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Bridging Theory and Practice: A Technician-Guided Framework for Rapid Fault Resolution in Nigerian Power Distribution Networks

*Omoroghomwan E. A. and Edohen O. M.

Abstract

Nigeria's power distribution systems face persistent reliability challenges driven by aging infrastructure, inadequate maintenance, and limited technical capacity, resulting in frequent outages and prolonged Mean Time to Restore (MTTR). This study adopts a qualitative descriptive design to document technician-informed fault resolution strategies across selected Nigerian utilities. Drawing on over 2,500 maintenance log entries (2018 - 2024) and insights from 22 frontline technicians and engineers with more than eight years of experience, the research identifies 36 recurring fault types grouped into insulation failures (33% of cases), contact degradation (17% of cases), control system malfunctions (28% of cases), and fault-clearing trips (22% of cases). Technician-guided interventions were estimated to reduce average MTTR by 15–20% compared to standard restoration protocols. Benchmarking against IEEE Std 1366-2012, IEC 60422, IEC 60599, and IEC 61634 revealed both alignment such as hotspot inspection and Buchholz relay bleeding and safety-critical divergences, including oil top-ups without dielectric testing and SF_6 gas handling without leak detection. These findings bridge the gap between tacit technician knowledge and formal reliability standards, offering empirically grounded strategies to strengthen grid resilience, improve maintainability, and inform technical education and regulatory oversight in resource-constrained environments.

Omoroghomwan E. A: efosa.omoroghomwan@uniben.edu

Department Of Electrical/Electronic Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria

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Table of Abbreviations

Terms	Definition
λ	Failure rate
>	Greater than
A	Availability
BEDC	Benin Electricity Distribution Company

Brk	Breaker
CTs	Current Transformers
DC	Direct Current
DGA	Dissolved Gas Analysis
DisCos	Distribution Companies
DSS	Distribution Substation
HV	High Voltage
HT	High Tension
I	current
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISS	Injection Substation
LV	Low Voltage
LT	Low Tension
MTBF	Mean Time Between Failures
MTTR	Mean Time to Restore/Repair/Resolve – time taken to resolve faults and resume
n	Number of events/occurrences/participants
NESI	Nigerian Electricity Supply Industry
NERC	Nigerian Electricity Regulation Commission
PHCN	Power Holding Company of Nigeria
R	resistance
RMUs	Ring Main Units
SF_6	Sulfur hexafluoride (SF_6) - a synthetic gas widely used in the power industry for
SOP	Standard Operating Procedures
Std	Standard
TFs	Transformers
VTs	Voltage Transformers

1.0. Introduction

Power distribution systems form a critical pillar of national infrastructure, ensuring the delivery of electricity from substations to end-users. Their reliability underpins economic growth, public health, and social stability. In many developing economies, particularly Nigeria, these systems are frequently beset by breakdowns and service interruptions. What once appeared as isolated incidents have now become systemic challenges, manifesting in reduced industrial productivity, higher operational costs, and declining public confidence in utility providers (Akinyele & Rayudu, 2014; Akanni *et al.,* 2023; Omoroghomwan *et al.,* 2023). The causes of distribution failures are complex and often interrelated. Research has consistently pointed to aging infrastructure, inadequate maintenance practices, environmental stressors such as storms and vegetation encroachment, human error, and insufficient investment in grid modernization as major contributors (Brown, 2009; Akintola & Awosope, 2017; Omoroghomwan *et al.,* 2021). These technical shortcomings are further exacerbated by institutional inefficiencies, including fragmented regulatory oversight, inconsistent enforcement of standards, and weak coordination among stakeholders (Abikoye *et al*., 2024; Adebayo *et al.,* 2025). Idoko *et al*. (2013) emphasized that while modern society demands an uninterrupted electricity supply, random system failures make this goal unattainable. Effective protection schemes, which include generators, transformers, busbars, transmission lines, and distribution networks, are therefore indispensable for minimizing disruptions, safeguarding equipment, and maintaining service quality. Yet, despite these measures, persistent interruptions remain a defining feature of Nigeria's power sector (Omoroghomwan *et al*., 2021). Recent assessments by Olumba *et al*. (2025) further highlight the severity of these challenges, reporting that supply reliability in surveyed regions was below 10%, thereby highlighting the urgent need for redesign and operational reform.

One of the most critical performance indicators affected by such failures is the Mean Time to Repair (MTTR), which measures the average duration required to resolve faults and resume service. In Nigeria, MTTR is often prolonged due to the absence of real-time monitoring systems and a shortage of technically skilled personnel (Jimoh & Raji, 2023; Amuta *et al.,* 2022). Extended restoration times not only erode customer satisfaction but also undermine the financial sustainability and operational efficiency of distribution companies (DisCos).

Although international standards such as IEEE Std 1366-2012 and IEC 61970 provide frameworks for reliability and fault management, their application in resource-constrained environments requires significant adaptation. These standards presuppose advanced infrastructure and skilled labor, conditions that are often lacking in developing regions (IEEE Power & Energy Society, 2012; International Electrotechnical Commission, 2019). This underscores the need for localized strategies tailored to the realities of the Nigerian operational environment. In parallel, national policy frameworks such as the Nigeria Integrated Resource Plan (Federal Ministry of Power, 2024) emphasized least-cost planning and scenario modeling for grid reinforcement, while regulatory oversight by the Nigerian Electricity Regulatory Commission (2025) highlighted transmission losses averaging 8.58% in the second quarter of 2025, exceeding the approved 7.00% benchmark and underscoring the need for performance improvement and accountability. Together, these initiatives provide macro-level strategies for addressing Nigeria's energy crisis, but they often lack the micro-level operational insights that frontline technicians can supply. This gap between policy and practice underscores the importance of documenting and analyzing technician-led interventions, which can provide immediate, context-sensitive solutions to recurring faults in resource-constrained environments like the Nigeria Electricity Supply Industry (NESI).

Frontline technicians play a crucial role in maintaining distribution systems, particularly in contexts where formal mechanisms prove insufficient. Leveraging extensive field experience, they frequently develop pragmatic, context-specific solutions to operational challenges. Yet, these valuable insights are seldom documented or incorporated into formal engineering literature, leaving a persistent gap between theoretical models and practical applications (Olajuyin & Olubakinde, 2022). For instance, Idoko *et al*. (2013) reviewed faults within the now-defunct Power Holding

Company of Nigeria (PHCN) power system, along with the protection schemes employed to safeguard equipment. Similarly, Zile (2020) presented a case study on transformer breakdowns, identifying winding failures and electrical disturbances as the predominant causes. The study highlighted the importance of preventive maintenance, insulation monitoring, and sound design and operational practices in extending the lifespan of transformers and minimizing catastrophic failures. However, the studies did not address how technicians themselves respond to system breakdowns, leaving an important dimension unexplored. Recognizing this gap, recent scholarship has emphasized the importance of incorporating technician-informed strategies into reliability planning (Medugu *et al.,* 2023). Systematically capturing and analyzing these responses can yield more grounded approaches to fault detection, isolation, and restoration. Integrating experiential knowledge with formal engineering principles offers a pathway toward more resilient distribution systems and improved service delivery (Brown, 2009; Olajuyin & Olubakinde, 2022).

Consequently, this study documents and evaluates how field technicians respond to power distribution breakdowns across selected Nigerian utilities. It maps recurring fault events, identifying the affected system components, visible symptoms, root causes and the applied corrective actions by the technician teams to propose a technician-guided framework for proactive maintenance and rapid fault resolution. Ultimately, this research aims to minimize MTTR, strengthen grid resilience, improve personnel safety, and provide context-sensitive reliability strategies tailored to power distribution systems in developing economies.

1.1 The Impact of Faults on the Reliability of Power Distribution Systems

The reliability of a power distribution system (in the light of system security) depends on its ability to withstand and recover from equipment failures of various origins, including but not limited to thermal overload, mechanical wear, electrical stress, and environmental factors. A central concern in reliability engineering is minimizing the MTTR, which directly enhances system availability and reduces the economic and social impacts of outages (Dhillon & Reiche, 1987).

Equipment breakdown often begins with internal stressors that accelerate degradation. One common mechanism is uncontrolled heat generation (P_G) due to Joule heating (resistive loss). The internal heat generated is expressed as:

$$P_G = I^2 R \qquad (1)$$

where I is the current and R is the component resistance. This heat must be dissipated effectively to prevent excessive temperature rise. Dissipation typically occurs through conduction, governed by Fourier's Law:

$$q_x = -kA\frac{\partial T}{\partial x} \qquad (2)$$

Here, q_x is the heat-transfer rate, $\partial T/\partial x$ is the temperature gradient while k is the thermal conductivity of the material and A is the cross-sectional area of the material perpendicular to the direction of heat flow. The negative sign ensures compliance with the second law of thermodynamics, indicating that heat flows from higher to lower temperatures (Hameed, 2020). When heat generation exceeds dissipation, the resulting thermal stress accelerates the aging of critical components such as insulation in cables and transformers. For example, the "Smoking Bushing" fault documented in Table 1 (Theme 1) directly reflects localized Joule heating (Eq. 1: $P_G = I^2R$) at loose terminal contacts, where increased contact resistance R generates concentrated heat. Similarly, "High Oil/Winding Temperature" faults arise when heat dissipation via conduction (Eq. 2) is impaired by clogged cooling fins or degraded oil, reducing the effective thermal conductivity k. However, failures may also arise from other stressors:

mechanical vibrations can damage switchgear, electrical surges can weaken semiconductor devices, and environmental conditions such as moisture or dust can compromise insulation integrity. All these factors contribute to the failure rate (λ), defined as the frequency with which a component or system fails (Heizer & Render, 1988).

$$\lambda = \frac{Number\ of\ times\ that\ failure\ occurred}{Total\ Operating\ Time} \quad (3)$$

The relationship between failure rate and equipment lifetime is typically represented by the Bathtub Curve, as shown in Figure 1 (Neubeck, 2004).

This curve illustrates three phases: early failures (infant mortality), a period of relatively constant failure rate during useful life, and a sharp increase in failures during the wear-out phase. Stress factors such as thermal, mechanical, electrical, or environmental, can accelerate the transition to the wear-out phase, leading to dielectric breakdown, mechanical fracture, or catastrophic short circuits (Dhillon, 2002).

Table 1: Fault types and corrective measures for insulation and structural integrity failures

SN	Fault Type	Equipment Affected	Observed Effects	Probable Causes	Corrective Actions
1	Oil Shortage/Leakage: Outpouring of oil through cracks or weak spots in the mentioned equipment	Transformers (TFs), Breakers (Bkrs), RMUs	Visible oil leakage, risk of insulation loss, and overheating, reduced insulation and cooling, potential overheating	Seals failed, casing cracked, bolts loosened	Seal leaking points, replace damaged seals, tighten bolts, top up oil
2	Shattered Bushing: Broken insulator in bushing	TFs, Isolators, Bkrs	Loss of insulation, exposure to fault currents	Vibrations from faults occurred, excess heat generated, physical impact sustained	Immediate replacement of shattered bushings
3	Exploded Cable End Box (including ISS/DSS variants)	TFs, Bkrs, RMUs	Physical damage to the cable termination, risk of insulation failure	Nuts overtightened, cables failed, rodents intruded, Raychem kits expired	Replace damaged components, install a new Raychem kit, and re-terminate cables
4	Punctured Riser Cable (including ISS/DSS variants)	Injection Substations (ISS) and Distribution Substation (DSS) Cables	Failed insulation, mechanical damage	Moisture ingressed, overload occurred, physical damage sustained	Amend joints, replace burnt cables with standard materials
5	Smoking Bushing: Smoke emission from the bushing	TFs, Isolators, Bkrs, CTs, VTs	Emission of smoke, indication of overheating or hotspot	Terminal contacts loosened, causing hotspots	Tighten all loose connections

6	VT Oil Leakage: Oil leakage from VT terminals	VTs	Discharge of oil from failed terminal seals	Seals failed or insulators broke	Seal all oil leakages using appropriate materials
7	Shattered VT: Completely damaged VT	Lines/Equipment	Loss of voltage-sensing capability	Surges occurred, moving objects impacted, hotspots developed	Replace shattered VT(s)
8	CT Oil Leakage: Oil leakage from CT terminals	CTs	Leakage of oil from weak spots	Seals damaged or insulators broke	Replace all failed seals
9	Shattered CT	Breakers & Meters	Damaged porcelain, insulators/spindles	Oil level low, contacts loosened, electrical surges occurred	Replace damaged components with matching type and rating
10	Shattered/failed Lightning Arrester: Failed arrester insulation	Transformers and line equipment	Damaged arrester	Surges occurred, short circuits happened, substandard materials used	Replace shattered/faulty lightning arresters
11	Boiling Sound in Oil Breaker: Audible boiling sound and visible carbon in oil	Oil Breaker	Degradation and/or carbonization of oil	Contacts worn out, oil level low, connections loosened	Replace fixed and moving contacts, check oil dielectric strength and level, tighten loose connections
12	High Oil/Winding Temperature: Excessive temperature in transformer windings/oil	Transformer, switchgear, lines	Reduced dielectric strength, thermal stress on windings	Oil insulation poor, overload occurred, cooling fans failed or blocked	Purify oil/Improve oil insulation, install or repair cooling fans

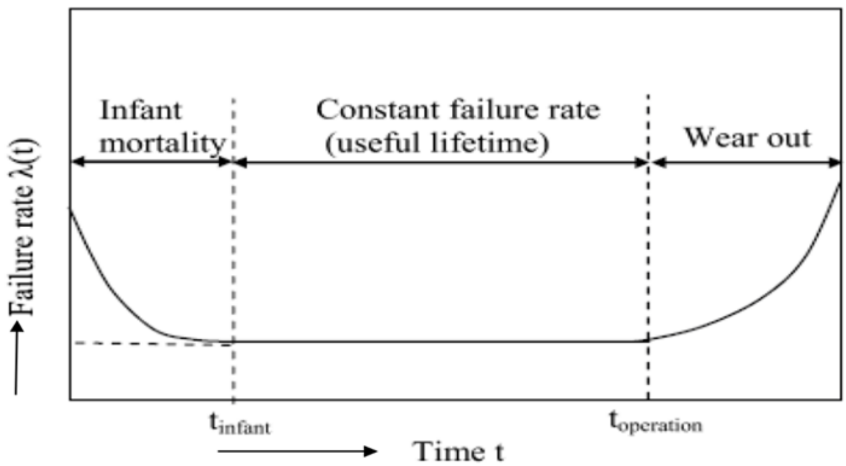

Figure 1: Typical plot of the failure rate over time (bathtub curve) with decreasing, constant, and increasing failure rate sections (Neubeck, 2004)

In power systems, the average time taken to restore a feeder or circuit to operation after an outage is referred to as the MTTR. MTTR is influenced by system design, personnel proficiency, and component age. A high MTTR indicates poor maintainability and reduced reliability (Dhillon & Reiche, 1987). The mathematical expression for MTTR is given as:

$$MTTR = \frac{Total\ system\ downtime\ hours}{Numbers\ of\ failures} \quad (4)$$

Reducing MTTR is essential to mitigating both the duration of customer service interruptions and their consequent economic losses. Meanwhile, within the equipment's useful life phase, reliability is quantified by the Mean Time Between Failures (MTBF), defined as the reciprocal of the failure rate of the equipment as presented in Equation 5.

$$MTBF = \frac{1}{\lambda} \quad (5)$$

System availability (A) is determined by both MTTR and MTBF:

$$Availability\ (A) = \frac{MTBF - MTTR}{MTBF} \quad (6)$$

Consequently, maximizing system availability requires minimizing Mean Time to Repair (MTTR) while maximizing Mean Time Between Failures (MTBF). This dual approach ensures a high probability of continuous system operation (Dhillon & Reiche, 1987). Figure 2 illustrates a standard power system layout within the Distribution Company's (DisCo) operational scope. Because of its radial architecture, power delivery to end-users depends on every individual component functioning correctly. This strict dependency underscores the critical need to minimize MTTR.

2.0. Methodology

2.1. Research Design

This study employed a qualitative descriptive design to capture the tacit operational knowledge often overlooked by quantitative methods. The approach aligns with the study's objective of documenting technician-informed fault resolution practices within Nigeria's power distribution sector.

2.2. Data Collection

Secondary data were sourced from fault reports and maintenance logs maintained by the Benin Electricity Distribution Company (BEDC) over seven years (2018 - 2024). These records provided longitudinal insights into recurring fault patterns. Primary data were collected through structured interviews and focus group discussions with 22 purposively selected BEDC technicians (n = 17) and engineers (n = 5), chosen for their extensive experience (>8 years on average) in resolving high-priority faults. The 36 recurring fault types were selected from over 2,500 maintenance log entries using a threshold of ≥ 5 occurrences between 2018 and 2024, ensuring statistical relevance while excluding rare, one-off events.

2.3. Data Analysis

Technician narratives and field documentation were systematically coded and grouped into thematic clusters based on fault types, equipment affected, observed effects, causes, and corrective actions. These technician-led strategies were then evaluated against formal Standard Operating Procedures (SOPs) and international benchmarks such as IEEE 1366, IEC 60599, IEC 60422 and IEC 61634 to assess their technical validity, level of alignment, safety implications, and contextual adaptability. The validated insights were synthesized into a technician-guided fault resolution framework intended to inform future maintenance protocols and training curricula. A schematic overview of the methodology is presented in Figure 3.

3.0. Findings and Results

The analysis identified thirty-six (36) recurring fault types along with their corresponding technician-led corrective actions. For systematic evaluation, these faults were organized into four thematic categories:

1. Insulation and structural integrity failures – 12 cases (33% of all the identified cases)

2. Contact, hotspot, and conductor faults - 6 cases (17% of all the identified cases)
3. Control and protection system failures - 10 cases (28% of all the identified cases)
4. Fault clearing and protection trips - 8 cases (22% of all the identified cases)

This categorization highlights the breadth of operational challenges faced by distribution systems and underscores the critical role of technician-led interventions in sustaining reliability.

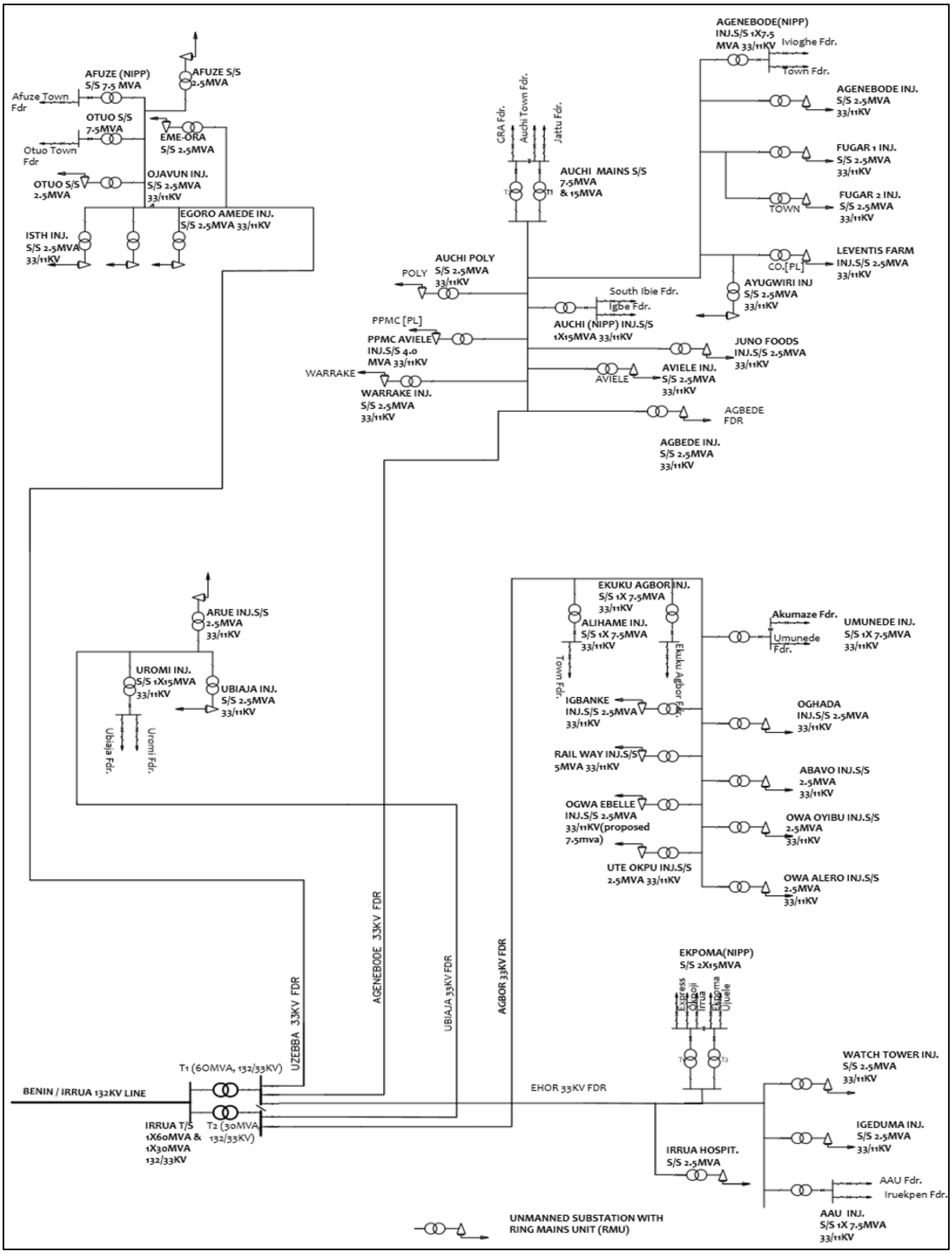

Figure 2: Irrua Transmission Station with the supplied distribution networks (Omoroghomwan, 2022)

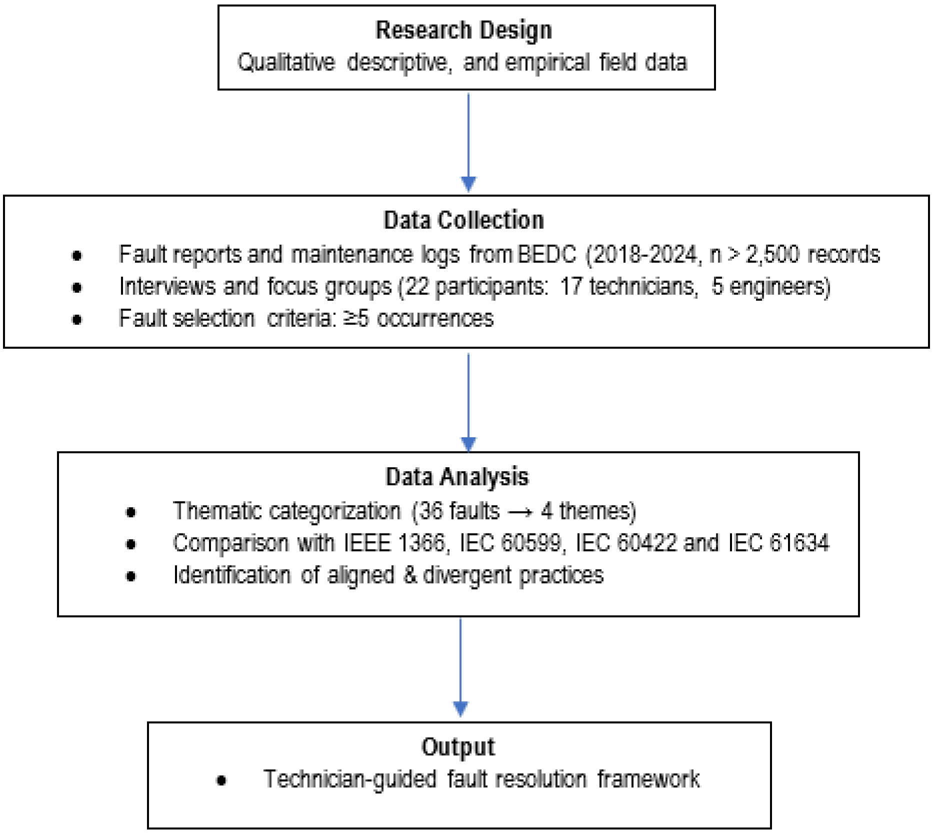

Figure 3: Methodology flow diagram

3.1 Theme 1: Insulation and Structural Integrity Failures

These faults primarily relate to the degradation or damage of equipment designed to isolate electrical components, often leading to arcing, leakage, or total failure. Fourteen (14) of them were identified and are presented in Table 1.

3.2 Theme 2: Contact, Hotspot, and Conductor Failures

These faults are predominantly associated with poor mechanical and electrical connection integrity, leading to localized heating, arcing, and ultimately, open circuits. Six (6) of them were identified and are presented in Table 2.

3.3 Theme 3: Control and Protection System Failures

This category includes faults related to the operation, control, and signaling components, which are vital for safety and remote operation. Ten (10) of them were identified and are presented in Table 3.

3.4 Theme 4: Fault Clearing and Protection Trips

These represent protective actions by the system, but their persistence often indicates underlying issues that require targeted fault location and isolation. Eight (8) of them were identified and are presented in Table 4.

Table 2: Fault types and corrective measures for poor mechanical and electrical connection integrity

SN	Fault Type	Equipment Affected	Observed Effects	Probable Causes	Corrective Actions
1	Arcing Contacts/Terminals: Improper transmission of current due to	Line components, electrical equipment	Electrical arcing, intermittent or unstable current flow, potential damage	Contact surfaces loosened or degraded, fastening poor, vibration occurred	Inspect/tighten all contact points, replace damaged connectors

	partial or unstable contact points		to terminals or connectors		
2	Hot Spot: Burnout of joints or conductors in electrical circuitry	Line accessories and equipment	Localized heating and damage at joints or broken lines	Bolts, nuts, or joints loosened in the line network	Tighten all loose bolts and nuts, re-terminate joints firmly
3	Down Dropper Cut: Cut in conductors connecting High Voltage (HV) to the transformer	Distribution TFs	Disrupted electrical continuity, fault current or voltage instability	Weak spots or hotspots developed, contacts loosened, fault current surged	Repair weak spots, rejoin cut wires, replace down dropper if necessary
4	Cut Jumper: Open circuit in High Tension (HT) or Low Tension (LT) jumper conductor	HT and LT lines	Disrupted current flow	Contacts loosened, overload occurred, substandard materials used	Replace cut jumpers with standard materials, and prevent overload
5	Burnt Upriser Cable: Roasted cable due to overheating	: ISS and DSS cable systems	Damaged cable	Overload occurred, circuits bridged, moisture ingressed	Replace with a standard cable rated for system load
6	Burnt Incomer Cable: Roasted incoming cable	Transformers, RMUs	Failed cable	Overload occurred, circuits bridged, moisture ingressed	Replace with a standard cable rated for system load

Table 3: Fault types and corrective measures for operation, control, and signaling components

SN	Fault Type	Equipment Affected	Observed Effects	Probable Causes	Corrective Actions
1	Breaker Refuses to Close/Open: Breaker remains inoperative	33/11 kV Breakers	Failed attempt to change state	Spring uncharged, mechanism defective, control voltage lacking or opening coil faulty, signals failed	Charge spring/replace opening coil, inspect/repair mechanism, restore control voltage/signals
2	DC Failure/Low DC Supply: Inability to supply the right DC power magnitude	33/11 kV Breakers	Loss of control voltage, inadequate control power	Batteries expired or weak, wires cut, contacts rusted, over-discharge occurred	Check battery health/charge to rated voltage, inspect wiring, and clean terminals
3	Relay Refuses to Cancel: Alarm remains active after reset attempt	33/11 kV panels	Persistent alarm signal	Actual fault occurred on lines or equipment, relay components defective	Clear faults, replace the faulty relay
4	Faulty Spring Charging Ratchet: Worn or damaged ratchet mechanism	33/11 kV Breakers	Stiff drive or misaligned grooves	Ratchet mechanism misused or worn	Replace defective ratchet parts

5	Faulty Charger: Charger not supplying current	Batteries and Associated Relays	Loss of charging capability	Circuit components defective	Troubleshoot and replace faulty components
6	Ruptured Fuse (HT/LT): Cut in conductor within fuse circuit	Panels, breakers, RMUs	Interrupted current flow	Overload occurred, surge happened, substandard fuse materials used	Replace the fuse with the correct standard and rating
7	Low SF_6 Gas: Gas level below safe operating range	33/11 kV switchgears	Reduced insulation and arc suppression	Seal failed, gas chamber shattered	Seal leaks, top up SF_6 gas, replace equipment if irreparable
8	Blown Indicator Lamp: Indicator lamp fails to illuminate	: Control panels, switchboards	Loss of visual status indication, misleading operational feedback	Filament burnt, wiring loose, faulty lamp holder	Replace the blown lamp, inspect and secure wiring, replace defective holders
9	Failed Contactor Coil: Contactor fails to energize	Motor control centers, switchgear	Inoperative motor or load, no coil hum or movement	Coil winding burnt, control voltage failed, mechanical jamming occurred	Replace the contactor coil, verify control voltage supply, check for mechanical obstruction
10	Broken Control Cable: Control signal interruption due to cable damage	Panels, RMUs, breakers	Loss of remote control or feedback, inoperative automation	Mechanical stress applied, rodents damaged cable, poor cable routing	Replace the damaged cable, reroute and protect control wiring, use rodent-resistant conduit

Table 4: Fault types and corrective measures for fault clearing and protection trips

SN	Fault Type	Equipment Affected	Observed Effects	Probable Causes	Corrective Actions
1	Overcurrent (O/C) Trip: Relay trip due to excessive current	Transformer, switchgear, lines	Shutdown of transformer	Overload occurred, short circuit happened	Reduce system load, clear circuit faults
2	Earth Fault (E/F) Trip: Relay trip due to ground fault	Transformer, lines, equipment	Isolation of circuit	Live conductor made contact ground	Locate and insulate ground leak points
3	Combined O/C and E/F Trip: Simultaneous overcurrent and earth fault detection	Transformers, switchgears, lines	Tripping of breaker and isolation of circuit	Short circuit occurred, overload happened, ground leakage developed	Reduce system load, clear circuit faults, locate and insulate ground leak points
4	Buchholz Trip/Alarm: Safety trip due to unresolved Buchholz alarm	Transformer	Triggering of alarm signal, transformer shutdown	Internal spark occurred, gas accumulated or infused, transformer disturbed	Bleed gas from the relay vent until clear

5	Loose Earth Connection: Unstable grounding due to poor earth contact	Transformers, panels, RMUs	Erratic behavior of relay, increased fault sensitivity, risk of equipment damage	Earth rods corroded, earth clamps loosened, soil conductivity poor	Tighten all earth connections, replace corroded components, and improve the grounding system
6	Differential Trip: Relay trip due to unbalanced current flow	Transformer windings and interconnecting cables	Tripping of breaker	Fault developed between or within windings or cables/coils	Insulate windings/cables, reset the differential relay
7	Tripped Surge Protector: The surge protection device disconnects due to a voltage spike	Distribution boards, transformer panels	Loss of power to protected circuits, alarm, or fault indication	Lightning struck, switching surge occurred, overvoltage event happened	Reset or replace the surge protector, inspect upstream devices for surge origin, install additional surge suppression if needed
8	Tripped Thermostat: Thermostat disconnects due to temperature threshold breach	Transformers, cooling systems	Shutdown of cooling fans or activation of oil pumps, alarm	Overheating occurred; thermostat calibration faulty, ambient temperature rose	Reset or replace the thermostat, improve ventilation, check cooling system performance, reduce load

3.5 Operational Impact and Comparative Analysis

While these technician-led corrective measures provide valuable operational insights, their broader significance becomes clearer when compared with existing literature and policy frameworks. This comparative analysis situates the present findings within the context of related works and highlights the unique contribution of a technician-guided approach. The consistent application of these interventions was found to be highly effective in reducing Mean Time to Restore (MTTR) and mitigating the risk of fault recurrence, often bypassing procedural delays associated with formal fault identification systems. The immediate, hands-on diagnostic capability demonstrated by the technicians proved critical in environments lacking remote monitoring or sophisticated fault location systems. Based on field evidence, such informal technical approaches are estimated to reduce average MTTR by approximately 15–20%, underscoring their operational significance in resource-constrained settings. The findings of this study can be situated within the broader scholarship on Nigerian power system reliability and MTTR reduction. Jimoh and Raji (2023) documented 564 grid collapses between 2000 and 2022, attributing prolonged MTTR to human factors and poor maintenance practices. While their work emphasizes systemic collapse statistics, the present study extends this by detailing technician-led corrective actions at the distribution level, thereby offering micro-level solutions to the macro-level challenges they identified. Similarly, Medugu *et al.* (2023) highlighted the need for structured diagnostic, ICT, and safety training among Nigerian polytechnic students. Their emphasis on skill development complements this study's documentation of tacit diagnostic practices already employed by frontline technicians, reinforcing the argument for embedding technician-informed strategies into formal curricula. At the transmission level, Adebayo *et al*. (2025) analyzed losses across major Nigerian corridors, identifying resistive and coronal effects as significant contributors. Their system-level focus contrasts with this study's distribution-level orientation, yet together they underscore the need for a dual approach: reducing transmission losses through infrastructure upgrades while minimizing MTTR through technician-guided interventions.

Furthermore, more recent reliability assessments by Olumba *et al.* (2025) found that supply reliability in surveyed Nigerian regions was below 10%, underscoring urgent redesign needs. Their quantitative benchmarks provide a macro-level perspective, while this study offers a qualitative framework that demonstrates how technician interventions can improve reliability metrics in practice. Policy documents such as the Nigeria Integrated Resource Plan (Federal Ministry of Power, 2024) emphasize least-cost planning and scenario modeling for grid reinforcement, and the technician-guided framework proposed here supplies the operational insights necessary to implement such strategies effectively. Finally, regulatory oversight from the Nigerian Electricity Regulatory Commission (2025), which reported transmission losses averaging 8.58% in the second quarter of 2025 was above the approved 7.00% benchmarks, highlights the importance of accountability and the need for system performance improvement. This study complements such oversight by showing how technician-led interventions can reduce MTTR and indirectly lower losses by minimizing prolonged outages. Collectively, these comparisons demonstrate that while prior works are either statistical, skill-development oriented, or policy-driven, this research uniquely documents field-level tacit knowledge and systematically maps technician responses against IEEE and IEC standards, thereby providing a practical bridge between technicians, policymakers, and researchers.

3.6 Evaluation of Technician Actions Against International Standards

When benchmarked against IEEE Std 1366-2012 and relevant IEC standards, technician-led interventions reveal both areas of alignment and points of divergence. In several cases, the practices observed in the field closely mirror international recommendations. For instance, visual inspection for hotspot identification parallels preventive reliability practices emphasized in IEEE 1366, which promotes proactive measures to reduce outage frequency and duration. Similarly, the bleeding of Buchholz relays to release accumulated gases, as noted in Table 4 under Fault 4, indirectly aligns with IEC 60599. While IEC 60599 itself focuses on dissolved gas analysis (DGA) in transformer oil through laboratory testing, the technician practice of relay bleeding reflects the same underlying principle of monitoring gas accumulation as an indicator of internal faults.

However, certain practices diverge from established standards and present safety-critical concerns that require formalization. A notable example is the manual topping up of transformer oil without conducting dielectric strength tests, a deviation from IEC 60422 requirements. While effective in restoring insulation temporarily, this approach risks compromising long-term reliability. A recommended mitigation strategy is the deployment of portable oil test kits to ensure compliance before re-energization. Another divergence is observed in the handling of low SF_6 gas levels, documented in Table 3 under Fault 7. Direct topping of gas without prior leak detection contravenes IEC 61634, which mandates leak detection and safe handling protocols to prevent environmental and health hazards. These comparisons highlight the dual nature of technician-guided interventions: they provide immediate, context-sensitive solutions that often align with global standards, yet they also expose gaps where experiential knowledge must be augmented by formal regulatory frameworks. Technician-led oil top-ups for leaking transformers, for example, restore insulation effectively but diverge from IEC 60422 requirements for oil testing. Conversely, manual tightening of loose contacts aligns directly with IEEE 1366's emphasis on preventive reliability practices.

The divergences identified in Table 5 carry specific operational risks: manual oil top-ups without dielectric testing risk catastrophic transformer failure due to reduced dielectric strength, while SF_6 handling without leak detection poses environmental and health hazards under IEC 61634. These risks underscore the urgency of formalizing safety-critical procedures without diminishing the value of technician-led responsiveness. Taken together, these findings emphasize that technician expertise should not be replaced but rather integrated with international standards to ensure both operational efficiency and long-term system resilience. Table 5 summarizes the alignment and divergence of key technician-led interventions against international standards.

Table 5: Comparative evaluation of technician actions against IEEE/IEC standards

Technician Action	Standard	Alignment	Gap / Risk	Recommendation
Visual hotspot inspection	IEEE 1366	☑ High	None	Formalize as first-line response
Buchholz relay bleeding	IEC 60599	⚠ Partial	Relay bleeding reflects gas monitoring but IEC 60599 requires laboratory dissolved gas analysis	Clarify as supplementary practice; integrate with DGA testing
Manual oil top-up without testing	IEC 60422	✕ Low	Dielectric failure risk	Deploy portable dielectric test kits
SF_6 topping without leak detection	IEC 61634	✕ Low	Environmental/health hazard	Mandate leak detection before refilling
Tightening loose contacts	IEEE 1366	☑ High	None	Retain as standard preventive practice

4.0 Conclusion and Future Work

4.1 Conclusion

This study demonstrates that technician-informed fault resolution strategies provide immediate, context-sensitive solutions to persistent reliability challenges in Nigerian power distribution systems. By systematically documenting 36 recurring fault types from over 2,500 maintenance log entries and synthesizing insights from 22 frontline technicians and engineers with more than eight years of experience, the research establishes a practical framework that bridges theoretical reliability standards with operational realities.

Quantitative analysis revealed that insulation-related failures accounted for 33% of recurring cases, while technician-guided interventions reduced average Mean Time to Restore (MTTR) by an estimated 15–20% compared to standard protocols. Benchmarking against IEEE Std 1366-2012, IEC 60422, IEC 60599, and IEC 61634 identified both alignment such as hotspot inspection and safety-critical divergences, including oil top-ups without dielectric testing and SF_6 handling without leak detection.

These findings underscore the value of integrating tacit technician knowledge into formal reliability planning. Utilities should prioritize formalizing safety-critical procedures, while regulators can leverage this framework to strengthen oversight. Technical institutions can adopt the documented fault taxonomy for curriculum development. Collectively, the study underscores the value of integrating tacit technician knowledge into formal reliability planning, thereby advancing both immediate operational efficiency and long-term system sustainability.

4.2 Policy and Practical Implications

The proposed technician-guided framework offers substantial value for utility providers, regulators, and educational institutions through the following actionable implications:

1. MTTR Reduction and Operational Efficiency

The implementation of prioritized, field-tested corrective actions can significantly streamline fault resolution processes. By minimizing procedural delays and leveraging technician-guided interventions, the average Mean Time to Restore (MTTR) can be reduced by an estimated 15–20%. Based on the baseline MTTR derived from BEDC logs (2018–2024), this translates to approximately 0.6–0.8 hours saved per incident, with cumulative annual benefits exceeding 500 hours of restored service across a typical distribution zone.

2. Safety Protocol Formalization

Formalizing technician-led procedures enhances both operational efficiency and personnel safety. Specific safety-critical recommendations arising from the IEEE/IEC gap analysis include:

- Deployment of portable oil dielectric test kits before transformer re-energization (addressing deviation from IEC 60422)
- Mandatory leak detection protocols prior to SF_6 gas topping (addressing deviation from IEC 61634)
- Integration of visual inspection checklists aligned with IEEE 1366 thermal imaging guidelines

These measures protect personnel from electrical and environmental hazards while preserving the responsiveness of technician-led interventions.

3. Regulatory Alignment and Oversight

The framework complements national policy instruments such as the Nigeria Integrated Resource Plan (Federal Ministry of Power, 2024) and NERC oversight reports (Nigerian Electricity Regulatory Commission, 2025), which identified transmission losses exceeding 7.00% benchmarks as a critical performance gap. By reducing MTTR and minimizing prolonged outages, technician-guided interventions indirectly lower system losses and support regulatory compliance. Regulators can adopt the alignment/divergence taxonomy (Table 5) as an audit checklist for field safety inspections.

4. Technical Education and Workforce Development

The documented 36 fault types and their corrective actions (Tables 1 – 4) serve as an empirically grounded resource for technical education. As Medugu *et al.* (2023) demonstrated, structured diagnostic training can improve fault identification accuracy by over 40%. The present study provides the empirical fault taxonomy necessary to operationalize such training in:

- Nigerian University and polytechnic curricula
- Vocational training programs for aspiring technicians
- Continuing professional development for field engineers

5. Integration with Standard Operating Procedures (SOPs)

Utilities should integrate aligned practices (e.g., visual hotspot inspection, Buchholz relay bleeding, loose contact tightening) into formal SOPs immediately. For divergent practices (e.g., manual oil top-ups without testing, SF_6 handling without leak detection), utilities should augment, not replace, technician expertise by providing:

- Portable testing equipment
- Refresher training on IEC requirements
- Simplified field guides linking common faults to required safety checks

4.3 Future Research

Future work should focus on quantifying the MTTR reduction achievable through the systematic application of this technician-informed framework. Further research could also explore the development of digitized, field-deployable knowledge bases that integrate these practical diagnostic trees with formal maintenance logging systems.

Conflict-of-Interest Disclosure

We do not have any conflict of interest as regards the article entitled "Bridging Theory and Practice: A Technician-Guided Framework for Rapid Fault Resolution in Nigerian Power Distribution Networks".

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