Journal of the Nigerian Association of Mathematical Physics
Volume34,(March, 2016), pp 299 – 304

Transformer Condition Monitoring: A Case for Policy Formulation

EfosaO*, Sadjere E.G and Asibor J.O

Department of Mechanical Engineering, University of Benin, Benin City, Nigeria.

Abstract

In this paper a case for policy formulation was created for the maintenance of power transformers using Transformer Condition Monitoring (TCM) as a way of improving the life span and efficiency of power transformers. This work was carried out by using existing data on power transformers and acquiring information from local sources (The University of Benin Power Service) by means of questionnaires. The questionnaires were recovered and analyzed using category weighting. The results gotten after analyzing the questionnaires were compared with researched data on TCM. On comparison of result, it was realized that there was no awareness of TCM, and as such, transformers in the University of Benin continue to undergo sudden breakdown which leads to severe damage of major component of the transformer. Hence, necessitating the need for a case for policy formulation with regards to the maintenance of power transformers.

Keywords: Transformer, Power, Maintenance Practice.

1.0 Introduction

It is no longer news that power generation and distribution is a major problem in Nigeria. One of the key components of power transmission and distribution is the transformer. The transformer is a high efficient static electrical device used for power transfer from one voltage level to the other and plays a vital role in electrical transmission and distribution system. From the day of this equipment's active operation, different stresses like electrical, mechanical, chemical, and environmental factors affect the condition of the transformer [1]. The power transformer being a key component in power transmission system, any event of failure would cause huge economic losses and even catastrophic consequences. Therefore, timely and accurate early detection of potential transformer failure, transformer master operation, and the power system security are of important guarantee for a reliable electricity supply [2]. One of the major problems facing the power system managers is the ability to determine the expected life of the power transformer [3].

The transformer just like all other devices is susceptible to failure and more so with its service age (see Figure 1). Failures in a transformer can be caused by electrical, electromagnetic, dielectric, thermal and chemical factors [4].

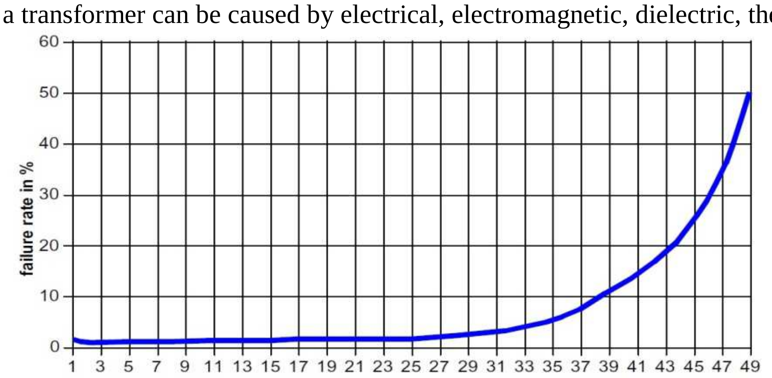

Fig. 1: Chart showing failure rate as a function of transformer age [4].

These failures affect the service life of the transformer.Transformer service life refers to the period of active service of a transformer before a complete overhaul or refurbishment of the transformer is required. The service life of a power transformer is estimated to be between 20-30 years [5].In addition to the failure factors listed above, some other factors that affect the service life of a transformer include;

Corresponding author: Efosa O, E-mail:o.efosa@uniben.edu, Tel.: +2348142131195

i. Environmental factors (the ambient temperature of the surrounding, over-voltage surges from lightning and moisture). The transformer useful life can be calculated using the formula below:

$$Life(pu) = 9.8 \times 10^{-18} \exp\left(\frac{15000}{\theta_{HS}+273}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$RealLife = Life(pu) \times normalinsulationlife \ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where $\theta_{HS}$is the hot spot temperature and *pu* is per unit of life

Now from the above formula it shows that to increase the useful life of the transformer, the winding hotspot temperature(θ_{HS}) should be reduced to the barest minimum if the transformer life is to be extended. This rise in temperature is caused primarily by the ambient condition, average winding rise and hot spot rise [6].

ii. Design factors(Short circuits, Over-voltage, Loading beyond the nameplate ratings (normal rating)

iii. Maintenance

iv. Operation conditions(Under frequency operation, Overvoltage operation) [7].

These transformers being expensive devices need to be properly maintained for efficient performance and minimal down-time. Due to the complexity of the power transformer design, operation and maintenance policies, it is impossible to accurately predict the expected life of a transformer. Consequently, power system operators have to depend on various condition monitoring and condition assessment techniques available to determine plant condition and remnant life [3]. Transformer maintenance can be categorized into two areas: Routine maintenance and Reactive maintenance [8]. In Nigeria today, the maintenance practice adopted is the corrective method which requires the continuous operation of the transformerwithout maintenance until a breakdown occurs. This has led to increased cost in procurement of damage transformer components, loss in service life of the transformer as well as loss in productive work hours.

In a bid to correct these problems, power stations have been created and more transformers have been provided to lessen the load on existing transformers but this hasn't yielded the desired result of increasing the efficiency of power distribution in the country. Hence, the need for a proactive maintenance method (Condition Monitoring).

1.1 Transformer Condition Monitoring (TCM)

Condition Monitoring of Transformers is the process of acquisition and processing of data related to various parameters of transformers so as to predict and prevent the failure of a transformer.Transformers just like human beings need a physical check up for a clean bill of health [3].

There are various transformer condition monitoring techniques as shown in the figure below.

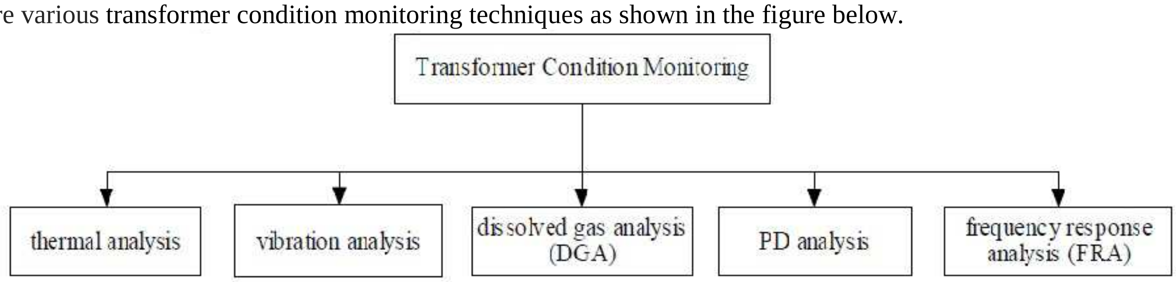

Fig. 2: Transformer condition monitoring techniques [9].

1.1.1. Condition Monitoring by Thermal Analysis

The useful life of a transformer is determined partially by the ability of the transformer to dissipate the internally generated heat to its surroundings. The comparison of actual and predicted operating temperatures can provide a sensitive diagnosis of the transformer condition and might indicate abnormal operation. Thermal analysis involves the development of a mathematical model that predicts the temperature profile of the power transformer using the principle of thermal analysis. Thermal analysis is used to determine the top oil temperature and hot spot temperature (maximum temperature occurring in the winding insulation system) [10]. Thermal analysis also involves the use of thermal models [9].

1.1.2. Condition Monitoring by Thermal Analysis

The health condition of the core and windings can be assessed using vibration signature of transformer tank. Vibration analysis is used for assessing the health of the On Load Tap Changer [9]. Accelerometers are used to collect the vibration signals by attaching it to the transformer walls. The vibration signal is collected and analyzed using Fourier transform to show that the transient vibration signals are concentrated in the range from 10 to 2000 Hz [9].

1.1.3. Condition Monitoring by Dissolved Gas Analysis (DGA)

The purpose and function of DGA is to provide an indication as to whether there may be an active or incipient transformer fault affecting the operation and continued health of the equipment [9]. It does this by measuring the dissolved gas content of the transformer oil using a number of qualitative and quantitative means including; key gas analysis, IEEE gas guide tables, Roger's ratio method, Duval's triangle, Domeberg ratio method and the IECmethod [3].

1.1.4. Condition Monitoring by Partial Discharge Analysis (PD)

Partial discharges which occur in oil filled transformers is caused by voids in the solid insulation, wet fibers in oil, gas bubbles in the oil etc. PD measurement is done in following ways: Infrared receivers, Special sensitive microphones Acoustic sensors/piezo-electric transducers, Radio receivers [1]. By taking measurements at a number of places in the transformer tank, PD activity region can be identified.

1.1.5. Condition Monitoring by Frequency Response Analysis (FRA)

This method is used to detect deformations which result in relative changes to the internal inductance and capacitance of the winding [9]. The FRA method uses a sweep generator to apply a sinusoidal voltage at different frequencies to the terminals of a transformer winding. The problem with FRA is that it needs special arrangements for its application and it can't be performed online easily [9].

In addition to the five methods stated above, sensor signal conditioning is also used for monitoring the condition of a transformer.

1.2. Benefits of Transformer Condition Monitoring

The following are benefits of transformer condition monitoring:

i. Timely field measurement.
ii. Confirmation of the presence of fault.
iii. In time proactive decisions.
iv. Reduction of unplanned outage.
v. Predictable and reliable maintenance schedule.
vi. Prevention of catastrophic failure and destruction of peripheral equipment.
vii. Reduction of maintenance cost.
viii. Provision of obtaining quality control features.
ix. Increment of the system stability.
x. Minimizes the severity of any damage and eliminates consequential repairs
xi. Increase safe working environment.
xii. Information for future plan, regarding up rating, and refurbishment of equipment.
xiii. Use of equipment for maximum economic efficiency.
xiv. Manages and extends the life of equipment with efficient and cost effective maintenance.

Today, as a result of the numerous benefits associated with Transformer Condition Monitoring, it is being practiced in some developed countries like China, Great Britain, Australia and India. Some large companies where transformers are made like TATA in India have been able to formulate policies for the effective monitoring of transformer conditions [8].

The **objective** of this paper therefore is to review the current transformer maintenance practice adopted in the University of Benin in order to generate **a case** for policy formulation using transformer condition monitoring.

2.0 Methodology

The steps taken in this research include: Survey of transformers within the University of Benin; Interview of the staffs in charge of transformer maintenance in University of Benin; Distribution of questionnaires; Analysis of questionnaires and Comparison of results.

2.1 Survey of Transformers within University of Benin

University of Benin has a total of 41 working transformers which are located within the school. 40% of this transformer has been in use since 1970 with a few damaged. 25% were recently installed in the last eight years meaning thus showing that the rate of consumption of power in the last eight years has drastically increased. Different types of transformers are used in University of Benin, they include 300KVA, 500KVA, 800KVA 1000KVA, etc. with the type used depending on the load or the location of these transformer. The University of Benin uses the underground distribution system althoughthe overhead type is also used at Senior Staff quarters. Its power source is from BEDC (Benin Electricity Distribution Company) where 33KVA of power is transmitted to UBTH (University of Benin Teaching Hospital) where it is stepped down to 11KVA. This 11KVA of power is then transmitted to the Oil Circuit Breaker (OCB) at the power house wherethe value of the voltage is checked, then stepped down to415V.It isthen distributed to the transformers through a Ring Main Unit (RMU) which then steps it down to 240V.

2.2 Interview of Maintenance Staff

From the interview of some of the staff at the University's power house, it was discovered that majority of them had limited knowledge on the causes of transformer breakdown as well as standard maintenance procedures.

2.3 Distribution of Questionnaires

A detailed questionnaire was developed aimed at determining the type of transformer maintenance practiced in University of Benin. The questionnaire was designed to address issues like the number of working transformers, the type of transformer faults usually encountered, the life span of the transformer, how faults are reduced, kind of maintenance being adopted etc. Four questionnaires were retrieved which is relatively a small sample. This is due to the fact that staffs with the basic knowledge of transformers maintenance in University of Benin are few.

3.0 Analysis of Result & Discussion

In analyzing the questionnaire, researched data on the use of Transformer Condition Monitoring is used as base point for comparison. The responses were rated on a scale of 1-5, Five (5) being a case of concurrency between currently practiced method and researched data on Transformer Condition Monitoring, and One (1) a case of sharp contrast between these two methods and other ratings based on the differences between the two methods.
The responses were weighed as shown in Table 1.

Table 1: Weight categorization for Responses to Questionnaire

Response Weight	Description
5	Accurate correlation between currently practiced method and researched TCM data
4	Very close correlation between currently practiced method and researched TCM data
3	Fair correlation between currently practiced method and researched TCM data
2	Little correlation between currently practiced method and researched TCM data
1	No correlation between currently practiced method and researched TCM data

The currently practiced method refers to preventive/corrective maintenance strategy being practiced in University of Benin.
All of the responses to a question were given Category Weighting estimated by

$$CategoryWeighting\ (CW) = \frac{\sum_{i=1}^{n} W_n}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where $W_1, W_2, W_3, \ldots W_n$are the weights of each response.$\sum_{i=1}^{n} W_n$ - Summation of Weights for each response from 1 to nn is the number of responses.
On collation and analysis of the questionnaires, the result presented in Table 2 was obtained.
From the results, it was gathered that the life span of most of the transformers in the University of Benin is approximately 30years, this shows that the life span of a transformer is conclusively 30years. Thus, given a category weight of 5.From question number 2, it is discovered from research that Transformer Condition Monitoring is used in extending the life span of a transformer by using monitoring devices like sensors and mobile device which the currently practiced method does not use rather protective device such as Ring Main Unit (RMU) is used, thus, giving a category weight of 3. From question number 3, with Transformer Condition Monitoring, incipient faults are detected and correctedbefore occurring therefore faults hardly or never occur. In contrast, the current practiced method allows fault to occur before maintenance is done, hence, a category weighting of 3.25. From question number 4, in Transformer Condition Monitoring the fault detected are basic transformer faults such as deformation of winding, de-polymerization of paper insulation, etc. whereas, in the current practiced method secondary faults (networking fault) like short circuiting, voltage surge etc. are detected, hence, a category weighting of 2.

Table 2; Category Weighting of Response from Questionnaires

S/No.	QUESTION	CATEGORY OF SAMPLE RESPONSE					
		W_1	W_2	W_3	W_4	CW	Conclusion
1.	What is the predicted service life of a newly installed transformer?	5	5	5	5	5	30years
2.	How do you extend the life span of the transformers?	3	3	3	3	3	Use of protective devices
3.	How often do they generate faults?	3	3	4	3	3.25	Rarely
4.	What kind of faults are commonly encountered?	2	2	2	2	2	Networking faults
5.	How do you reduce these faults?	2	2	2	1	1.75	Little knowledge
6.	What type of maintenance is being practiced – Corrective or Preventive Maintenance or Transformer Condition Monitoring	1	1	1	1	1	Transformer Condition Monitoring is not practiced
7.	When was the last maintenance done	1	2	2	1	1.25	Year 2013 (yearly bases)
8.	What do you know about Transformer Condition Monitoring and is it being practiced?	1	1	1	1	1	No idea
9	Which method has been practiced? Offline or Online maintenance	3	2	2	1	2	Offline
10	Is there any maintenance record or log?	1	1	1	1	1	None

From question number 5, since the fault that is usually detected in the current practiced method is networking fault little knowledge is known on how to reduce this fault, thus a category weighting of 1.75. From question number 6, the current maintenance that is practiced is not Transformer Condition Monitoring rather preventive and corrective maintenance, hence, a category weighting of 1. From question number 7, with Transformer Condition Monitoring, maintenance is done every day by the continuous monitoring of the transformer whereas, in the current practiced method maintenance is done yearly, thus, a category weighting of 1.25.

From question number 8, Transformer Condition Monitoring is not known let alone practiced, hence, a category weighting of 1. From question number 9, Transformer Condition Monitoring can be done both offline and online. The current practiced which is corrective is basically offline method, hence a category weighting of 2. From question number 10, in Transformer Condition Monitoring, maintenance log is kept whereas in the current practiced method there is no maintenance log or record, hence, a category weight of 1.

4.0 Conclusion and Recommendation

It can be inferred from the research work, that the need for Transformer Condition Monitoring is of paramount importance not because the current method is no longer working but because of its benefits, efficiency and reliability.

From the analysis of results, we hereby make the following recommendations;

i. We recommend that the current maintenance practice (Reactive) adopted by the University should be jettisoned for a more proactive method (Transformer Condition Monitoring) which will enhance the expected life of the transformers, its efficiency, and also reduce the cost of operation.

ii. Also, as a matter of necessity, we recommend that the maintenance staffs should be properly trained on the techniques of TCM as this will aid their work and in turn reduce the cost of operation and maintenance.

5.0 References

[1.] Kumar A. (2006) ‘Transformer Condition Monitoring Practices with A Special Approach for Detection of Electric Arcs’, IEEMA Journal, Pp.1.

[2.] Guping Z, and Fugui D. (2009) ‘Power Transformer Condition Monitoring Based on MAS’, InternationalConference on Artificial Intelligence and Computational Intelligence School of Computer Science and Technology North China Electric Power University Baoding, DOI 10.1109/AICI.2009.101; China Pp.520.

[3.] Sethuraman M. (2009) 'Transformer Condition Monitoring', Senior Engineers (Condition Monitoring) Asset Maintenance, TNB Transmission, Pp.1 - 8.
[4.] Gockenbach E and Borsi H. (2008) 'Condition Monitoring and Diagnosis of Power Transformers' Proceedings of International Symposium on Electrical Insulating Materials, September 7-11, 2008, Yokkaichi, Mie, Japan Pp.16-18.
[5.] Jcmiras Wikimiras (2007), Online resource: Access June 2014; Retrieved from www.jcmiras.net/wiki/typicaltransformerlifespan20.htm.
[6.] Amrollahi M. H., Hassani S. (2011) 'Determination losses and estimate life of distribution transformers with three computational, measurement and simulation methods, despite harmonic loads' Pp. 2-4; 2011.
[7.] McNutt W. J. (2002) 'Operation of Power Transformers during Major Power System Disturbances' Pp. 1- 4.
[8.] Budin J. K. (2007) 'Transformer Mid-Life Refurbishment- Prevention or Cure?' Pp.10-11.
[9.] Abu-Elanien, M. M., Ahmed E. B., A. Salama.(2008) 'Survey on the Transformer Condition Monitoring'Pp.188-189.
[10.] Tang, W. H., Q. H. Wu, and Z. J. Richardson.(2002) 'Equivalent heat circuit based powertransformer thermal model',Electric Power Applications, IEEE Proceedings-. Vol. 149. No. 2.