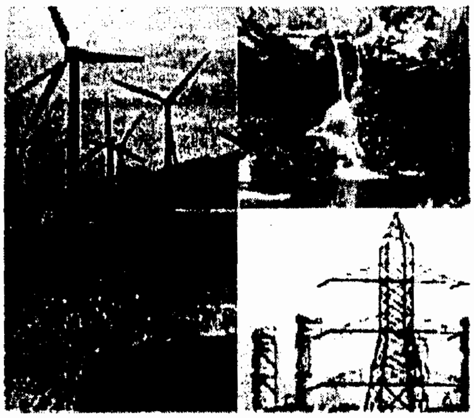
96

ICPSOP 2007

PROCEEDINGS OF THE 7TH INTERNATIONAL CONFERENCE ON POWER SYSTEM OPERATION AND PLANNING



January 22–25, 2007
University of Cape Town, South Africa

National Science Foundation
Howard University
University of Cape Town

OPTIMAL OPERATION OF POWER TRANSFORMERS IN POWER SYSTEMS IN A DEPRESSED ECONOMY

By

J.C. Ekeh engr_ekeh @yahoo. co.uk
S.T. Wara docwarati@yahoo.com
E.O. Ikwu edochas@yahoo.com
H. R. Torru aserifa2005@yahoo.com
Department of Electrical and Electronics Engineering, Igbinedion University, Okada, Nigeria
Abuja Distribution Zone, Abuja, Nigeria

Correspondences to: J.C. Ekeh, Department of Electrical and Electronics Engineering, Igbinedion University, Okada, Nigeria. e – mail: engr_ekeh @yahoo . co. uk, GSM: +2348055126655

ABSTRACT

Power transformer is one of the most important equipment in an electric power transmission and distribution system. It is very essential in ascertaining the reliability of any power utility. It is therefore critical therefore that the power transformer operates continuously in order to offer reliable and efficient electricity supply. Utilities are therefore facing considerable concern to ensure their critical asset's reliability due to deregulation, increased demand, economic pressures, and profit constrains. Most of the power transformers develop faults and get critical over a period of time.

This paper presents the major causes of power transformers' failure and maintenance strategy and optimization techniques presently being adopted in Abuja Distribution zone. The results of the study and analysis on 107 injection substations serving about 3876 distribution transformers show that the major contributing factors includes: earth faults and over currents.

Useful recommendations based on new technologies are presented on how to ensure that power transformer would serve closer to its rated output and life without sacrificing its integrity. The paper will be of importance to power systems managers and operators for improving the reliability of transformers.

Keywords: Power transformer, Optimal operation, Failure, Asset management, Reliability

1.0 INTRODUCTION

One of the most serious challenges for power industry restructuring is to maintain power system reliability at an acceptable level and to promote the overall economic efficiency of the whole power industry [1]. Because of the declining investment in the power industry, especially in the depressed economy like Nigeria, the average life of any equipment should be reached if not exceeded. The power transformer is not an exception. Now more than ever that the electricity industry is moving from regulated to competitive industry, there is the need to optimize the use of the existing equipment and to develop new, lower cost, more efficient and reliable ones. This new reality is complicated by the fact that a significant amount of the station equipment in use today has already accumulated between 20 to 40 years in service. The consequence of this is that maintenance costs will rise as the inherent reliability of aging plants starts inevitable decline [2].

The power transformer is one of the most important equipment in an electrical power transmission and distribution system [3]. They are an integral part in ascertaining the reliability of any power utility [4]. It is critical that the power transformer operate continuously in order to guarantee reliable and efficient electricity supply. The transformer insulation deteriorates due to a physico – chemical reaction in the presence of heat, moisture and oxygen and this process of degradation is known as aging. Aging is further aggravated due to overheating on transformers beyond the nameplate ratings to satisfy the increasing load demand in case of emergencies [2]. This aging phenomenon has been difficult to measure and analyze, as the effects of operating conditions on a transformer vary according to its family, make, model, age, and application [5].

It is important therefore to understand completely the condition of the power transformers and to manage their remaining life to avoid unplanned outages and catastrophic failure. This is the thrust of this paper. At the same time, transformer-loading analyses, based on historic and current conditions, will allow utilities to apply resultant transformer ratings from an operations and planning perspective [5].

The benefits of optimal operation of power transformers can be summarized as follows [6]:

i. Save electricity costs without capital investment.
ii. Extend the lifetime of most power transformers.
iii. Increase electrical system reliability, which reduces downtime and unplanned maintenance.

2.0 ABUJA DISTRIBUTION ZONE

The Abuja Distribution zone started in the early 1990s as Abuja special duties office, catering for the electricity needs of the Federal Capital Territory (FCT), Abuja. It later metamorphosed into a colossus known as Abuja Distribution zone, having been established in 1997 as Abuja zone of the deformed National Electric Power Authority, one of the eleven distribution zones in Nigeria. Its area of jurisdiction includes the Federal Capital Territory, Abuja and the adjourning States of Niger, Nasarawa, and Kogi [7]. The Abuja Distribution zone lies between longitudes E005°28.933′ to E006°43.845′ and latitudes N07°05.806′ to N10°25.156′. The zone is basically served from the 600MW Shiroro hydro power station (4 x 150MW) through a 144km, 330kV double circuit line direct to Abuja and a 132 kV double circuit line which passes through Minna District as an alternative supply to the FCT. This also serves the Lafia District of the zone [8].

The zone consists of five Business Units, viz: Garki and Wuse Business Units covering the Federal Capital Territory, Minna Business Unit which covers Niger State, Lafia Business Unit which covers Nasarawa State, and Lokoja Business Unit which covers Kogi State. Abuja distribution zone, along with other major electrical authorities, is undergoing a period of significant and fundamental reform in its endeavour to become competitive in the commercial market place. As a consequence, approval has been granted for the establishment of four additional Business Units to bring the services of the company nearer to customers in the zone. These are Gwagwalada, Kubwa, Karu, and Suleja Business units, which are in the take off stages.

The core business of Abuja Distribution zone is the delivery of electrical energy to its customers via a network of distribution lines. The network has a route length of 3679.41 km of 33kV and 3248.56km of 11kV of overhead lines and 44.35km of 33kV and 405.42km of 11kV underground lines. It has a total of 107 number of 33/11kV injection substations with capacity of 1291 MVA. The zone has an average annual load growth of about 7% and customer population growth of about 12%. The highest maximum demand recorded was 382.585MW with an average annual energy demand of about 1510593.12MWH [8]. Table 1 shows the summary of the statistics of Abuja Distribution zone for the five Districts.

The zone has pioneered the pre-payment metering on a pilot scale and found that it is more effective as all problems associated with disputes arising from electricity bills and settlement of the old order are eliminated. The scheme is now to be adopted in a larger scale especially in housing estates in the zone.

Table 1 Statistics of Abuja Distribution zone for the five Districts

S/N	Description	Business Units					Total
		Wuse	Garki	Minna	Lokoja	Lafia	
1	Injection S/S capacity (MVA)	390	588.5	169.0	75	68.5	1291.0
2	Distribution capacity (MVA): 11kV 33kV	 612.12 74.57	 388.60 94.40	 37.85 215.645	 55.40 65.06	 25.07 88.38	 1119.04 538.055
3	Number of Injection S/S	22	37	23	11	14	107
4	Number of Distribution S/S	1155	1117	907	466	231	3876
5	33kV line O/H (km)	140.92	522.81	1157.16	1081.99	776.53	3679.41
6	33kV line U/G (km)	25.28	14.74	4.30	Nil	0.03	44.35
7	11kV line O/H (km)	104.4	485.38	2060.31	383.37	215.10	3248.56
8	11kV line U/G (km)	30.50	222.58	114.23	7.61	30.50	405.42
9	Av. Annual energy demand (MWH)	104.50	140.19	96.00	38.10	28.0	406.79
10	Max. demand (MW)	93.50	107.69	110.30	47.10	24.0	382.59
11	Population	75291	83109	85424	60418	31557	335799
12	Customer Population: Max. demand customer Non max. demand customers	 645 74646	 476 82633	 1771 83653	 116 60302	 151 31406	 3159 332640

3.0 TRANSFORMER AGE PROFILE AND FAILURE DATA

Abuja distribution zone owns and operates 107 injection substations and 3876 distribution transformers with an estimated value of about 85 billion naira. The power transformers in the injection substations range in capacity from 2.5 MVA to 15 MVA. Some of these transformers had been in service before the creation of the zone in 1997.

The summary of the age profile of the injection sub-station transformers in Abuja distribution zone is shown in figure 1.

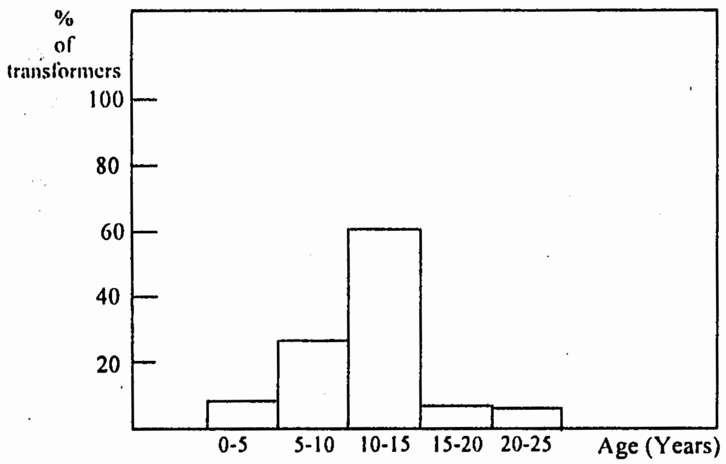


Figure 1 Transformers' age profile in Abuja Distribution zone

A typical injection substation within the switchyard is shown in figure 2.

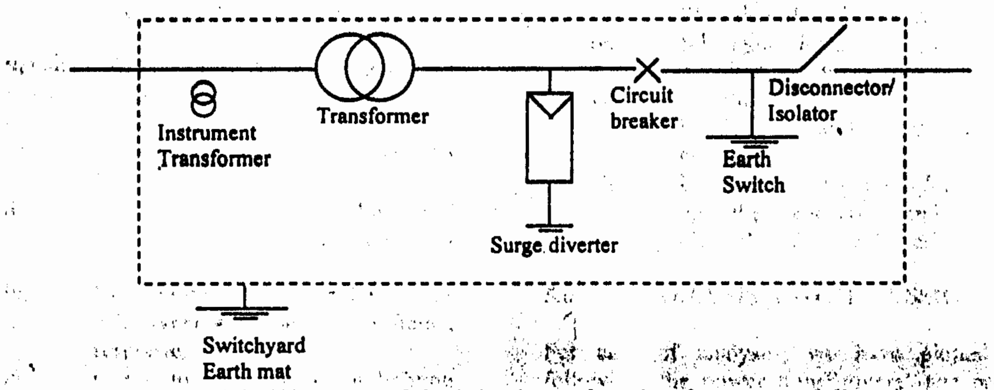


Figure 2 Main Elements of the injection substation for energy delivery process

They core function of the switchyard is the transformation of electrical energy by the transformer to a suitable voltage for transmissions. A major unplanned failure of this asset would result in significant income loss, as the expected replacement lead-time for a transformer is about 8 months. The Abuja distribution zone has witnessed a number of failures in recent years. These include the following: earth faults, over currents, insulation issues, loose connections, failures of the lightning arrestors and poor maintenance.

4. MAINTENANCE AND MANAGEMENT STRATEGIES PRESENTLY BEING ADOPTED

Abuja Distribution zone, like other major electrical authorities, has a number of optimizations and management strategies to minimize transformer usage and prevent premature failures. The annual preventive maintenance schedules by the Protection, Control and Metering (PC&M) department, Abuja zone are usually categorized into three parts, namely [8]:

Schedule 1: Is a check which must be carried out in all the substations at least every two months. These include the following:

i. Check on the operators log book to ascertain that the circuit breaker's trip circuits respond to fault.
ii. Check on the tripping units and test for battery voltage and charger voltage outputs independently.
iii. Check the electrolyte level. Test the specific gravity of the battery electrolyte for possible changing if found bad. Clean the batteries, clean the tripping unit and free it of cub-webs and dust.
iv. Check the substation environment and report any possible overgrown or presence of reptiles.
v. Check that the operator resets the excitation reset and know when excitation comes up.
vi. Check the silica gel for possible changing if found bad.

Schedule 2: The maintenance strategies are carried out every 4 months. They include the following:

i. Check the effectiveness of the CTs and VTs through the ammeters and voltmeters.
ii. Check that the alarm circuits are working and that the alarm comes up when there is a trip.
iii. Take transformer and Ring Main Unit (RMU) oil samples and test for effectiveness.
iv. Test the substation earthing and check that all earth terminations are film.
v. Check all panel indication lamps and substation illumination lamps and bulbs and report for possible changes.
vi. Check to ensure that the lightning arrestors are in place in all the phases.
vii. Check the presence of fire extinguishers and ensure that the available ones are not empty.
viii. Re-calibrate the relays for effectiveness and efficient response.
ix. Functional test, comprehensive checks/tests on the entire protection system in the injection substation.

x. Carryout minor repairs where possible, while major defects will be reported for necessary action.

Schedule 3: Is a check, which is carried out every 6 months.

i. Take oil samples of the transformers and the RMU and test for effectiveness.
ii. Test the substation earthing and ensure that all the earth connections are film.
iii. Recalibrate the relay for effectiveness and efficient response.
iv. Check to ensure that the lighting arrestors are in place in all the phases.

The materials and equipment that are needed for the effectiveness of the maintenance are:

i. Multi-amp (secondary injection test) equipment – for relay calibrations.
ii. Hand blower – for panel cleaning.
iii. Universal indicator – for testing the PH value of acid/base.
iv. Silica gel – lots.
v. Alkaline pallets – lots.
vi. Vaseline – lots.
vii. Lead acid (raw) – for lead acid batteries.
viii. Distilled water – lot – for topping up the batteries and mixing electrolyte for new batteries.

5.0 ANALYSIS AND DISCUSSIONS

For ease of analyses, we have plotted the following: the power transformers' age profile shown in figure 1 and the frequency – number curve for the various causes of failures of figure 3.

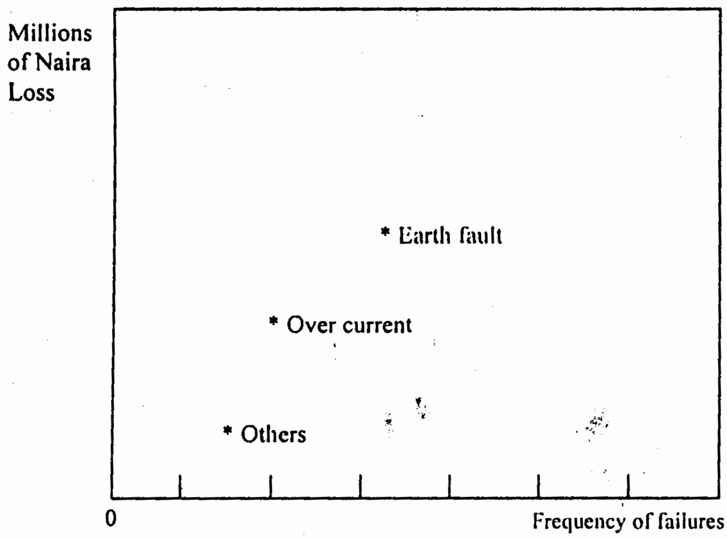


Figure 3 The relative F – N curve of the causes of transformer failures in Abuja distribution zone

As can be seen from figure 1, most of the transformers lie in the age of 10 – 15 which account for more than 60 per cent. Thus it can be concluded that most of the power transformers are approaching the end of their estimated nominal service life of 25 years. Therefore, there is need to commence sound maintenance and risk management plan to extend their life span.

Figure 3 is a log – log scatter plot, or sometimes referred to as frequency – number curve or the 'F – N curve'. The number of failures for each cause is on the x – axis, and the estimated naira paid for each cause is on the y – axis.

According to our database, the earth faults are the highest risk for all type of transformers. It is followed by the over current. The over current has led to the upratings/ upgrading of most of the power transformers. Others include: insulation issues, loose connections, failures of the lightning arrestors and sabotage. According to a study by Ekeh, Ikwu, and Nwadinobi [10], the five major causes of failures in the distribution transformers in order of their severities include:

over loads, improper earthings, bad oil/ low oil level, faulty lightning arresters, and bad cables.

The PC& M department of the zone centred their maintenance and optimization strategies on the time scheduled check and measurements. The transformer condition – based management strategy is conspicuously lacking. The application of condition assessment criteria and the quality index value can estimate the transformer's time insulation age from which the annual business risk and transformer reinforcement and replacement timing is determined.

The condition – based management strategy will identify:

i. Transformers that can continue to operate as is.
ii. Transformers that can be modified, or refurbished.
iii. Transformers that should be relocated.
iv. Transformers that should be retired from service.

6.0 NEW MAINTENANCE AND RISK MANAGEMENT STRATEGIES

In recent time, new maintenance and risk management strategies have evolved to prolong the entire life of the transformers. The traditional time – based preventive maintenance presently being adopted by the distribution companies in Nigeria is old fashioned that require serious overhaul. The time – based preventive maintenance involves number of operations, operating hours, or seasonal change. The following maintenance and risk management strategies are suggested [11,12,13,14,15]:

1. Continuous monitoring. One of the optimal operation strategies of power transformers is continuous monitoring. The advantages of continuous monitoring of power transformers include:
   - Prevention or minimizing the risk of failures and downtimes of the transformers.
   - Transformer life extension leading to the delay of investment for new transformers.
   - Optimization of transformer use by means of condition – based maintenance instead of the time – based maintenance.
   - Providing potential for changing the maintenance strategies.

The above can be achieved by the use of modern equipment such as microprocessor equipment for power transformer protection and operation monitoring, type MONITRA. The equipment or the likes is mounted in the control room and measures the following operation parameters: oil temperature, phase current and oil level, partial discharge level and dissolve hydrogen concentration, and calculates the winding temperature.

Also, the use of sensors such as: transformer fault gas analyzer might prove to be beneficial. This device provides real time measurement of the four key gases associated with fault currents in the transformer: carbon monoxide, hydrogen, acetylene, and ethylene.

There is the need to incorporate an additional sensor to detect the presence of moisture, which can reduce dielectric strength and lead to failure. This will be used with another device that measures the transformer loading so that the evolution of key gases and moisture can be characterized as a function of load. With the moisture sensor and load current monitor, we can develop accurate criteria for loading transformers under stressful conditions rather than having to rely on the werly conservative ratings now provided.

2. Condition – based maintenance. This applies to the situation when the condition of equipment reaches a limit, or when continued satisfactory operation can not be essured. It prevents incipient failure from becoming real failure. Condition – based monitoring is the monitoring or diagnostic activity that is used to predict equipment failure. The following new technologies have been reported:

- Partial discharge detection. This employs electrical sensor, which is used to detect the initial insulation breakdown in electrical equipment such as insulators and terminators. It could be used to detect incipient failures before significant damage occurs.
- Transformer gas – in – oil analysis. This is needed to keep the transformer on – line as much as possible. One indicator of abnormalities is the dissolved gas content in the transformer oil. Certain gas levels can indicate ageing, the need for maintenance, and potential failure.
- Infrared Thermography. It involves the use of an infrared camera to detect hot spots in large machines such as transformers, motors, and generators.

- Sound intensity measurement. This identifies potential problems in equipment and record the historical changes in sound and output of equipment.

The condition - based management strategy will estimate insulation age which will in turn identify transformer refurbishment and replacement timing. It will also identify transformers that would be relocated.

3. Reliability centred maintenance (RCM). This is a set of methods and tools aimed at helping the utility to determine the minimum set of preventive maintenance tasks necessary to appropriately address critical equipment failures without compromising service reliability. It is a structured process used to determine optimal maintenance requirements for equipment in a particular operating environment. The reliability centred maintenance (RCM) combines the strategies of corrective maintenance, preventive maintenance, and applies these strategies where each is appropriate, based on the consequence and frequency of functional failures. This combination produces a maintenance program which optimizes both reliability and cost effectiveness.

The Reliability centred maintenance (RCM) is a condition – based maintenance program that focuses on preventing failures that are likely to be most serious. Some of the benefits of the RCM are:

- Reduces major corrective actions.
- Eliminates unnecessary overhauls and routine tasks that provide little benefits.
- Optimizes the frequency of required overhauls.
- Increases use of predictive technology that help with resource planning.
- Decreases use of instructive tasks that can induce equipment failure.
- Improves cost effectiveness of routine tasks.
- Creates documented technical bases for maintenance programs.
- Allows easy implementation by incorporating existing maintenance practices that have proven to be cost effective.

4. Investment in staff and hardware/software development to actively manage the maintenance program. A team approach to Reliability Centred Maintenance (RCM) must be established and the concept of RCM must be accepted in the organization.

5. Development and sustaining a successful maintenance program, which will ensure the continuance of maintenance over a long period of time. It is necessary to periodically review and update the maintenance program using a structured method.

6. Life optimization through the acquisition of insulation aging/deterioration control equipment, validating tools for predicting remaining life, life extension of equipment.

CONCLUSIONS

Today, more than ever before, minimizing operations and maintenance costs and preserving service reliability are the top priorities for managers of power utility systems. The concept of optimal operation/asset management of transformers is sound and should provide utilities with a structured approach to a maintenance program with an optimum balance between cost of maintenance and reliability improvement.

An optimized transformer maintenance strategy, taking into consideration the latest technology and best practices as outlined in the above, is critical to continued reliable transformer operation for aging assets. Properly applied condition – based maintenance and reliability centred maintenance can improve transformer availability, maximum practicable operation efficiency, minimize life cycle costs, and optimum life up to 40 years.

REFERENCES

1. F.Wen, F.Zheng, and F.F. Wu, "Transmission Investment and Planning in a Deregulated Market Environment: A literature Survey (Part I)", The IASTED Conference Proceedings (465) on Energy and Power Systems, Chiang Mai, Thailand, March 29 – 31, 2006.

2. CEATI Publication. "Life Cycle Management of Substation Equipment and Applications", Internet Source, 2006.

3. http://www. Itee.uq.edu.au/~ seminar, J.H. Yew, "Predicting the Condition of Aged Transformer by Frequency Domain dielectric measurements", Ph.D seminar paper, School of Information Technology and Electrical Engineering, The University of Queensland, Australia, 2006.

4. M. Arshad and S.M. Islam, "Power Transformer Life Cycle Management Using Fuzzy Logic Technique", Conference proceedings, Power and Energy Systems, Australia, 2005.

5. http:// auto.search.msn.com/response.asp, Transformer Condition Assessment and Life Management Program.

6. http://myaau.com/cportal/aau. Electrical Districal System Optimization.

7. PHCN News, Jan – April 2006.

8. E.O. Ikwu, "Distribution Challenges in Abuja Zone , Nigeria", West African Power Industry Convention (WAPIC), Novotal Hotels, Dakar, November, 2005. Available at: WWW.Spintelligent - events.com/wapic 2005.

9. PHCN log book on annual preventive maintenance schedules by the PC & M department, Abuja Distribution zone, 2006.

10. J.C. Ekeh, E.O. Ikwu, and C.C. Nwadinobi, "Assessing the Impact of Distribution Transformer Failures in Warri NEPA District", ICPSOP, Cape Verde, 2005, Pp.185 – 191.

11. ICMET Craiova pubication, "Microprocessor Equipment for Power transformer Protection and Operation monitoring, type MONITRA",. Internet Source, 2006.

12. M. Mirzai, A. Gholami, and F. Aminifar. , "Failures Analysis and Reliability Calculation for Power Transformers", Journal of Electrical Systems, Vol. 2, No. 1. 2006, Pp.1 – 12.

13. S. Asgarpoor and M. Doghman, "A Maintenance Optimization Program for Utilities' Transmission and Distribution Systems". Internet Source, 2006.

14. W.H. Bartley, "Transformer Asset Management". Internet Source, 2006.

15. R. Houbaer and K. Gray, "Power Transformer Asset Management', NRCC/CPWA Seminar Series "Innovations in Urban Infrastructure", 2000. Pp.75 – 85.

OUR SPONSORS

SUMA JKT

TANZANIA PEOPLES DEFENCE FORCES

JANDU PLUMBERS

HOWARD HUMPHREYS

NIMETA CONSULT (T) LTD.

D. F. MISTRY & CO. (1974) LTD.

inter - Consult Ltd.

NORPLAN

PUBLIC PROCUREMENT REGLATORY AUTHORITY

BQ CONTRACTORS LIMITED

TANZANIA COMMUNICATIONS REGULATORY AUTHORITY

CONTRACTORS REGISTRATION BOARD