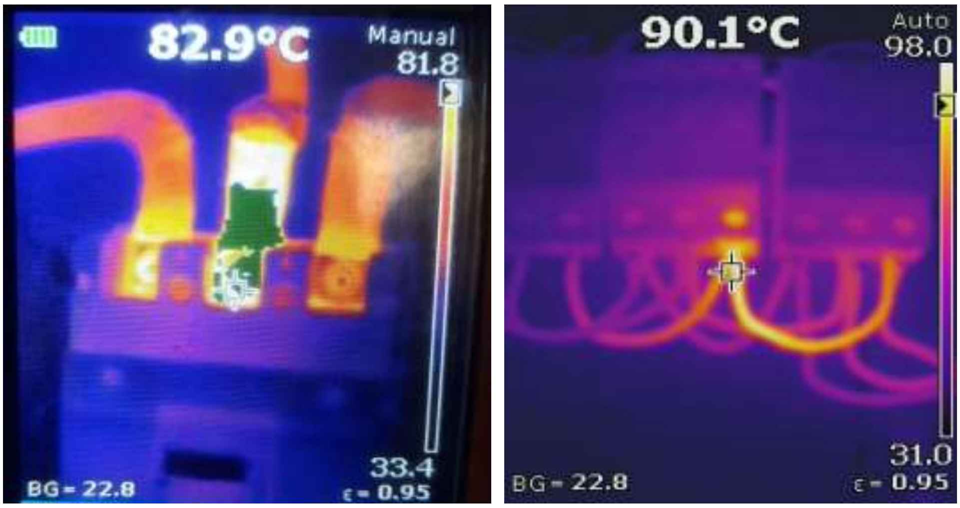


**Figure 7.** Excessive heat found in circuit breaker terminal by thermal imaging

## 3. ANALYSIS & RESULTS

As a part of the data analysis, 120 factories of different production variants were considered. Field visits for data acquisition and previous safety assessment reports (Accord & DIFE factory inspection report) were studied for factories, including plastic product manufacturing, garments, pharmaceuticals, and others [Figure: 8].

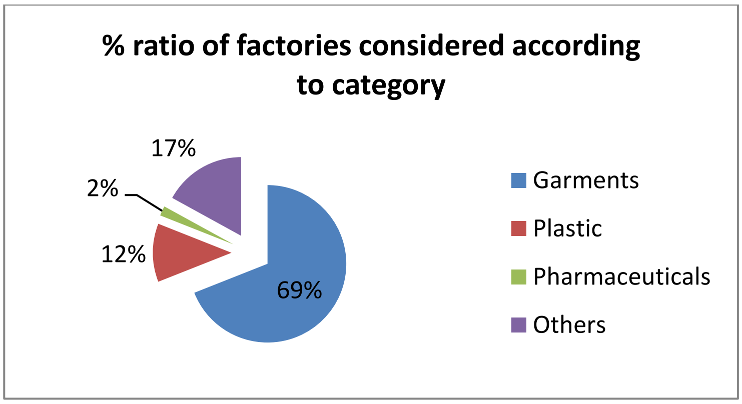


**Figure 8.** Type of factory considered for field visit and assessment report

Lists of findings were used to collect initial data considering the research objective. Major electrical findings of industries include electrical design as per guidelines, circuit breaker selection compared to wire and load capacity, periodic maintenance of substation & power distribution system, standard cable joint, equipment & electrical testing, etc. [Figure: 9].

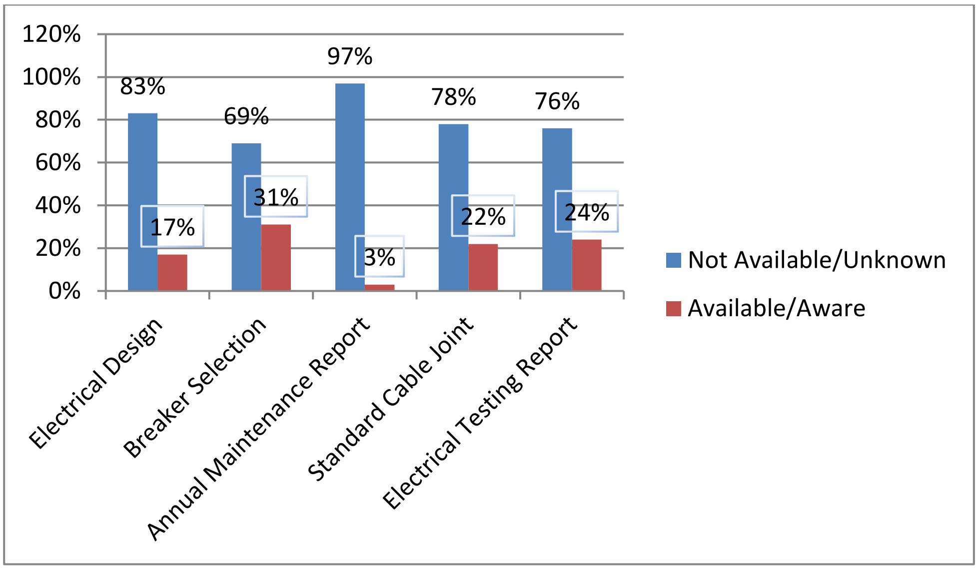


**Figure 9.** Five major electrical findings considered for analysis

## 4. CHALLENGES & FUTURE DIRECTION

**Integration of Advanced Monitoring Systems**

Future directions in RCA involve leveraging advanced monitoring systems equipped with sensors, data analytics, and predictive algorithms. These systems continuously gather real-time data on various parameters such as voltage, current, temperature, and vibration. By analyzing this data, anomalies and potential fault precursors can be detected early, allowing for proactive maintenance and intervention. However, integrating these systems into existing infrastructure poses challenges related to compatibility, data management, and cybersecurity.

**Adoption of AI and Machine Learning**

Artificial intelligence (AI) and machine learning (ML) algorithms hold immense promise in enhancing the effectiveness of RCA for electrical faults. These technologies can analyze vast amounts of data to identify patterns, correlations, and predictive models for fault prediction and prevention. By learning from historical data and real-time inputs, AI-driven RCA systems can provide insights that enable proactive decision-making. Nonetheless, challenges such as data quality, algorithm transparency, and the need for domain expertise persist in the adoption of AI and ML in RCA.

**Emphasis on Human Factors and Organizational Culture**

While technological advancements play a crucial role, the human element remains central to effective RCA. Future directions involve placing greater emphasis on understanding human factors and organizational culture in relation to electrical faults. This entails fostering a culture of safety, promoting effective communication, and providing comprehensive training for personnel involved in fault analysis and resolution. Furthermore, incorporating human-centric design principles into the development of RCA tools and processes can enhance usability and acceptance.

**Multi-disciplinary Collaboration**

Addressing complex electrical faults often requires collaboration across multiple disciplines, including electrical engineering, data science, maintenance, and operations. Future directions in

RCA involve fostering multi-disciplinary collaboration to leverage diverse expertise and perspectives. This collaborative approach facilitates holistic problem-solving and enables a more comprehensive understanding of the root causes underlying electrical faults. However, challenges such as siloed organizational structures, communication barriers, and differing priorities among stakeholders need to be overcome to facilitate effective collaboration.

**Sustainability and Resilience**

In the face of increasing environmental concerns and the imperative for resilience, future directions in RCA for electrical faults encompass considerations of sustainability and energy efficiency. This involves analyzing not only the immediate causes of faults but also their broader implications on energy consumption, resource utilization, and environmental impact. Implementing sustainable practices, such as energy management systems and renewable energy integration, can mitigate the risk of electrical faults while advancing environmental goals. However, balancing sustainability objectives with operational requirements and economic constraints presents a significant challenge.

## 5. CONCLUSION

Root cause analysis of electrical faults in industrial and facility settings is evolving in response to technological advancements, changing organizational dynamics, and broader societal trends. Future directions emphasize the integration of advanced monitoring systems, adoption of AI and machine learning, emphasis on human factors and organizational culture, multi-disciplinary collaboration, and considerations of sustainability and resilience. However, realizing these future directions requires addressing various challenges related to technology integration, data management, organizational dynamics, and balancing competing priorities. By navigating these challenges and embracing innovation, stakeholders can enhance the effectiveness of RCA in mitigating electrical faults and promoting safety, reliability, and sustainability in industrial and facility operations. Based on the analysis in the article mentioned above, it is clear that there is a significant gap beginning from the electrical design, appropriate installation, proper maintenance, regular testing, and compliance with regulatory standards in the electrical system. A bunch of findings descriptions followed the conclusive suggestions is the best practice standard. This study will guarantee the mandatory adoption and observance of electrical safety requirements through proper installation with appropriate materials and services, building an electrically safer workplace in the industry, and saving property and lives.

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