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A Comprehensive Study on Electrical Analysis of Transformer Failures

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ABSTRACT
Transformers play a critical role in the transmission and distribution of electrical power, ensuring efficient energy delivery across vast distances. However, transformer failures can lead to significant disruptions in power supply, financial losses, and safety hazards. This study presents a comprehensive study of electrical analysis techniques employed to diagnose transformer failures, focusing on their underlying causes and implications. Through a detailed case study of a transformer malfunction, various electrical diagnostic methods including Dissolved Gas Analysis (DGA), Partial Discharge (PD) measurement, and insulation resistance testing are explored. The findings indicate that electrical failures often stem from a combination of factors, including insulation breakdown, overheating, and mechanical defects. By systematically analyzing the electrical parameters and gas compositions, this study identifies critical indicators of impending failure, providing insights into effective maintenance strategies. The research underscores the importance of regular monitoring and diagnostic practices in enhancing transformer reliability and operational longevity. Hence, this study aims to contribute valuable knowledge to industry professionals and researchers, fostering the development of more resilient power systems capable of meeting the increasing demands of modern society.

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I. INTRODUCTION

Transformers are fundamental to the operation of electrical power systems, playing a critical role in the efficient transmission and distribution of electricity [1]. By stepping up voltages for long-distance transmission and stepping them down for safe usage in homes and industries, transformers ensure that electrical energy can be transported over vast distances with minimal losses [2]. The reliability and functionality of transformers are therefore paramount to the stability and efficiency of power grids [3].

Despite their crucial role and generally robust construction, transformers are not immune to failures [4]. These failures can result from a variety of causes, including electrical faults, mechanical issues, thermal stress, environmental factors, and human errors [5]. Electrical failures might arise from insulation breakdowns or winding faults, mechanical failures from structural deformities, thermal failures from overheating, environmental factors from moisture or contamination, and human errors from improper installation or maintenance practices.

Failures in transformers can lead to severe consequences, including prolonged power outages, costly repairs or replacements, and, in extreme cases, catastrophic damages that can affect entire power systems [4]. For instance, a transformer failure in a major substation can disrupt the supply of electricity to thousands of homes and businesses, leading to significant economic and social impacts [5].

Understanding the root causes of transformer failures is essential for developing effective strategies to prevent them [6]. This involves not only recognizing the signs of impending failure through diagnostic techniques but also implementing robust maintenance practices to ensure transformers remain in optimal working condition [7]. Modern diagnostic tools and technologies, such as Dissolved Gas Analysis (DGA), Partial Discharge (PD) measurement, and insulation resistance testing have become standard practices in transformer maintenance. DGA involves sampling the insulating oil to detect gases produced by insulation breakdown and other fault mechanisms, providing valuable information about the internal condition of the transformer. PD measurement monitors for electrical discharges that can indicate insulation defects, while insulation resistance testing assesses the integrity of the transformer's insulation system [8].

In addition, the evolving landscape of power systems, with increasing integration of renewable energy sources and the advent of smart grids, poses new challenges and stresses on transformers [9]. These developments necessitate continuous research and adaptation in transformer design, diagnostics, and maintenance practices [10].

This study is motivated by the need to improve the reliability and longevity of transformers, thereby enhancing the overall stability and efficiency of power systems [1]. By providing a comprehensive analysis of electrical failures in transformer, their causes, diagnostic methods, and preventive measures, this study aims to contribute valuable insights and practical recommendations for industry professionals and researchers.

II. ELECTRICAL FAILURES IN TRANSFORMERS

Electrical failures in transformers are critical issues that can lead to significant operational disruptions and damage. These failures can arise from insulation breakdown, winding faults, partial discharge (PD), and external electrical stresses.

2.1 Insulation Breakdown

Insulation breakdown is a leading cause of transformer failures, typically resulting from overvoltage conditions, aging, contamination, and thermal stress. Overvoltage, often caused by lightning strikes or switching operations, can exceed the dielectric strength of the insulation, causing it to fail. Over time, insulating materials such as paper, oil, and synthetic polymers degrade due to constant thermal, electrical, and environmental stresses. Contamination from moisture, dust, and other particulates can also reduce insulation resistance. Thermal stress from repeated heating and cooling cycles can cause the insulation to crack and degrade, leading to short circuits between windings or between the winding and the core.

2.2 Winding Faults

Winding faults, such as turn-to-turn, phase-to-phase, and ground faults, are significant causes of transformer failures. Turn-to-turn faults occur when the insulation between adjacent turns of the winding breaks down, causing a short circuit. Phase-to-phase faults arise from insulation failure between different phases, leading to imbalanced currents and overheating. Ground faults occur when insulation between the winding and the core or the tank fails, causing a direct short to ground. These faults result in localized heating, which can further degrade the insulation and cause catastrophic failure. They also reduce transformer efficiency, leading to increased losses and accelerated aging.

2.3 Partial Discharge (PD)

Partial discharge is another critical issue, occurring when localized dielectric breakdown happens within the insulation system. Causes include void formation within the insulation material, sharp edges or points created by manufacturing defects or damage, and contaminants such as foreign particles or moisture. Partial discharge can gradually erode insulation, leading to eventual breakdown and failure. Additionally, PD generates electrical noise, which can interfere with other electrical equipment and communication signals.

2.4 External Electrical Stresses

External electrical stresses, including harmonics, voltage swells and sags, and transient overvoltage, contribute significantly to transformer failures. Harmonics generated by nonlinear loads such as variable frequency drives and power electronics cause additional heating and stress on transformer windings and insulation. Voltage swells (temporary overvoltage) and sags (temporary under voltage) can stress transformer insulation and windings. Transient overvoltage from switching operations and lightning strikes can induce immediate or cumulative damage to the transformer, causing dielectric breakdown and excessive heating.

III. ELECTRICAL ANALYSIS TECHNIQUES

Diagnosing electrical failures in transformers is essential for ensuring their reliability and longevity. Various diagnostic techniques are employed to detect early signs of failure, allowing for timely maintenance interventions. The following techniques are widely used in the electrical analysis of transformers.

3.1 Dissolved Gas Analysis (DGA)

DGA is a vital technique that monitors the gases dissolved in transformer oil, which are generated by the decomposition of oil and insulating materials under thermal and electrical stresses. Key gases such as hydrogen, methane, ethane, acetylene, ethylene, carbon monoxide, and carbon dioxide are analyzed using gas chromatography. The presence and concentration of these gases help identify early-stage faults like overheating, arcing, and partial discharges. DGA provides critical information for maintenance planning and fault severity assessment.

3.2 Frequency Response Analysis (FRA)

FRA assesses the mechanical integrity of transformers by analyzing their response to a range of frequencies. A sweep frequency signal is applied to the winding, and deviations from a baseline response indicate physical changes or displacements within the transformer. FRA is particularly effective in detecting mechanical issues such as winding displacement, deformation, core movement, and shorted turns. This technique is essential for post-transportation checks and assessing transformers after significant operational events.

3.3 Partial Discharge (PD) Measurement

PD measurement detects localized dielectric breakdowns within the transformer insulation system. These partial discharges occur when the electric field exceeds the dielectric strength of the insulation at specific points. PD activity is measured using electrical detection, acoustic emission sensors, or UHF sensors. This technique helps identify insulation defects, voids, and inclusions, allowing for the assessment of the severity and potential risk of insulation breakdowns. It is crucial for maintaining insulation health and preventing catastrophic failures.

3.4 Insulation Resistance Testing

Insulation resistance testing measures the resistance of the transformer's insulation to ensure it is within acceptable limits. Low insulation resistance indicates moisture ingress, contamination, or insulation aging. This technique involves applying a DC voltage to the windings and measuring the resistance. Insulation resistance testing is a fundamental maintenance check that helps evaluate insulation health, detect moisture, and identify potential points of failure.

3.5 Power Factor Testing

Power factor testing measures dielectric losses in the insulation system, with a high power factor indicating higher losses due to degraded insulation. An AC voltage is applied, and the power loss is measured to calculate the power factor. This test assesses the overall condition of the insulation system, identifying degradation and contamination, and providing insights into the transformer's long-term reliability.

IV. PREVENTIVE MEASURES FOR ELECTRICAL FAILURES

Preventive measures and maintenance are critical for ensuring the reliability, efficiency, and longevity of transformers. Implementing a comprehensive maintenance strategy helps in early detection of potential issues, minimizing the risk of failures, and reducing downtime. The key preventive measures focus on regular maintenance, continuous monitoring, proper installation, the use of quality materials, and surge protection.

4.1 Regular Maintenance

Routine inspections and maintenance activities are crucial for the early detection of potential issues that could lead to transformer failures. Key maintenance activities include:

4.1.1 Oil Testing

This involves the regular analysis of insulating oil to monitor for dissolved gases, contaminants, and moisture levels. Gas chromatography is often employed to identify gases such as hydrogen, methane, and acetylene, which can indicate developing faults. Testing for moisture content helps assess the condition of the insulation, as excessive moisture can compromise dielectric strength and lead to electrical failures.

4.1.2 Insulation Resistance Testing

Frequent assessments of insulation integrity help ensure that the insulation system can withstand the electrical stresses placed upon it. This testing measures the resistance between the windings and ground as well as between different windings, allowing operators to identify any deterioration that may compromise the transformer's performance.

4.1.3 Thermographic Inspections

Using thermal imaging technology, operators can identify overheating components and connections. These inspections allow for the detection of hot spots that may indicate loose connections or overloaded components. Regular thermal assessments are essential for identifying issues before they escalate into significant failures.

4.2 Condition Monitoring

Implementing continuous condition monitoring systems provides real-time tracking of critical parameters affecting transformer health. Key monitoring practices include:

4.2.1 Temperature Monitoring

Continuous monitoring of winding and oil temperatures using sensors helps prevent overheating. Temperature spikes can indicate overload conditions or cooling system failures. Setting thresholds for alarm triggers allows operators to take prompt action when temperatures exceed safe limits.

4.2.2 Dissolved Gas Monitoring

Regular monitoring of dissolved gas levels in transformer oil can provide early indications of internal faults. Establishing a baseline of normal gas levels allows for effective trend analysis over time, enabling operators to detect deviations that could signal impending failures.

4.2.3 Partial Discharge Monitoring

Continuous tracking of partial discharge activity helps identify insulation issues at an early stage. Advanced PD monitoring systems utilize various methods, such as UHF and acoustic sensors, to provide detailed insights into the condition of the insulation, allowing for timely interventions.

4.3 Proper Installation and Operation

Ensuring transformers are installed and operated correctly is vital for their longevity. Key considerations include:

4.3.1 Appropriate Grounding

Proper grounding of transformers is essential for effective fault protection and safety. This involves using grounding systems that meet industry standards to dissipate fault currents safely and prevent electrical shock hazards.

4.3.2 Protection Systems

Incorporating protective devices such as circuit breakers and relays helps safeguard transformers from overloads and short circuits. These devices automatically disconnect the transformer from the power supply in the event of a fault, preventing extensive damage.

4.3.3 Operating Within Capacity

Operating transformers within their specified capacity is crucial to avoid excessive heating and stress on components. Regularly reviewing load conditions and managing demand can help prevent overload scenarios.

4.4 Use of High-Quality Materials

Utilizing high-quality insulating materials and advanced manufacturing techniques enhances the robustness of transformer insulation systems. Key considerations include:

4.4.1 Selecting Insulation Materials

Using insulation materials with higher dielectric strengths reduces the risk of breakdowns under electrical stress. Newer materials such as cross-linked polyethylene (XLPE) or epoxy resins can provide improved thermal and electrical properties.

4.4.2 Implementing Quality Control

Stringent quality control during manufacturing ensures that materials meet industry standards and performance specifications. Regular audits of suppliers and manufacturing processes help maintain high-quality standards.

4.5 Surge Protection

Installing surge protection devices is essential for shielding transformers from transient overvoltages caused by lightning strikes, switching operations, and other electrical disturbances. Key aspects include:

4.5.1 Surge Arresters

These devices protect transformers from voltage spikes by diverting excess voltage to ground. Proper selection and installation of surge arresters can significantly reduce the risk of damage from transients.

4.5.2 Coordination with Protective Devices

Ensuring that surge protection devices work in conjunction with circuit breakers and other protective systems enhances overall protection. Regular testing and maintenance of these devices are critical to ensure their reliability during fault conditions.

V. RESEARCH FINDINGS

The population of this study is drawn from the different cadre of the engineering team in the Utility Company. This ranges from Technicians, Engineers, assistant managers and managers manning all the activities of maintenance/repairs of distribution transformers and other electrical faults that may occur.

The Rigasa Area was divided into 6 zones (zone 1 to 6) by the researcher for easy identification with a total number of 40 distribution transformers.

All the transformer specification are of 11/0.415KV, 3-phase, 200KVA, Oil-immersed installed 15 years ago. Each zone has a number of transformers as shown in the Table 1.

Table 1: Distribution of Distribution Transformers (DTs) and the Engineering Team

Rigasa Area	Number of Distribution Transformer	Technician	Engineer	Assistant Manager	Manager
Zone 1	6	20	15	10	5
Zone 2	8				

Zone 3	5				
Zone 4	8				
Zone 5	7				
Zone 6	6				
Total	40	20	15	10	5

From Table 1, the population of this study comprised of the managers, assistant manager, engineers and technicians and combine together. This brings the sum total of the population to fifty (50) on location and size.

5.1 Sample and Sampling Techniques

The sample size of this study was drawn from the specific population of study 50.Therefore, sample size was determined using research advisor 2006[19], where the population size of 50 corresponds with the sample size of 44 at confidence level of 95% with 5% margin error [17].

Table 2: Respondents on Bio data

		Count	N %
Gender	Male	28	63.6%
	Female	16	36.4%
	Total	44	100.0%
Age/Years	18-30	2	4.5%
	31-44	2	4.5%
	44-55	14	31.8%
	55 and above	26	59.1%
	Total	44	100.0%
Academic Qualification	Tech Cert	0	0.0%
	ND	2	4.5%
	HND	15	34.1%
	B.tech/BSc/BEng	24	54.5%
	Masters	3	6.8%
	PhD	0	0.0%
	Others	0	0.0%
	Total	44	100.0%
Years of Experience (Years)	0-10	4	9.1%
	11-20	0	0.0%
	21-30	16	36.4%
	31 and above	24	54.5%
	Total	44	100.0%

Table 2 above has shown that 63.6% of respondents are male and 36.4% are female respectively, 18-30 and 31-44 years accounted for 4.5% of respondents each and 55 and above accounted for 59.1% of the respondents.

From respondents level of education, Tech Cert, PhD and others shows to have 0.0% of respondents and B.tech/BSc/B.eng accounted for 54.5% of the total respondents, 9.1% of respondents has shown to attain 0-10 years of experience, 36.4% shows to have 21-30 years' experience and 54.5% shows to have 31 above years of experience.

Table 3: Assessment of Sufficiency of Test Instruments and correct utilization

	SD	D	A	SA			
	Count	Count	Count	Count	Total	Mean	Standard Deviation
There are enough testing instruments e.g. Digital Multi meters, Digital Megger etc. for the Engineering Team	0	4	12	28	44	3.55	.66
The testing instruments/tools are always functional and ready for use	0	4	16	24	44	3.45	.66
The testing instruments/tools are being kept in a safe and conducive environment	0	0	20	24	44	3.55	.50
The leads and other accessories for the test instruments are always handle with care	0	4	16	24	44	3.45	.66
Test instruments are not exposed to heat, chemicals and moisture	0	0	20	24	44	3.55	.50
Testing instruments/tools are being subjected to a stock inventor periodically	0	4	16	24	44	3.45	.66

Testing instruments are always switch off after use	0	0	20	24	44	3.55	.50
Testing instruments are always kept clean and protected	0	0	16	28	44	3.64	.49
Safety precautions are essential when working with electricity and it must be disconnected from the power and auxiliary sources	0	0	12	32	44	3.73	.45
Always take precautions when using test instruments by wearing appropriate PPE e.g. Gloves	0	0	16	28	44	3.64	.49
Testing Instruments are been utilized correctly	0	8	12	24	44	3.36	.78
All testing activities carried out are organized periodically for engineering team on test instrument usage	0	30	10	4	44	2.41	.66
All testing activities carried out it recorded immediately	0	23	14	7	44	2.64	.75
Customized check list for different kinds of testing are always available for use	0	30	14	0	44	2.32	.47
The data records are transferred to a dedicated data bank for reference and future use	0	30	14	0	44	2.32	.47
Safety wears: Boots, helmets etc. are sufficient and being utilized accordingly	0	16	21	7	44	2.80	.70
On the job training are organize for the younger technicians and engineers periodically to enhance their knowledge and skills	0	37	7	0	44	2.16	.37
Remember Safety first and always	0	0	3	41	44	3.93	.25
Grand					44	3.19	.55

Table 3 above shows that all of the statements that assessed the sufficiency of testing instruments/tools and correct utilization have their mean values greater than 2.5 which imply that they agree. Grand mean = 3.19 with a standard deviation = .552 indicates that there are sufficient testing instruments/tools and are being utilize correctly and accordingly. These statements have answered the research question one.

Table 4: Assessment of Effects Periodic Maintenance Activities

	SD Count	D Count	A Count	SA Count	Total		
					Count	Mean	Standard Deviation
Periodic Maintenance (PM) is a strategy in which maintenance work is performed ahead of time to prevent failure	0	0	4	40	44	3.91	.29
Periodic Maintenance (PM) is critical distribution transformers because they are costly to replace	0	0	0	44	44	4.00	.00
Periodic Maintenance (PM) boost up time and reduces cost	0	0	11	33	44	3.75	.44
Periodic Maintenance (PM) prolongs life span of distribution transformers	0	0	11	33	44	3.75	.44
Periodic Maintenance (PM) checklist ensures all the tasks are completed	0	0	17	27	44	3.61	.49
Periodic Maintenance (PM) is also called scheduled maintenance ensures continued operational efficiency, reliability and safety of any equipment	0	0	7	37	44	3.84	.37
Periodic Maintenance (PM) is the daily process that ensures organization’s assets remain in good condition	0	4	3	37	44	3.75	.61
Periodic Maintenance (PM) is the daily basis for distribution transformer are being carried out	0	32	0	12	44	2.55	.90
Oil level (Magnetic Oil Gauge) of the main tank and conservator are checked daily	0	40	0	4	44	2.18	.58
Replacement of Silica gel when its color turns pink	0	40	0	4	44	2.18	.58
If any leakage is observed, seal it	0	8	28	8	44	3.00	.61
Periodic Maintenance (PM) on the monthly basis for transformer are being done	0	44	0	0	44	2.00	.00
The oil level in the caps is checked monthly	0	44	0	0	44	2.00	.00
Keep breathing hole in the gel is cleared to ensure proper breathing action always monthly	0	44	0	0	44	2.00	.00
Distribution transformer that has oil filled bushing, ensure oil is filled up to the correct level	0	23	21	0	44	2.48	.51
Periodic Maintenance (PM) prevents costly unplanned downtime	0	0	22	22	44	3.50	.51
Planning plays an important role in all periodic in all periodic maintenance activities in an organization	0	0	29	15	44	3.34	.48
Annual Maintenance Activities are scheduled and executed accordingly.	0	37	4	3	44	2.23	.57
Grand Mean					44	3.00	.41

Table 4 above shows that all of the statements that assessed the effects of periodic maintenance have their mean values greater than 2.5 which imply that they all agree to the positive effects of periodic maintenance activities. The Grand mean = 3.00 with a standard deviation = .41 this indicates that Periodic maintenance ensures prolong life span and operational efficiency of distribution transformers. Inadequate attentions on daily, monthly basis and annual maintenance activities have been observed. They are not been carried out on scheduled considering the mean their value of 2 while the threshold mean value is 2.5 This is a bad maintenance practice and can lead to failure short time of operation. Therefore, the research two has been answered.

Table 5: Assessment of causes of Distribution Transformer Failure

	SD Count	D Count	A Count	SA Count	Total		
					Count	Mean	Standard Deviation
Windings are made up of copper or aluminum. It is wound around the core to facilitate induction process required for voltage transformation. If the winding fails, the distribution transformer failure occurs.	0	0	26	18	44	3.41	.50
Windings in a distribution transformer play a crucial role in the transformers function and transformation process.	0	0	18	26	44	3.59	.50
Core is made from layers of laminated silicon steel which reduces eddy currents that cause additional heat	0	0	18	26	44	3.59	.50
The core of transformer carries magnetic flux and provides mechanical strength to the transformer	0	0	14	30	44	3.68	.47
Core fails due to dc magnetization or displacement of the core steel during construction and this can results in failure of the transformer	0	0	22	22	44	3.50	.51
The function of the tank is to enclose the transformer windings and Core for physical protection as well as container for oil used as coolant and withstand environmental stresses	0	0	18	26	44	3.59	.50
Internal arcing in an oil filled transformer tank can lead to high gas pressure in the tank and subsequently rupture the tank and then transformer failure occurs.	0	0	22	22	44	3.50	.51
Transformer oil provides insulation between windings along with desired cooling in the transformers. Contamination of the transformer oil can result in transformer failure through short circuiting of windings due to failure of oil insulation	0	0	18	26	44	3.59	.50
The failure of cooling oil occur to the malfunction of oil circulation or poor heat eat transfer to secondary 1cooling circuit	0	0	22	22	44	3.50	.51
Bushings are used to take out the windings terminal outside the tank with electrical insulation to connect the transformer with the power system.	0	0	14	30	44	3.68	.47
Damages, cracks in the porcelain and bad gasket enable ingress of water inside insulation of the bushing leading to its failure.	0	0	18	26	44	3.59	.50
The main failure mode of bushing is short circuit, this may be due to material fault in the insulation or due to damage	0	0	14	30	44	3.68	.47
Insulation is made up of cellulose base product such as press board and paper. The life of an aged transformer is dependent on the life of the insulation.	0	0	22	22	44	3.50	.51
Proper insulation is vital in preventing short circuit between winding and core. Its failure may lead to transformer failure equally.	0	0	10	34	44	3.77	.42
Tap changer purpose is to regulate the output voltage, this is achieved by altering the number of turns in one winding, usually i-1V winding by changing the turn ratio of the transformer	0	0	18	26	44	3.59	.50
Tap changer failure is commonly occurs in a transformer, according to the classification of the detection failure	0	0	10	34	44	3.77	.42
Tap changer failure can be caused by lack of maintenance (Dirty contacts) and burnt out capacitor in the motor	0	0	10	34	44	3.77	.42
Grand Mean					44	3.60	.48

Table 5 above shows that all of the statements that assessed the causes of distribution transformer failure have their mean values greater than 2.5 which imply that they all agree to the causes of transformer failure. Grand mean = 3.60 with a standard deviation = .48 indicates that statements on failure causes of these key distribution transformers components lead to subsequent transformers too. These also have answered the research question three.

Table 6: Assessment of Transformer Failure Investigation Analysis

	SD Count	D Count	A Count	SA Count	Total		
					Count	Mean	Standard Deviation
Transformer Failure can be attributed to the combination of Electrical, Thermal and Mechanical factors while considering the age of the transformer as critical	0	0	26	18	44	3.41	.50
Transformer failure investigation starts with consumers complaints of power outage in a particular area.	0	0	30	14	44	3.32	.47

Onsite investigation and testing are conducted to collect all vital data from the site and other historical data related to the transformer.	0	0	34	10	44	3.23	.42
Failed transformer is inspected external and internal before finally de-tanking and tear down inspection is performed, so that analysis of the cause of the failure is done.	0	0	22	22	44	3.50	.51
To thoroughly analyses DTs failure, axial and radial forces need to be understood. Directions of forces and mechanism of failure in core types differs with that of shell type transformer	0	0	30	14	44	3.32	.47
Windings failure modes r core type transformers include radial tension failure, radial compression failure, axial expansion failure, axial compression failure, axial telescoping failure, end turn failure etc. while windings failure modes for shell type co	0	0	26	18	44	3.41	.50
Transformer failure can be caused by transient surges, lightening, over-excitation, switching surges, turn to turn short circuit, layer to layer short circuit, windings resonance, partial discharges etc.	0	0	34	10	44	3.23	.42
Different kind of voltages an exist in the transformer windings and associated part of these include Normal Low frequency system operating voltages, normal low frequency induced vo1tages, abnormal low frequency system operating voltages., abnormal high frequency system operating voltages, abnormal high frequency system voltages and abnormal high frequency and low frequency voltages from other cause. These voltages arise from external solar or DC disturbances, changes in electrical field distribution.	0	0	34	10	44	3.23	.42
Grand Mean					44	3.33	.46

Table 6 above shows that all of the statement that assessed the method of conducting transformer failure investigation has their mean values greater than 2.5 which imply that they all agree. Grand mean = 3.00 with a standard deviation = .41 indicate that the statements on method of carrying out transformer failure investigations have been confirmed to have answered the research question four.

Therefore, the samples size is forty four (44) out of the entire population of fifty (50) and were randomly selected. About than 90% of the item statements have their mean values greater than 2.5 which means that they agree with the 4 research questions except 10% that are less than the threshold mean value of 2.5 This did not affect the general assessment as the grand mean values for each of the 4 research questions were greater than 2.5. The most significant finding was lack of periodic maintenance and scheduled annual preventive maintenance activities which can lead to the transformer failure with its unwanted consequences. Others are poor record-keeping and inadequate on-the-job training.

VI. CONCLUSION

In conclusion, transformer failures can significantly disrupt electrical power systems, resulting in extended outages and costly repairs. To mitigate these risks, a multifaceted approach is essential, incorporating regular maintenance practices such as oil testing, insulation resistance assessments, and thermographic inspections to detect potential issues early. Continuous condition monitoring techniques, including temperature monitoring, dissolved gas analysis, and partial discharge measurement, provide real-time insights into transformer health, enabling proactive maintenance strategies. Ensuring proper installation, utilizing high-quality materials, and implementing effective surge protection further enhance transformer resilience. As electrical power systems evolve with the integration of renewable energy sources and smart grid technology, ongoing research and adaptation in transformer design and maintenance practices are crucial. This comprehensive approach emphasizes the importance of proactive measures and timely interventions to prevent failures and ensure reliable electricity delivery, ultimately supporting the growing demands of modern society while fortifying the stability and efficiency of power systems.

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