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THE RELIABILITY ASSESSMENT OF POWER TRANSFORMERS

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ABSTRACT

This research investigated the assessment of power transformer reliability with emphasis on the transmission network within Rivers State in Nigeria, focusing on the perspectives of electricity consumers, organizational personnel, and business operators using descriptive survey. The study encompassed the entire population of 725,372 electricity consumers in the Port Harcourt Electricity Distribution Company (PEDC) in Rivers State, which included both households and business owners. To select a representative sample, the Convenience Sampling Technique was employed, resulting in the inclusion of 390 electricity consumers in Rivers State. Data collection utilized the Consumers Perception of Electricity Power Transformer Reliability

(COPEPT) questionnaire and Structured Interview, with the instrument's reliability established through the test-retest technique, yielding a reliability coefficient for each investigation. Research questions were addressed through the weighted mean score (WMS) analysis. Key findings indicated dissatisfaction among electricity consumers in Rivers State, primarily attributed to factors such as transformer age, overall condition, uncontrolled overloading, adverse weather conditions, and inadequate transformer capacity to meet increasing demand. Addressing these issues, different approaches including upgrading or replacing outdated transformers, implementing limits on transformer loading, introducing robust earthing systems, and increasing transformer capacity, were recommended to enhance consumer satisfaction and overall reliability. The study further revealed that persistent power transformer failures resulted in power outages, adversely impacting businesses, households, communication, and contributing to reduced production and national income. Based on these findings, recommendations in the form of strategies were provided, emphasizing a comprehensive analysis of power surge control during adverse weather conditions, a plan for upgrading or replacing outdated transformers, an assessment of power transformer capacity needs, and collaboration with relevant stakeholders to develop strategies mitigating the negative economic impact and enhancing communication with consumers.

Keywords: Reliability Assessment, Power Transformers, Rivers State and Transmission Network.

INTRODUCTION

Upon the activation of a switch in residential spaces, offices, and industries, electric lights illuminate, appliances initiate operation, and large-scale industries commence the transformation of raw materials into both semi-finished and finished products. This progression adheres to a systematic process encompassing power generation, transmission, and distribution. The sequence initiates at the power plant, where electricity is generated and subsequently transferred through a series of components: from the Power Plant to the Transmission Sub-Station then to Distribution Sub-Station, and ultimately reaching Homes, Offices, and Industries (Sa'ad, 2018).

Without the transmission link, the sequential movement of electricity from generating plants to the final users can not be achieved as it provides a platform for the evacuation of electricity from the generating companies (Gencos) to the distribution network for onward transmission to final users.

The operational and maintenance responsibilities for Nigeria's transmission network lie with the Transmission Company of Nigeria (TCN), a government-owned corporation established in 2004 (Sa'ad, 2018). This transmission network is intricately linked to diverse regional networks, facilitating the seamless exchange of electricity between states and regions. This interconnected structure plays a pivotal role in guaranteeing a dependable power supply across different parts of the country and Rivers state in particular, while optimizing the utilization of generated electricity. Comprising high-voltage transmission lines and substations, the Nigerian transmission network is a critical component of the nation's electrical infrastructure (Sa'ad, 2018). The transmission lines have a voltage rating of 132kV and 330kV, which allow for the long-distance transmission of electricity. These lines are made of conductors and supported by transmission towers to ensure their stability and reliability. The substations are integral part of the transmission network as they facilitate the transformation and control of electricity at different voltage levels. Electricity from power plants or other substations are received by these substations and step up the voltage to transmit it over long distances. Substations also regulate the voltage, provide protection mechanisms, and enable the transfer of electricity to different distribution networks. To ensure the efficient and reliable operation of the transmission network, TCN employs various technologies and control systems. These include Supervisory Control and Data Acquisition (SCADA) systems, which monitor and control the network in real-time. SCADA systems provide important information about the status of transmission lines, substations, and transformers, allowing for timely response to faults or disruptions. They also help in load balancing, optimizing network performance, and preventing grid instability (NERC, https://www.nercng.org/).

In order to achieve efficient transmission, a number of equipment (Transformers, circuit breakers, isolators, Isolators, shunt reactors, earthing switches etc) are needed and must be reliable, one of which is the Power transformers which are undoubtedly the most important equipment in the transmission stations (Sa'ad, 2018 et al).

A Power transformer, an electrical apparatus utilizing electromagnetic induction, facilitates the transfer of electrical energy between multiple circuits. Commonly employed in alternating current (AC) electrical power systems, it serves the purpose of either stepping up or stepping down voltage levels (Wikipedia, 2021) as shown in the schematic diagram of types of transformers in Fig. 1. The reliability of power transformers is crucial to ensuring an uninterrupted power supply from the transmission network to consumers. They consist of a component consisting of a core with magnetic permeability and a series of windings, which are insulated conductors with low resistance wrapped around the core, a cooling and insulation arrangement that includes insulation paper and mineral oil surrounding the active portion and a transformer tank, connection terminals, and related accessories (***Adewuyi et al 2016***).

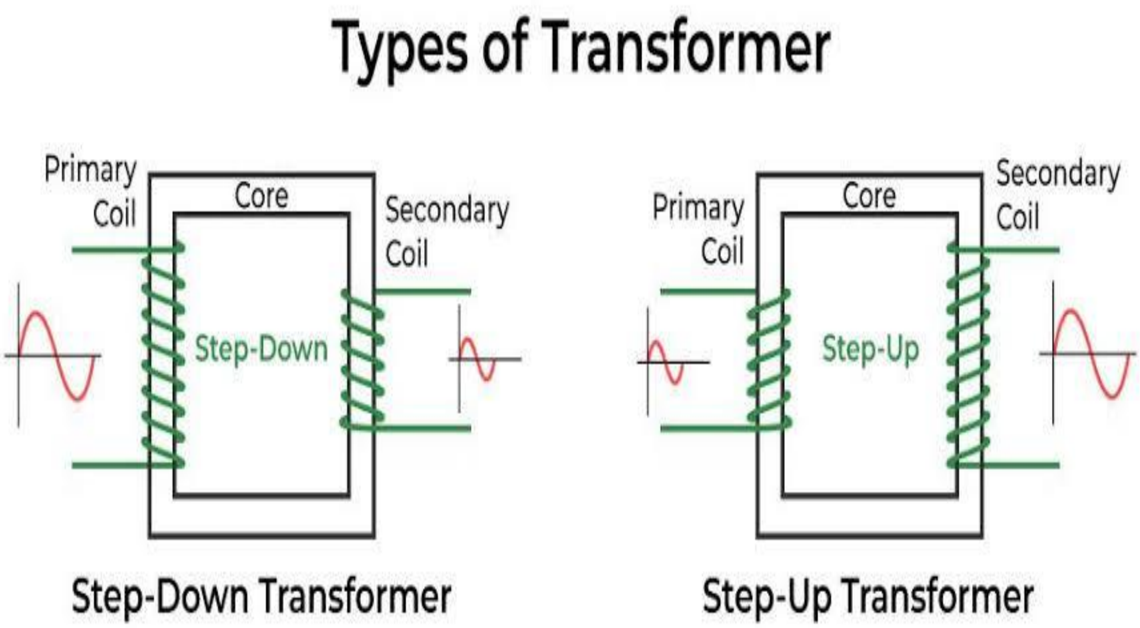

Figure. 1: Schematic Diagram of Types of Transformers.
Source: https://www.researchgate.net

As shown in the schematic diagram of types of transformers in Fig. 1., Power transformers stand out as the predominant category of transformers employed in electrical power systems. Specifically engineered for the transfer of electrical energy, they operate at high voltages, facilitating the transmission of power from generating facilities to distribution substations. At these substations, the voltage undergoes a reduction to facilitate subsequent distribution to end consumers. Renowned for their substantial size and capacity to manage formidable loads, power transformers play an indispensable role in the efficient transmission and distribution of electricity. Primarily designed for transmission applications, these transformers find application in power generation stations, substations, and the interconnection of grids. Power transformers can handle voltages ranging from 110 kV to 765 kV and are responsible for transmitting large amounts of electricity over long distances. They are usually oil-filled and have higher power capacities compared to distribution transformer. The reliabilities of these power transformers are instrumental in improving the quality of power supply in Nigeria and in Rivers state in particular.

Reliability, defined as the ability of a system to fulfill its intended function without failure over a specified period, underscores the critical importance of power transformer performance (Wikipedia, 2021). In the case of power transformer, this refers to its ability to operate continuously and reliably under normal operating conditions, without breakdowns or failures. Transformers are designed to have a long service life, often exceeding 30 years, and therefore, their reliability is of paramount importance (Oliveira, L. H., 2020). The reliability of a power transformer is influenced by various factors, including design, manufacturing quality, maintenance, and external conditions. A well-designed transformer should be able to withstand electrical, mechanical, and thermal stresses, while maintaining its integrity and optimal performance. The use of high-quality materials and advanced manufacturing processes helps to ensure reliability and durability (Adewuyi, Abodunrin, & Aderonmu, 2016). By and large, the reliability assessment is basically concerned with the evaluations, estimations or opinions formed regarding the attribute (reliability) of an equipment (Power transformers).

The location scope of this study is focused on Rivers State, Nigeria. This particular geographical area is chosen because it represents a specific region within Nigeria's Transmission industry. Investigating the reliability of power transformers in Rivers State allows for a more localized and context-specific analysis. Factors such as the local climate, infrastructure, maintenance practices, and consumer demographics in Rivers State may have unique characteristics and can significantly impact the reliability of power transformers. By narrowing the study to this specific location, researchers can gain a deeper understanding of the challenges and opportunities for improving power transformer reliability in Rivers State. The State is located in the southern region of Nigeria, along the coastline of the Niger Delta. It lies between longitude 6° 20' east and 8° 50' east, and latitude 4° 20' north and 7° 30' north. The state shares boundaries with Imo, Abia, and Akwa Ibom states to the north, Bayelsa State to the west, and the Atlantic Ocean to the south. It also shares an international boundary with Equatorial Guinea to the east.

In terms of occupation, Rivers State is an economic powerhouse in Nigeria. It is home to several multinational oil and gas companies, making it the hub of Nigeria's petroleum industry. Other sectors such as agriculture, manufacturing, trade, and services also contribute to the state's economy.

The reliability of power transformers in Rivers state has been a significant concern for consumers in the country. Like many other states, Rivers state faces numerous challenges regarding its electricity infrastructure, resulting in frequent power outages and inconsistent supply, affecting economic activities and over all wellbeing of the citizens.

Consumer expectations have shifted from merely seeking access to electricity to demanding high-quality, reliable power supply. Thus, the reliability of power transformers has gained significant attention in recent years, as it directly impacts the welfare and satisfaction of consumers.

This research was conducted to understand the Perception and Satisfaction of Electricity Customers on the Reliability of Power Transformers within Rivers State, the Dominant Factors Affecting the Reliability of Power Transformers, their Impacts on Customer Experiences and Businesses and Possible Recommendations on how to improve the existing situation based on customer feedbacks as well as to develop techniques for assessing and monitoring their conditions.

Significance of Power Transformer Reliability in Rivers State.

The importance of this investigation concerning the dependability of power transformers within the Rivers State Transmission Network is multifaceted; they find their usefulness among electricity companies, consumers (households, firms, industries and government), policy makers and contribution to literature.

Electricity Companies: This study holds significance for electricity providers as it offers insights into consumer perceptions and satisfaction levels regarding power transformer reliability. The outcomes can help companies in pinpointing areas for improvement and devising strategies to bolster power transformer reliability. Ultimately, this could lead to heightened customer satisfaction and loyalty.

Consumers (Households, Firms, Industries, and Government): Consumers directly feel the impact of power transformer reliability. This research helps consumers grasp the factors influencing power transformer reliability and evaluate their experiences within the Rivers state transmission network. By articulating their viewpoints, consumers can contribute to the formulation of effective policies and initiatives aimed at enhancing power transformer reliability.

Policy Makers: Policy makers wield significant influence in shaping the electricity sector. The insights derived from this study can guide policy makers in crafting regulations and policies conducive to promoting power transformer reliability. It also underscores the importance of investing in infrastructure and maintenance to ensure a dependable power supply for consumers.

Contribution to Literature: This study enriches the existing literature on power transformer reliability within the Nigerian transmission industry by focusing on consumer perspectives. It offers a comprehensive analysis of the factors influencing reliability, shedding light on their impact on consumer experiences and industry performance as a whole. Moreover, the study proposes practical recommendations based on consumer feedback, thereby contributing valuable insights to the realm of power system reliability and addressing a gap in understanding consumer perceptions within the Nigerian transmission industry.

LITERATURE REVIEW

In the context of power transformers, reliability is of utmost importance as electricity transmission primarily relies on a stable and efficient power transformer. Power transformers are responsible for converting electricity to the desired voltage levels, allowing for transmission and distribution across the grid. Therefore, any failures or breakdowns in these transformers can lead to power outages, affecting industries, households, and critical infrastructures.

Reliability Theory

The Reliability Theory offers a systematic approach to evaluate the reliability of power transformers by considering various factors such as design, manufacturing quality, maintenance practices, and environmental conditions. It provides tools and techniques to assess the probability of failure, mean time between failures, and overall performance of power transformers. The concept of this theory help power companies to identify weak points in their transformer systems, implement better maintenance practices, and make informed decisions regarding investments in infrastructure improvement (***Emmanuel, 2017***).

By improving the reliability of power transformers, Nigeria can enhance the stability and quality of its electricity supply, thereby boosting industrial productivity, attracting investments, and improving the overall living standards of its population.

Electricity Transmission in Nigeria

The radial transmission grid, incorporating 330kV and 132kV networks, is under the management of the Transmission Company of Nigeria (TCN). TCN is responsible for both system operation and market settlement functions (Folorunso and Olowu, 2014). This extensive network, covering 5523.8km of 330kV and 6801.49km of 132kV transmission lines, includes 32 number 330/132kV substations and 105 132/33/11kV substations as shown in the Electricity Transmission Line in Fig. 2. The total installed transformation capacity is 7688MVA for 330/132kV and 9130MVA for 132/33/11kV, with an average available capacity of 7364MVA for 330/132kV and 8448MVA for 132/33kV (Folorunso and Olowu, 2014, Labo, 2010).

The Nigerian 330kV transmission grid encounters challenges, primarily notable power losses attributed to lengthy transmission lines. These losses diminish power availability to consumers, resulting in insufficient power for operating appliances. The escalating power demand strains the network, potentially reducing its lifespan or leading to a complete collapse (Folorunso and Olowu, 2014). The major issues identified in the Nigerian transmission system include insufficient funding, incomplete coverage, limited electricity wheeling capacity, outdated sections with inadequate redundancies, financial constraints for expansion and maintenance, frequent vandalism, poor voltage stability, inadequate tools and vehicles, lack of modern communication and monitoring technologies, overloaded transformers, inadequate spare parts, and insufficient technical staff recruitment and training (***Johnson, B. 2017***).

In an effort to address these challenges, the Power Holding Company of Nigeria underwent unbundling, leading to the establishment of the Transmission Company of Nigeria.

The Transmission Company of Nigeria (TCN)

The Transmission Company of Nigeria (TCN) oversees the electricity transmission network within the nation and by extension, in Rivers state. It is made up of three operational departments namely the Transmission Service Provider (TSP), the System Operations (SO) and the Market Operators (MO).

1. Transmission Service Provider (TSP): The TSP is responsible for the development and maintenance of the national inter-connected transmission system, managing substations, power lines, and providing open access transmission services. Its focus includes the maintenance and expansion of the physical infrastructure constituting the transmission grid.

2. System Operations (SO): The SO oversees the flow of electricity from generation to distribution companies, operating under the Grid Code for the Nigerian Electricity Supply Industry (NESI). Its key responsibilities involve ensuring the reliability of transmission grid lines and maintaining technical stability through planning, dispatch, and control operations. Specific duties of the SO include: Controlling grid frequency and voltage, allocating power loads during insufficient generation, designing, installing, and maintaining Supervisory Control and Data Acquisition (SCADA) and communication facilities, economic dispatch of generating units, procuring and managing ancillary services, enforcing the grid code and operational procedures, coordinating planned outages for system equipment maintenance, conducting post-fault analysis of major grid disturbances.

3. Market Operations (MO): The MO plays a pivotal role in administering the market rules within the Nigerian Electricity Supply Industry (NESI). Its primary responsibility is to oversee the Electricity Market, ensuring efficiency and adherence to market regulations. The specific functions of MO include: Implementation and administration of the Nigerian Electricity Market Rules, drafting and execution of Market Procedures, oversight of the commercial metering system, ensuring each trading point has appropriate metering systems, management of the market settlement system, administration of the payment system and commercial arrangements within the energy market, including ancillary services, supervision of electricity market participants' compliance with and enforcement of the market rules and the grid code, periodic reporting on the implementation of the market rules, capacity building for market participants on the market rules, procedures, and trading arrangements (Folorunso and Olowu, 2014).

The TCN infrastructure is mainly radial, lacking redundancies, leading to inherent reliability issues. With transmission losses averaging around 7.4%, these figures are notably high compared to benchmarks set by emerging countries, ranging from 2-6%. While the number of system collapses has decreased in recent years, dropping from a peak of 42 in 2010 to a few in recent years, these trends highlight the significant infrastructure and operational challenges within the transmission subsector of the industry.

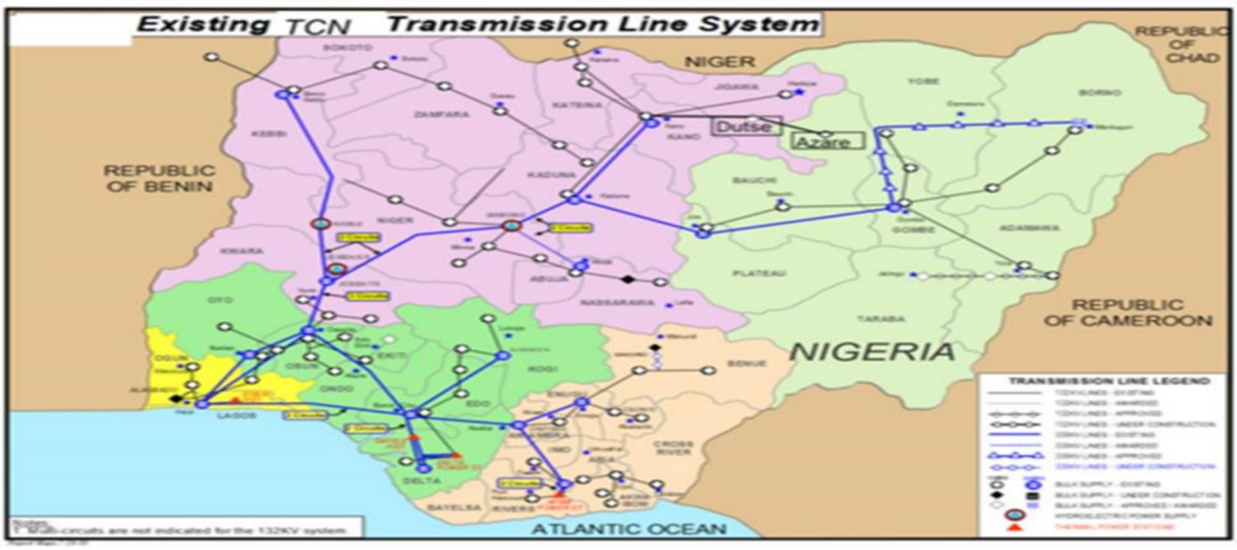

Figure 2: Electricity Transmission Line.
Source: https://www.researchgate.net

Power Transformers

Power transformers represent stationary devices designed for the transfer of electrical energy between various voltage levels while maintaining a consistent frequency. Comprising multiple windings, namely primary and secondary, these windings remain electrically isolated but are magnetically interconnected through a shared magnetic core. The primary winding establishes a connection with the input power source, while the secondary winding delivers power to either the load or another transformer (***Oliveira, L. H. et al 2020***).

In terms of operating principle, the functionality of power transformers hinges on the principle of electromagnetic induction. As alternating current (AC) courses through the primary winding, it generates a dynamic magnetic field within the iron core. This magnetic field, in accordance with Faraday's law of electromagnetic induction, induces an electromotive force (EMF) in the secondary winding. The voltage transformation ratio of the transformer is determined by the ratio of turns between the primary and secondary windings (***Oliveira, L. H. et al 2020***).

Transformer Efficiency, Losses and Factors Contributing to Failure

Transformer efficiency pertains to the transformer's capability to convert electrical energy from one voltage level to another with minimal energy losses. It is a crucial parameter influencing the overall performance and operational expenses of the transformer, essential in various applications like power generation, transmission, and distribution systems.

Operated on electromagnetic induction principles, transformers employ a primary winding energized by alternating current, inducing a voltage in the secondary winding for energy transfer. However, energy losses occur in this process, categorized into copper losses and core losses (Redaelli & De Mello, 2019).

1. Copper Losses: They occur within the windings and are due to electrical resistance of the conductor. They include I^2R Losses and eddy current losses.

(a). I^2R Losses: Arising from winding resistance during load current flow, these losses are proportional to the square of the current. Mitigation involves using thicker wires with materials featuring lower resistivity.

(b). Eddy Current Losses: Induced in the winding's laminated structure, these currents circulate within, dissipating energy. Laminated cores made of thin metal sheets reduce eddy current losses.

2. Core Losses: They occur as a result of hysteresis and eddy current losses.

(a). Hysteresis Losses: Resulting from changes in the core's magnetic field direction, magnetic domains realign, causing energy dissipation. Utilizing materials with lower hysteresis losses, like silicon steel or amorphous alloys, reduces this loss.

(b). Eddy Current Losses: Induced by a changing magnetic field, these currents circulate within the core, causing energy dissipation. Laminated cores effectively minimize these losses.

The transformer's overall efficiency is determined by the ratio of output power (Pout) to input power (Pin) (Redaelli & De Mello, 2019). Understanding these losses is vital for effective transformer design, operation, and maintenance.

The efficiency (η) and the losses (Ph) can be expressed as: $\eta = Pout / Pin = 1 - (Ph / Pin)$.

To achieve high efficiency, transformer design takes into account various factors such as optimal sizing of conductors, selecting core materials with low losses, minimizing air gaps, and efficient cooling mechanisms.

Power Transformer Failure in Electricity Transmission Networks

Failures of power transformers within electricity transmission networks pose substantial threats to the reliability and stability of the electrical grid. The repercussions of such failures encompass power outages, equipment impairment, and economic downturns. A comprehensive comprehension of the root causes of these failures is imperative for the efficient operation and maintenance of power transformers in transmission networks. Numerous factors contribute to power transformer failures in electricity transmission networks, broadly classified into two main categories: external and internal factors. External factors are related to the environment in which the transformer operates, while internal factors are related to the design, manufacturing, and maintenance of the transformer itself.

External factors that can cause power transformer Failure

1. Lightning and surge voltages: Lightning strikes or other high-voltage surges can cause voltage spikes in the transmission network, which can lead to insulation breakdown and transformer failure. Surge arresters are installed to protect transformers from these high voltages.

2. Overloading: Power transformers are designed to handle a specific load capacity. If they are consistently operated beyond their rated load capacity, the excessive heat generated can degrade the insulation and cooling systems, leading to failure. Excessive loading of power transformers can cause overheating, insulation breakdown, and winding failures. Overloading can occur due to system imbalances, voltage fluctuations, or improper planning and design of the network.

3. Temperature variations: Extreme temperature variations, both hot and cold, can affect the performance and lifespan of power transformers. High ambient temperatures can increase the operating temperature of the transformer, causing accelerated insulation ageing and reducing its lifespan. Conversely, extremely low temperatures can cause issues with the transformer's oil and cooling systems.

4. Environmental factors: Harsh environmental conditions, such as high temperatures, humidity, corrosive gases, and salt-laden air, can accelerate the ageing and deterioration of transformer components, leading to premature failures.

5. Contamination: Pollution and contamination from dust, moisture, and chemical substances can accumulate on the transformer's insulation, reducing its dielectric strength and thus increasing the risk of failure.

Internal factors that can cause power transformer failures include:

1. Thermal Aging: Transformers have a limited lifespan due to the ageing of insulation materials and other components. Over time, the insulation's dielectric strength and mechanical properties degrade, making the transformer more prone to failure. Power transformers are subjected to constant heating and cooling cycles due to normal load variations. Over time, these cycles can cause degradation of the insulation materials, resulting in reduced insulation strength and increased risk of failures.

2. Poor design or manufacturing: Inadequate design or manufacturing processes can result in transformers with inherent weaknesses or faults, such as improper core clamping, inadequate insulation, or substandard materials. These issues can lead to premature failures. Poor workmanship, substandard materials, or design flaws during the manufacturing process can significantly increase the risk of transformer failures. These defects may not be immediately evident, and failures can occur after years of operation.

3. Internal faults: Electrical faults within the transformer, such as short circuits or winding insulation breakdown, can cause localized heating, arcing, and thermal runaway, resulting in failure.

4. Lack of maintenance: Inadequate or irregular maintenance of power transformers can lead to failures. Maintenance tasks such as oil analysis, inspection of cooling systems, and regular testing can detect and prevent potential troubles before they escalate.

RESEARCH METHODS AND MATERIALS.

This section centers on outlining the methods and techniques employed in conducting the study. The various aspects related to the methods are discussed under the following sub-headings: Research design, population of the study, sample and sampling technique, nature and sources of data, validity and reliability of the instrument, method of data collection, method of data analysis, ethical approval, and research methodology.

Research Design

The study employed a descriptive survey design, a research method aimed at collecting information about a population in an unbiased manner. Before implementing the survey, the researcher conducted a pilot test of the questionnaire to ensure it is clear and can effectively collect the desired data. This involve administering the survey to a small group and refining the questionnaire based on the feedback received. Overall, the process carried out in the descriptive survey design for this study involved careful planning, structured data collection, and rigorous analysis to assess the view of respondents concerning reliability of power transformers in the Nigerian transmission network in Rivers State.

Population for the Study

The population of this study comprised all the 725,372 consumers (households, firms and Industries) of electricity supply in Rivers State (Source: Nigeria Electricity Report: Energy Billed, Revenue Generated and Customers, DISCOS, 2023).

The population of the study encompasses the complete set of individuals, cases, or entities that the researcher aims to investigate or comprehend. It constitutes the specific group of interest from which a sample is selected to represent the broader entity. The researcher took meticulous steps to clearly define the study's population, ensuring that the outcomes could be accurately generalized and applied.

Sample and Sampling Techniques

The study sampled 390 respondents using the Convenience Sampling Technique (CST). The size of the sample pertains to the quantity of individuals or observations encompassed within a sample for a particular study or research endeavor.

In this study, the Convenience Sampling Technique (CST) was employed. Convenience sampling is a non-probability sampling method wherein participants are chosen based on their convenient availability and accessibility to the researcher. The researcher selects on selected respondents who were readily available, rather than randomly sampling from the entire population.

Nature/Sources of Data

Data was collected from both the primary and secondary sources through, the use of Questionnaire, Archival, and Structured Interview methods. The researcher used a predetermined set of questions to interviewed consumers of electricity in Rivers State.

The researcher titled the questionnaire used for the study as Consumers Perception of Electricity Power Transformer Reliability (COPEPT) questionnaire. The questionnaire was crafted utilizing the Likert 5-point rating scale, assigning values as follows: Strongly Agree (SA) represented 5 points, Agree (A) denoted 4 points, Undecided (U) was assigned 3 points, Disagree (D) equated to 2 points, and Strongly Disagree (SD) held a value of 1 point. The questionnaire comprised two distinct sections, labeled Section A and Section B. Section A was formulated to extract demographic details from the respondents, while Section B was tailored to gather information pertaining to the problem under investigation.

Validity/Reliability of Instrument

To test the validity and reliability of the test instrument, the Structured Interview Questions and the questionnaire were designed by the researcher and inputs were received from other sources to improve and validate the test instrument.

Method of Data Collection

The Direct Delivery Technique (DDT) was adopted to collect data from the respondents. The researcher personally administered the questionnaires to the respondents and conduct the interviews with electricity consumers.

Method of Data Analysis

The data was analyzed using the Weighted Mean Score (WMS). In this approach, the number of respondents for each question under investigation is multiplied by the scale rating and the total sum is divided by the number of respondents to arrive at a mean value which is judged as accepted or rejected based on the criterion mean value.

Ethical Approval

The researcher adhered to ethical considerations throughout the study. Initially, a clearance letter of permission was acquired from the department to conduct the research. Subsequently, the researcher obtained the voluntary consent of the participants to willingly engage and share information for the study. Furthermore, the researcher respected the respondents' right to privacy and confidentiality concerning the information provided, safeguarding both personal identities and the disclosed information.

Research Methodology

1. Clearly define the objectives of the survey and the scope of assessment as well as the overall goals of the reliability assessment.

2. Determine the suitable sample size and selection method for the survey. In this case, the Convenience Sampling Technique (CST) was used.

3. Develop a structured questionnaire to gather information relating to the reliability and performance of power transformers. The questionnaire includes question on maintenance practices, historical performance, etc.

4. Data Collection Process: Administer survey to the selected respondent which include network operators, maintenance personnel, etc. The responses were collected and compiled to form a data set for analysis.

5 Data Analysis Procedure: The data underwent an analysis to discern patterns, trends, and potential areas of concern associated with power transformer reliability in the transmission network. This encompassed the statistical analysis of quantitative data.

6. Initiate a Plan of Action (PoA) to address/prevent future failure occurrences and provide recommendations for future research endeavors.

RESULTS AND DISCUSSIONS

This chapter analyzed the results generated from the data. The analysis is based on the research questions of the study.

Table 1 reveals that 420 questionnaires were distributed in three (3) areas in Rivers State. Out of the 420 questionnaires distributed, 390 were retrieved i.e. 93% retrieval and 30 were not retrieved which is about 7% non-retrieval. The table reveals that 420 questionnaires were distributed equally to the 3 areas but there was a shortfall in the retrieval of the questionnaire in the 3 areas (Oyigbo, Eleme and Obio/Akpor Areas).

Demographic Distribution

Table 1

Questionnaire Distribution/Retrieval

S/N	Areas	Questionnaire Distribution	Number Retrieved	Differences
1	**Afam, Oyigbo Local Government Area**	140	132	8
2	**Eleme Local Government Area**	140	123	17
3.	**Obio/Akpor Local Government Area**	140	135	5
Total		420	390	30

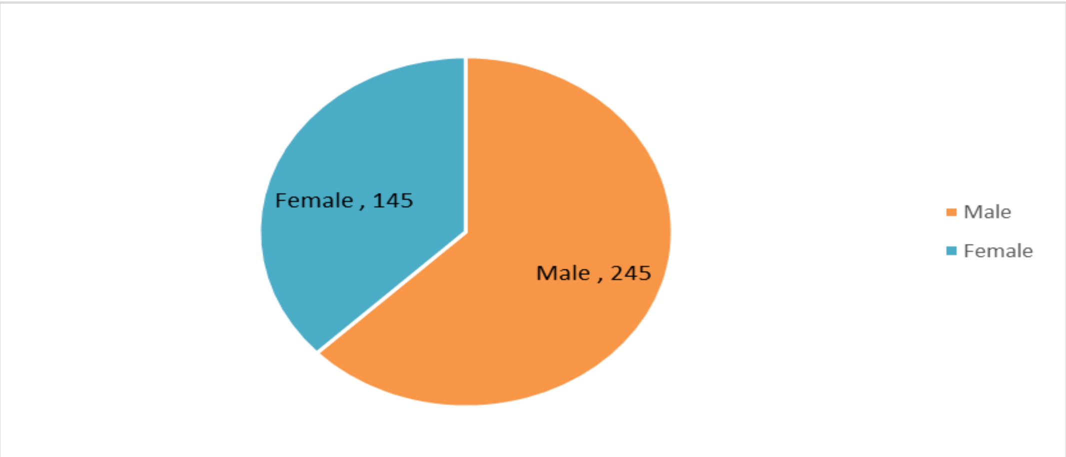

Figure 3: Sex Distribution

Fig. 3 Shows the statistical sex distribution of respondents. The results in the figure revealed that out of the 390 respondents, 63% (245) respondents are males while 37% (145) are females.

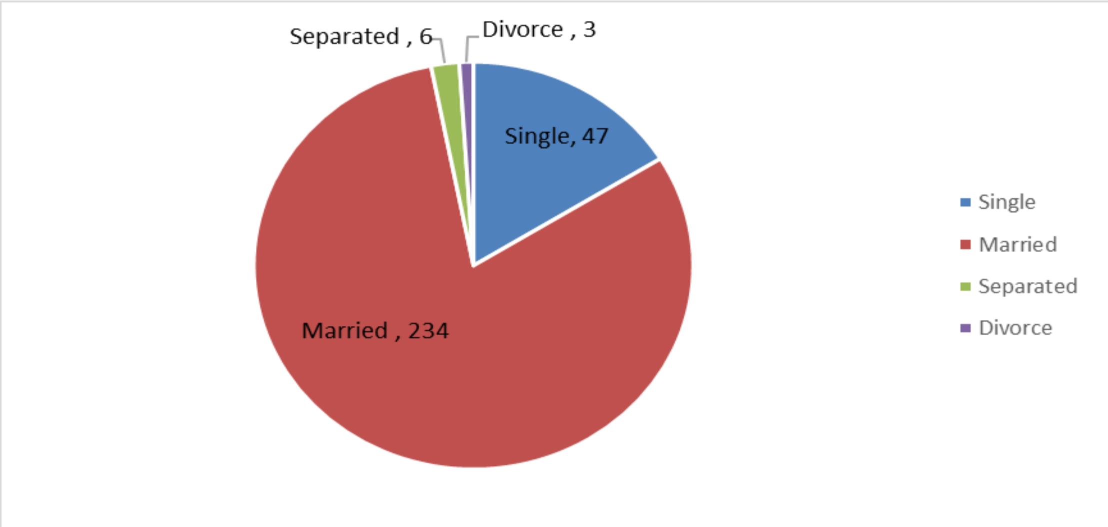

Fig. 4 revealed that out of the 390 respondents, 37% (147) are single, 60% (234), are married 2% (6) respondents are separated and 1% (3) are divorced.

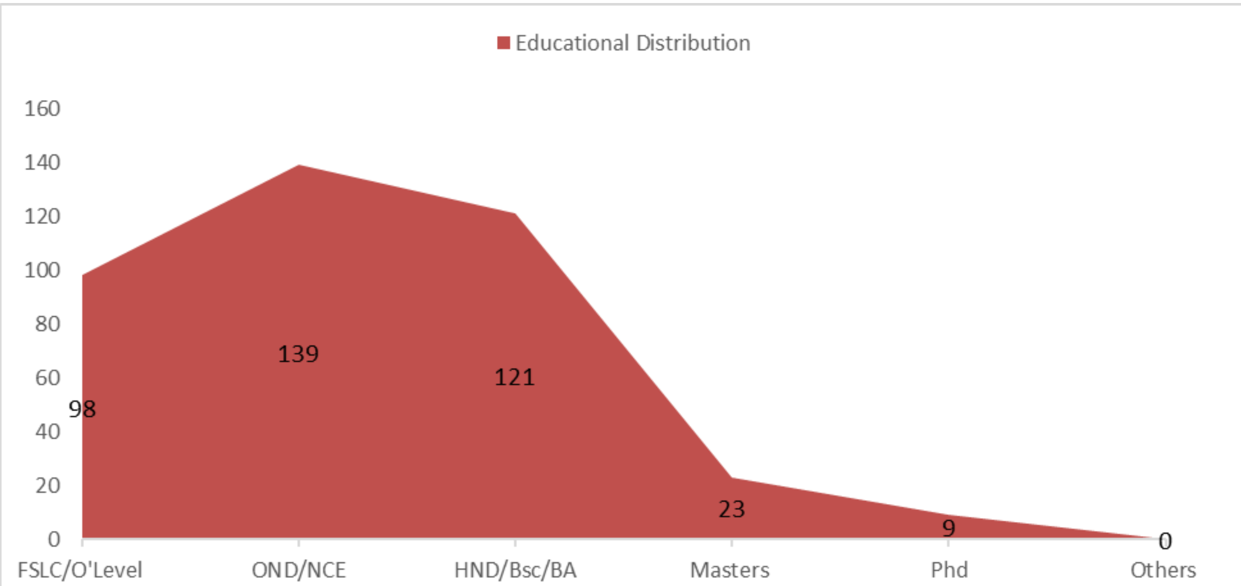

Figure 5: Qualification

Fig.5 Shows the educational distribution of the respondents. The distribution on the table shows that out of the 390 respondents, 26% (98) has FSLC/O'Level, 36% (139) has OND/NCE, 31% (121) has HND/B.Sc/B.A, Master 5% (23), P.hD 2% (9) and others 0%.

The above section is on demographics showing the description of the 390 respondents along gender, marital and educational lines while the next section is a result of the investigation carried out on the same number of respondents concerning their perception and satisfactory level of electricity supply, their positions on the dominant factors affecting power transformer reliability, their impacts and possible recommendations.

Research Question 1: How reliable are the power transformers currently employed in the Rivers State Transmission Networks?

Table 2

The Perception and Satisfaction of Consumers Regarding the Reliability of Power Transformers Currently Employed in the Rivers State Transmission Networks Based on Customers' Feedback.

S/N	STATEMENT	RESPONSE OPTION						
		SA 5	A 4	U 3	DA 2	SD 1	TOTAL	MEAN
A	The perception of consumers regarding the reliability of power transformers currently employed in the Rivers State Transmission Network.							
1	Electricity Power supply in your area is consistent and uninterrupted.	-	-	-	127	263	390	1.3
		-	-	-	(254)	(263)	(517)	
2	The cost of electricity supply in your area is reasonable and within your means.	-	-	-	11	379	390	1.0
		-	-	-	(22)	(379)	(401)	
3	The capacity of Power Transformer in your area is sufficient and adequate for the needs of the people.	-	-	-	-	390	390	1.0
		-	-	-	-	(390)	(390)	
4	There is always transparency and accountability in billing via meter reading from the Electricity Power Providers.	390	-	-	-	-	390	5.0
		(1950)	-	-	-	-	(1950)	
5	The customer services are timely and efficient in issues resolution to gain public trust and confidence.	-	-	-	375	15	390	1.96
		-	-	-	(750)	(15)	(765)	
6	There is high level innovation and cutting-edge technology introduced to foster expansion and future readiness	-	41	290	45	14	390	2.92
		-	(164)	(870)	(90)	(14)	(1138)	

Criterion Mean: 3.0

Research Questions 2: What are the common factors that contribute to the unreliability of power transformers in the Rivers Transmission network?

Table 3

Common factors affecting the reliability of power transformers in the Rivers Transmission Network Based on Customers' Feedback.

S/N	STATEMENT	RESPONSE OPTION						
		SA 5	A 4	U 3	DA 2	SD 1	TOTAL	MEAN
B	Common factors affecting the reliability of power transformers in the Rivers State Transmission Network.							
1	The age and overall condition of power transformers have a significant influence on their reliability.	390 (1950)	- -	- -	- -	- -	390 (1950)	5.00
2	Power transformers may fail to function effectively when they are overloaded uncontrollably.	333 (1665)	51 (204)	1 (3)	3 (6)	2 (2)	390 (1880)	4.80
3	Harsh weather conditions, such as heavy rain, lightning, and extreme temperature variations, can cause transformer failures.	321 (1605)	69 (276)	- -	- -	- -	390 (1881)	4.80
4	One of the major factors affecting the reliability of power transformers and electricity supply in Nigeria is the inadequate maintenance.	- -	- -	- -	- -	390 (390)	390 (390)	1.00
5.	Electrical and mechanical stresses such as power surges, vibrations affect power transformer reliability.	274 (1370)	92 (368)	13 (39)	2 (4)	9 (9)	390 (1790)	4.60
6	The impact of vandalism and theft on power transformer accessories can bring about unreliability in electricity service delivery.	390 (1950)	- -	- -	- -	- -	390 (1950)	5.00
7	Poor investment in capacity building and training of Engineers and Technicians can affect power transformer operations.	381 (1905)	9 (36)	- -	- -	- -	390 (1941)	4.98

Criterion Mean= 3.0

Research Question 3: How do unreliable power transformers in the Rivers Transmission Network impact consumer experience and business operations?

Table 4

The Impact of Unreliable Power Transformers on the Consumer Experience and Business Operations in the Rivers Transmission Network via Customer Response

S/N	STATEMENT	RESPONSE OPTION						
		SA 5	**A 4**	**U 3**	**DA 2**	**SD 1**	**TOTAL**	**MEAN**
C	The Impact of Unreliable Power transformers on the Consumer Experience and Business Operations in the Rivers State Transmission Network.							
1	When a power transformer fails, it can have significant adverse effects on the economy, resulting in financial and economic losses.	390 (1950)	- -	- -	- -	- -	390 (1950)	5.0
2	Transformer failures can lead to prolonged power outages, resulting in production halts and decreased productivity.	390 (1950)	- -	- -	- -	- -	390 (1950)	5.0
3	Voltage fluctuations or power surges caused by unreliable transformers can damage sensitive equipment used in industries.	359 (1795)	22 (88)	2 (6)	2 (4)	5 (5)	390 (1898)	4.8
4	Unplanned failures of power transformers necessitate urgent repairs or replacements, often leading to higher costs.	383 (1915)	7 (28)	- -	- -	- -	390 (1943)	4.9
5	Poor electricity supply can reduce investors' confidence and by extension, discourage potential private players' involvement in economic growth	321 (1605)	56 (224)	07 (21)	03 (06)	03 (03)	390 (1859)	4.77

Criterion mean = 3.0

Research Question 4: What measures can be implemented to improve the reliability of power transformers in the Rivers Transmission Network, as perceived by the consumers?

Table 5

Recommendations for improving the reliability of power transformers in the Rivers Transmission Network based on consumer feedback

S/N	STATEMENT	RESPONSE OPTION						
		SA 5	**A 4**	**U 3**	**DA 2**	**SD 1**	**TOTAL**	**MEAN**
D	Recommendations for improving the reliability of power transformers in the Rivers State Transmission Network based on consumer feedback.							

1	Implementing a comprehensive and more robust maintenance program is vital to enhance the reliability of power transformers.	390 (1950)	- -	- -	- -	- -	390 (1950)	5.00
2	Regular inspections and maintenance are the foundation of any maintenance program for power transformers.	390 (1950)	- -	- -	- -	- -	390 (1950)	5.00
3	Implementing condition monitoring techniques can improve the reliability of power transformers.	355 (1775)	35 (140)	- -	- -	- -	390 (1915)	4.9
4	To ensure the efficient operation and maintenance of power transformers, it is crucial to invest in training programs for Engineers and Technicians.	223 (1115)	167 (668)	- -	- -	- -	390 (1783)	4.5
5	The adoption of security measure such as surveillance installations, substations fencing and engaging local communities can stop vandalization of power transformers' accessories.	365 (1825)	13 (52)	03 (09)	07 (14)	02 (02)	390 (1902)	4.88
6	Consumer education and awareness can play a role in power transformer reliability through efficient use of power supply.	94 (470)	164 (656)	03 (09)	32 (64)	97 (97)	390 (1296)	3.32

Criterion Mean =3.0

Discussion of Findings

The Perception of Consumers regarding the Reliability of Power Transformers currently employed in the Rivers Transmission Network.

Table 2 analyzed the perception of consumers regarding the reliability of power transformers currently employed in the Rivers State Transmission Network.

1. Statement 1 states that Electricity Power supply in your area is consistent and uninterrupted. The responses to the item indicated that 263 respondents with commutating rating scale of 263 points strongly disagree with the opinion, 127 respondents with commutating rating scale of 254 disagree to the opinion. The above quantitative assessment cumulated to mean of 1.3 for statement 1. The mean of 1.3 is relatively lower than the criterion mean of 3.0 used for value judgment in this research work. Based on the response from the respondents, it is concluded that Electricity Power supply in the various areas is not consistent and uninterrupted. Thus, the statement in item 1 which states that Electricity Power supply in your area is consistent and uninterrupted is rejected.

2. Statement two states that the cost of electricity supply in your area is reasonable and within your means. The distribution on the table shows that 379 respondents with commutating rating scale of 379 strongly disagree and 11 respondents with commutating rating scale of 22 disagree to the opinion. The above indications resulted to a mean of 1.0. Judging with the Likert 5 points rating scale, the above mean of 1.0 is less or lower than the criterion mean of 3.0 used for judgment in this study. The lower mean of 1.0 is an indication that greater number of respondents strongly disagree to the opinion in statement 2. Base on the above responses, the statement in item 2 that the cost of electricity supply in your area is reasonable and within your means is rejected.

3.The table reveals that the entire 390 respondents with commutating rating scale of 390 strongly disagree to the opinion in statement 3 which states that the capacity of Power Transformer in your area is sufficient and adequate for the needs of the people. The above responses cumulated to a low mean of 1.0. Since the above mean of 1.0 is less than the criterion mean of 3.0, it is therefore rejected that the capacity of Power Transformer in your area is sufficient and adequate for the needs of the people. This implies that the capacity of the electricity power transformers in the various areas is not sufficient and adequate for the needs of the people.

4. Statement 4 on the table reveals a mean of 5.0. This is an indication that the entire respondents strongly agree to the opinion that there is always transparency and accountability in the meter reading and billing from the Electricity Power providers. Base on this response, item 4 is accepted. This implies that there is transparency and accountability in the meter reading and billing from the Electricity Power providers in the areas under study.

5. Statement 5 on the table regarding customer efficiency on issues resolutions and timeliness showed 375 respondents disagreed with a commutating rating scale of 750 and 15 respondents strongly disagreed with a rating scale of 15. The responses cumulated to a mean of 1.96 which is lower than 3.0, hence, the customer service delivery in terms of timeliness and efficiency of issues resolution is rejected.

6. The statement on high level innovation and cutting-edge technology introduced to foster expansion and future readiness is rejected as a mean of 2.92 was obtained which is lower than the criterion mean.

The above findings support the work of Suraksha, (2020) who observed that for consumers to be satisfied with the electricity supply in their domain, they expect a continuous and uninterrupted supply of electricity for their daily activities, both at home and in businesses at affordable cost for energy consumed with a strong conviction of future improvement, however, this is not the case in this study.

Common Factors Affecting the Reliability of Power Transformer in the Rivers Transmission Network Based on Customer Feedback.

Table 3 shows the statistical presentation of the common factors affecting the reliability of power transformers in the Rivers State Transmission Network. Seven (7) statements were raised to assess the opinions of the 390 respondents and the following findings were made:

1. Statement 1 states that the age and overall condition of the power transformers have significant impacts on their reliabilities, the entire respondents demonstrated strong agreement to this statement just like they did to statement 6 that the impact of vandalism and theft on power transformer accessories can bring about unreliability in electricity service delivery. The obtained mean values for the two different statements were 5.0 which is higher than the criterion mean, hence, both statements are accepted.

2. Statements 2 and 3 produced individual mean values of 4.80 each which in either case is higher than the criterion mean of 3.0, hence, the statements that power transformers may fail to function effectively when overloaded uncontrollably and harsh weather conditions like heavy rain, lightning and extreme temperatures can cause transformer failures hold true.

3. Statement 4 on inadequate maintenance as one of the major factors affecting the reliability of power transformers and electricity supply in Nigeria showed the entire respondents strongly opposing that view. With a low mean score of 1.0, the statement is rejected.

4. The statements electrical and mechanical stresses such as power surges, vibrations affect power transformer reliability and poor investment in capacity building and training of Engineers and Technicians can affect power transformer operations showed mean values of 4.60 and 4.98 respectively, which means they are accepted based on customer feedbacks.

The Impact of Unreliable Power Transformers on the Consumer Experience and Business Operations in the Rivers Transmission Network.

The results on the table reveal the opinions of respondents on the impact of unreliable power transformers on the Consumer Experience and Business Operations in the Rivers State Transmission Network.

1. Statements 1 and 2 on the table show Mean of 5.0 for each of the statement respectively. The mean of 5.0 is higher than the criterion mean of 3.0 used in this study for judgment. The above mean of 5.0 for each of the items show that the entire respondents strongly agree that when a power transformer fails, it can have significant adverse effects on the economy, resulting in financial and economic losses and transformer failures can lead to prolonged power outages, resulting in production halts and decreased productivity.

2. Statements 3, 4 and 5 show mean values of 4.80, 4.90 and 4.77 respectively. This means that the majority of the respondents do agree to the opinion in statement 3, 4 and 5 on the table which states that voltage fluctuations or power surges caused by unreliable transformers can damage sensitive equipment used in industries, unplanned failures of power transformers necessitate urgent repairs or replacements, often leading to higher costs due to expedited procurement or emergency repairs and poor electricity supply can reduce investors' confidence and by extension, discourage potential private players' involvement in economic growth. The above mean of 4.8, 4.9 and 4.77 for each of statements 3, 4 and 5 respectively on the table are higher than the criterion mean of 3.0 used for judgment. Base on the response of the majority of the respondents, Item3, 4 and 5 on the table are therefore accepted.

The findings aligned with a study conducted by Girovich et al. (2013), titled "Power Quality Issues and Their Economic Impacts on Industries," examined the economic impacts of power quality issues, including voltage fluctuations caused by unreliable power transformers, on various industries. The study revealed that these power quality issues resulted in financial losses due to increased energy consumption, increased maintenance costs, and damage to equipment.

Recommendations for Improving the Reliability of Power Transformers in the Rivers Transmission Network based on consumer feedback

Table 5 shows the statistical distribution of respondents' opinions on the recommendations for improving the reliability of power transformers in the Rivers State Transmission Network.

1. Based on consumer feedback, statements 1 and 2 on the table reveal a mean of 5.0 for each of the statements respectively. This implies that the entire respondents strongly agree to the opinion that implementing a comprehensive maintenance program is vital to enhance the reliability of power transformers and regular inspections and maintenance are the foundation of any maintenance program for power transformers. The mean of 5.0 for each of statements 1 and 2 respectively is higher than the criterion mean of 3.0 used for judgement in this study. Based on the results on the table, statement 1 and 2 are accepted.

2. A high Mean of 4.9 is indicated for statement 3 on the table. The above high mean is a clear indication that majority of the respondents strongly agree that implementing condition monitoring techniques can improve the reliability of power transformers. Following the opinion of the respondents, statement 3 is accepted.

3. Statement 4 equally shows a high Mean of 4.5. Base on this high Mean obtained, the statement in item 4 is accepted. That is, to ensure the efficient operation and maintenance of power transformers, it is crucial to invest in training programs for engineers and technician.

4. Statement 5 on the adoption of security measure such as surveillance installations, substations fencing and engaging local communities can stop vandalization of power transformers' accessories gave a high mean value of 4.88 which when compared with the criterion mean, is accepted and holds true just like statement 6 with a mean value of 3.32 which shows that most of the respondents think that consumer education and awareness can impact in power transformer reliability through efficient use of power supply.

The above findings support earlier studies by Jiang, et.al., (2020), and Ullah, et.al., (2016) that hold the views that implementing a maintenance schedule as well as daily inspection can help improve transformer reliability and the training and retraining of field personnel will allow for greater efficiency and reduced down time in terms of corrective maintenance of power transformer respectively.

STRATEGIES FOR IMPROVING POWER RELIABILITY IN NIGERIA

Improving power reliability is crucial for ensuring uninterrupted electricity supply, enhancing customer satisfaction, and supporting economic growth. Here are several strategies that utilities and stakeholders can employ to enhance power reliability:

1. Establish a Comprehensive Maintenance Program: Implementing a comprehensive maintenance program is vital to enhance the reliability of power transformers. This program should include regular inspections, testing, and Proactive maintenance activities such as oil sampling and analysis, thermographic imaging, and insulation resistance testing. Proper maintenance ensures that potential issues are identified and addressed before they escalate to larger problems. Establishing a comprehensive maintenance program for electricity power transformers is crucial to ensure their reliable and efficient operation, prolong their lifespan, and minimize the risk of failures and costly downtime (Olatunji, et.al., 2019).

2. Load management: Ensuring that transformers are not overloaded and operated within their rated limits is essential to prevent overheating and insulation breakdown. Effective load forecasting, proper network planning, and real-time monitoring of load profiles can help in load management

3. Regular Inspections: Regular inspections are the foundation of any maintenance program for power transformers. These inspections should be scheduled at specific intervals to identify early signs of potential issues and make necessary repairs or replacements. Inspections should include visual checks of external components, such as bushings, tap changers, fans, cooling systems, and protective devices.

4. Condition Monitoring: Implementing condition monitoring techniques can improve the reliability of power transformers. Condition monitoring involves the use of advanced technologies, such as vibration analysis, infrared scanning, and partial discharge testing. These techniques can detect abnormalities in the transformer's operation and provide valuable data for making maintenance decisions.

5. Invest in Upgrading Aging Infrastructure: The Nigerian power grid consists of aging infrastructure, including transformers past their design life. Upgrading these transformers or replacing them with newer, more efficient ones can significantly enhance reliability. Investing in modern transformer technologies that offer better insulation materials, cooling systems, and fault detection systems can contribute to improved reliability and reduced downtime (Ogurinde, et.al, 2014l; Okunota, 2018).

6. Enhance Transformer Design Practices:

Optimizing transformer design practices can contribute to improved reliability. This includes adopting proper insulation, selecting appropriate cooling methods, and ensuring adequate fault detection and protection mechanisms. Furthermore, implementing design practices that consider the harsh climate and environmental factors specific to Nigeria can help increase transformer resilience and longevity (Adeitiba, 2018).

7. Strengthen Training and Capacity Building: To ensure the efficient operation and maintenance of power transformers, it is crucial to invest in training programs for engineers and technicians involved in transformer operations. Continuous professional development, capacity building workshops, and certification programs can equip personnel with the necessary skills and knowledge to identify and address potential transformer issues promptly (Ali & Samuel, 2018)

8. **Improved Security:** To mitigate the issue of transformer vandalism, security measures such as installing surveillance cameras, fencing substations, and engaging local communities in the protection of transformers should be implemented. Furthermore, stringent penalties and law enforcement should be enforced to deter potential vandalism and theft activities.

9. Consumer Education: Consumer education and awareness programs should be implemented to improve consumer perspectives on transformer reliability. This can involve providing regular updates to consumers on maintenance schedules, outage notifications, and responding promptly to consumer complaints. Building trust between electricity distribution companies and consumers help manage expectations and enhance consumer satisfaction with the overall reliability of power transformers.

10. Good Earthing System: The earthing system in transformer installations plays a critical role in ensuring both the safety and reliability of the electrical system by providing a low-resistance path for fault currents to flow to the ground, ensuring that in the event of a fault, excessive current is safely dissipated. This helps prevent electric shocks to personnel and minimizes the risk of electrical fires or equipment damage.

CONCLUSIONS

The reliability of power transformers is of paramount importance in maintaining a stable and resilient electrical grid. Power transformers serve as critical components in the transmission of electricity, facilitating the efficient delivery of power from generation sources to distribution networks to end-users. A reliable power transformer infrastructure ensures uninterrupted electricity supply, supports economic activities, and enhances the quality of life for consumers. By investing in modernization, proactive maintenance, and advanced monitoring technologies, utilities can mitigate the dominant causes of transformer failure, minimize downtime, and improve overall reliability thereby leading improved satisfaction on the part of users of electricity. In addition, strategies such as having a comprehensive maintenance schedule, proper load management, regular inspection, condition monitoring, upgrade of ageing transformer can enhance the resilience of the power system to withstand various challenges, including extreme weather events as well as electrical and mechanical stress thereby improving the reliability of the power transformers.

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