ANALYSIS OF POWER TRANSFORMER FAILURE IN OGBOMOSO SUB-STATION OF IBADAN ELECTRICITY DISTRIBUTION COMPANY

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Abstract

A modern electric power system is a very large and complex network consisting of generators, power transformers, transmission lines, distribution lines, and other devices. Power transformer is one of the most important electricity equipment in power system. It plays important roles both in transmission and in distribution system. Power transformer condition should be maintained because of its importance in electricity network. There is an increasing need for better diagnostic and monitoring tools to assess the condition of transformers. Many monitoring, testing and condition assessment techniques have been used. By means of statistical failure analysis, the ageing processes related to the ages of the transformer can be shown. The failure data is fitted with mathematical and statistical distribution and the accompanying parameter can be estimated. This research paper presented the analysis of power transformer failure in Ogbomoso Sub-station of Ibadan Electricity Distribution Company (IBEDC). Statistically linked mathematical equations were formulated for the analysis of power transformer failure in Ogbomoso Sub-station.in order to predict the future failure of power transformer previously installed and the existing one to be installed. The results of the analysis showed that the failure of power transformer increased with ageing and that the failure of transformer could be represented by Weibull distribution. For most transformers, the empirical Cumulative frequency ($F_{(t)}^{i}$) versus Age (t) on the weibull probability exhibited a remarkable linearity. The results obtained from this analysis will form a useful basis for power system engineers in order to predict the failure of power transformers in future and to put in place, adequate and appropriate maintenance strategies for the equipment.

Keywords: Complex Network, Electric Power, Transmission Line, Distribution Lines, Power Transformer, Statistical Failure Analysis, Ageing Processes.

I. INTRODUCTION

Electricity is a major priority of any society which should be reliable for a country to sustain economy. Modern society is dependent on an electrical supply that is both reliable (Alvehag and Sodar, 2011) and compatible with the need of equipment connected by utility customer (Cigre, 2011). An electric power system presents a significant role in modern society as well as in the growth of country economy where it is utilized in the industries, household and the commercial section. The growing use of sensitive electronic equipment and the increasing demand in utility customers demonstrate that the stability of the power supply have highlighted as importance of optimizing the reliability and power quality levels of electric system (Josee, 2016).

Failure of transformer can be defined as the termination of the ability of a circuit to perform its required functions (Keri, 2015).Home electricity has become a basic necessity in everyday life in developed and developing countries. The cost of home energy supplied by the electrical network is lowest when compared to the energy provided by different types of conventional and nonconventional processes (Sato et al, 2013).

Accurate reliability analysis of power systems helps to predict future failure behavior and make appropriate maintenance plans (Endrenyi and Anders, 2006). Reliability performance of distribution utilities has received considerable attention in recent years (Elena et al, 2010). For reliability evaluation purposes the commonly operating system are generally classified into two categories: repairable and non-repairable. For repairable system, if a component of the system fails, it is repaired and put back into operation. However, a non-repairable system dies when it falls and it needs to be replaced by a new one. Effective reliability analysis is an essential factor in long term and operational planning of electric power system (Meliopoulos et al, 2005).

The objectives of every power utility are to maintain integrity and stability throughout, and to promote accurate reliability of power supply to customer without interruptions. Power transformer condition should be maintained because of its importance to electricity network. There is an increasing need for better diagnostic and monitoring tool to assess the condition of transformer (Josep Franklin, 2012).

The better performance of power transformer implies high power system efficiency and enhanced power transfer capability. The design and maintenance of electric power network have developed to the extent of balancing it functionally. (Parthraval and vivikpandy, 2015).

II. POWER TRANSFORMER

The basic function of power transformer is to transfer electrical energy. The transmission of electric power is most efficient at high voltage as the energy loss is proportional to the square of the current. Considering the distance between the generators and the household and industries, it is essential to convert electricity to low current and high voltage at the generating end and then convert to high current and low voltage at the receiving end.

III. TRANSFORMER STRUCTURE

A power transformer is constructed of core, windings, solid insulation, oil, bushing, on-load or off-load tap changer, cooling system and tank. Each component is explained as follows:

A. Active Parts

Core and windings are considered as active parts of a transformer, i.e. where the actual transformation takes place:

i. Core: The core's function is to carry magnetic flux. The failure mode of this function is a reduction of the transformer's efficiency. The cause can be a mechanical fault in the core, due to DC-magnetism or displacement of the core steel during the construction, i.e. a construction fault (David, 2006)

ii. Windings: The windings belong to the active part of a transformer, and their function is to carry current. The windings are arranged as cylindrical shells around the core limb, where each strand is wrapped with insulation paper.

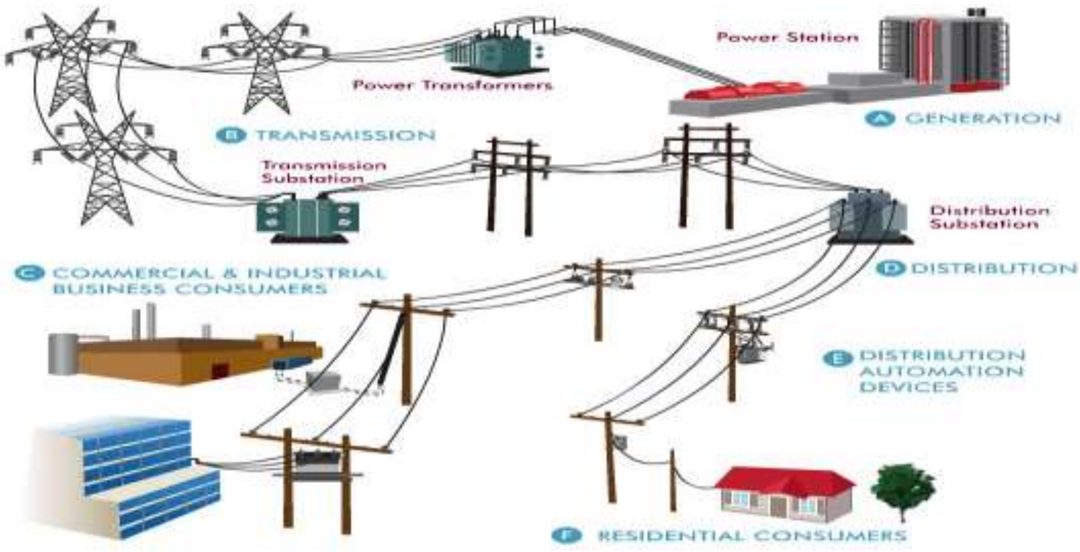

Figure 1: Power Generation and Distribution System

Source :http://www.bravoprojects.co.in/transmission.php

B. Passive Parts

The insulation system in a transformer consists of two parts: a solid part (cellulose) and a liquid part (transformer oil), The liquid part has a double function:

i. Solid insulation: The solid insulation in a transformer is a cellulose based product such as press board and paper. Its main function is to isolate the windings.
ii. Transformer oil: The oil serves as both cooling medium and as part of the insulation system. The quality of the oil greatly affects the insulation and cooling properties of the transformer.

C. Accessories

The following transformer components are defined as "accessories".

i. Tank: The tank is primarily the container of the oil and a physical protection for the active part of the transformer. It also serves as support structure for accessories and control equipment. The tank has to withstand environmental stresses, such as corrosive atmosphere, high humidity and sun radiation (Anna and Sabina, 2007). The tank should be inspected for oil leaks, excessive corrosion, dents, and other signs of rough handling. Internal arcing in an oil-filled transformer can instantly vaporize surrounding oil which can lead to a high gas pressure that may rupture the tank.
ii. Tap changer: The function of on-load tap-changer (OLTC) is to regulate the voltage level by adding or subtracting turns from the transformer windings. The OLTC is built in two separate sections; the diverter switch and the tap selector.

VI. POWER TRANSFORMER FAILURE AND CAUSES

During the course of its life, the power transformer as a whole has been suffering the impacts of thermal, mechanical, chemical, electrical and electromagnetic stresses during normal transient conditions. When a failure occurs, it is necessary to investigate the causes to improve production technology and maintenance programs.

Furthermore, transformers must be de-energized for some periodical tests and services. Therefore an outage will occur and it will decrease the component and ultimately the system reliability.

A failure is usually a "turning fork" of life management procedures. Failure analysis delivers key information providing insight for determining “what happened?” and “what to do?” in terms of managing network reliability , assessing risk, optimizing maintenance, and estimating end of life. Ultimately, the information aids in improving design and manufacturing of equipment. Failure modes and causes may differ markedly depending on user specifications, transformer application, design features, and, in particular, on the susceptibility to service deterioration and external exposure. In order to understand the cause of failure properly, all factors such as design anomalies, operating conditions and the mechanisms which reduce safety margins should be considered.

In industry, failure mode and effect analysis is a qualitative technique to identify potential failure of system process or machinery. It evaluates the likelihood and consequence of the failure and decides what action to be taken (As IEC, 2008). Failure that occurs in transformer can be grouped into three:

i. Severe: Transformer in this state is either repaired or removed from site on facilities within the factory. In this case, a new transformer will be installed to return the circuit to service
ii. Intermediate: Repair of transformer is carried out but it is implemented on site. This is carried out to restore the transformer to working condition and return it to service.
iii. Minor: These are trips that remove the transformer from service temporarily. Since the major component of the transformer are not been affected therefore no work is required to return plant to service.

A. Winding Failure

Winding is an important part of a transformer. In distribution side transformers there are commonly two windings. One is the primary side and the second one the secondary side. High voltage/low current flows in the primary side winding and through electromagnetic induction, voltage is stepped down and current stepped up in the secondary side winding. These windings withstand dielectric, thermal and mechanical stresses during this process. The faults that occur in the winding are due to these stresses. This causes the breaking of the windings or the burn-out.

B. Bushing Failure

Bushes are insulating devices that insulate a high voltage electrical conductor to pass through an earth conductor. In transformers it provides a current path through the tank wall. Inside the transformer paper insulators are used which are surrounded by oil that provides further insulation. Bushing failure usually occurs over time.

Causes: Seal breaking of bushes due to ingress of water, aging or excessive dielectric losses.

C. Tap Changer Failure

The tap changer in the transformer is to regulate the voltage level by adding or removing turns from the secondary transformer winding.

Causes: Lack of maintenance causes the shaft connection between the tap and the motor driver of the tap changer not to synchronize because the tap changer is not in the position where it needs to be.

D. Core Failure

Old capacitors or burned-out capacitor in the motor causes the tap changer to fail to control its direction movement. The transformers have laminated steel cores in the middle surrounded by the transformer windings. The function of the core is to concentrate the magnetic flux. Fault in the core directly affects the transformer windings, causing faults in them. The cores of the transformers are laminated to reduce eddy-current.

Causes: The over-heating reaches the core surface which is in direct contact with the windings.

E. Tank Failures

The function of the tank in the transformer is to serve as a container for the oil used in it. The oil in the tank is used for insulation and cooling. The tank can also be used as a support for other equipment of the transformer.

Causes: The reduction in oil level results in the reduction of insulation in the transformer and thus affecting the windings.

G. Cooling System Failure

Cooling system reduces the heat produced in transformers due to copper and iron losses. The cooling system contains cooling fans, oil pumps and water-cooled heat exchangers. The failure in the cooling system causes the heat to build up in the transformer which effect different parts of the transformer and also causes more gas pressure to be built inside which may cause the transformer to blow.

Causes: Fault in the cooling fans which rush-in cool air into the tanks for cooling purpose and leakage in the oil/water pipes.

H. Effect of Transformer Failure

When failure of transformer occurs, several consequences are created, first of it, the failure will cause damages to the transformer. A transformer can be partially damaged and remains repairable, or it can be totally destroyed with a need for replacement. Below are some effects of failed transformer.

i. Power delivery interruption to the power consumer of its area.
ii. Injuries to bystander, workers or emergency respondent.
iii. Environmental harm due to oil spillage.

I. Improvement of Transformer Reliability

Operating transformers in parallel will improve reliability of transformer failure, When one of the transformer becomes faulty, power is not interrupted because load will be moved to other transformer.

VII. RELATED WORKS

In 2017, Siontorou et al proposed a novel real-time diagnostic expert scheme for field-effect transistor (FET)-based bio sensing. They investigated the causes of sensor malfunctions by applying fault tree analysis (FTA). They have proposed a computer-aided method for diagnosing biosensor failure. Their tree structure serves as knowledge based (KB), and the fuzzy-rules-based decision mechanism is the inference engine for fault detection and isolation.

In 2018, Rao et al developed a fuzzy logic algorithm (FLA) which provided the vulnerability status of internal faults by considering thermal, electrical and mechanical conditions. For the reduction of misinterpretation, the results of dissolved gas analysis, insulating oil break down voltage, and sweep frequency response had been analyzed. Their system included 10 fuzzy logic controllers and they were connected by thinking about specialized conditions and reasons.

In 2015, Malik et al suggested that the UV-Spectrophotometer could be used to determine the transformer integrity. The health of the transformer could be accurately identified by this, but they have suggested that it is not useful in all aspects as it only provided the pictorial information of the age of the oil. They have presented fuzzy logic method for the health assessment of transformer oil.to provide the automatic and quick examination of transformer oil.

In 2018, Da Silva et al presented a transformer failure diagnosis system based on DGA. It was done by the extraction of the rules from Kohonen Self-Organizing Map. In this process the Kohonen net was trained first. It was used to capture the knowledge from the faulty transformers. Then in the learning stage Zero-order Takagi–Sugeno fuzzy rules had been transformed. They had also applied fuzzyfication process in the fuzzy system output.

Da et al in 2017 presented the results of a knowledge acquisition of vibrations in high power transformers. The region considered was the Amazon region, Brazil. They analyzed the vibrations by using the radial graphs. The results indicated that the largest mean vibration area occurred in the front of the transformer. These results have been used for the analysis of the vibration behavior. They used statistical analyses and the repeated measure analysis. It was used for the progression of a fuzzy inference system. They have suggested that this method was a low-cost analyses technique..

In 2018, Ramesh et al suggested that the inter turn short circuit fault was the main cause of power transformer failures. They suggested a physical model of a multi-winding power transformer of 100 MVA, 138/13.8 KV. It was simulated in a power system. Diverse rates of turns for example, 1%, 3%, 5%, 10%, 15%, and 25% were shorted on essential and auxiliary sides of the multilinking transformer to measure the terminal current. The adjustment in the terminal current was insignificant .In order to encounter noteworthy changes, negative grouping streams were separated utilizing symmetrical segment approach.

VIII. MATERIALS AND METHOD

The source data used in this study was obtained from Ogbomoso branch database of Ibadan Electricity Distribution Company (IBEDC). Data used in this research paper were for 9 years of case study. The data collected from IBEDC, Ogbomoso included;

i. Recorded number of transformer outage.
ii. Recorded outage time on each transformer.

IX. METHOD OF ANALYSIS

Statistical analysis was used to compute the cumulative failure and survival function of system reliability. Four steps were used in analyzing the method :.

i. Collection of data.
ii. Selection of proper distribution model.
iii. Fitting of data into distribution model and determining the best fitted parameter.

The Weibull probability distribution is given as:

$$F_{(t)} = \frac{i-0.5}{N+0.25} \quad (1)$$

where; *I*= Number of failure, N= Cumulative number.

Or

$$F^{i}_{(t)} = 1 - exp\left(\frac{-m}{t_o}\right) \quad (2)$$

where; $m = scale\ parameter, t_o = shape\ parameter$

(a) Survival function is given by:

$$S(t) = 1 - F(t) \quad (3)$$

where;

F(t)= weibull probability function

(b) Hazardous function or failure rate function is given by

$$H(t) = \left(\frac{m}{t_o}\right)^{t^{m-1}} \quad (4)$$

(c) Failure rate;

$$F_{r,av} = \frac{T^{m-1}}{t_0} \quad (5)$$

Finding the relationship between Age (t) and Weibull probability distribution

$$X = In[-In(1 - F(t)] \quad (6)$$

Getting the parameter, we compare it with

$$Y = mX + C \quad (7)$$

where; m= scale parameter, C= shape parameter

The step for Weibull probability distribution is given as:

i. Carrying out goodness-of-fit test to check the presumed distribution model.
ii. Plot a graph of number of failure versus operating time.
iii. Plot a graph of survival function versus time.
iv. Plot a graph of cumulative function (Y versus X) so as to determine the weibulll parameters.
v. Plot a graph of theoretical

X. DISCUSSION OF RESULTS.

The graphical representation of the failure rate versus the operating time for Ogbomoso power transformers is shown in Figure 2. It is observed that the failure rate increased as the age of transformer increased as well.
Figure 3 showed the relationship between the survival distribution and operating time. From the graph, it would be seen that the probability that a transformer will be surviving more than 8 years was 10%.
Figure 4 showed the relative cumulative function where the Weibull parameters were obtained. Thus, the scale parameter was 1.890 and the shape parameter was obtained as 5.5.
Figure 5 showed the relationship between the probability of failure and time of operation. From the graph it showed that 50% would fail at the age of 4.9 years and at the age of 9 years 100% would fail totally and replacement of new one would be carried out.
It would be seen from Table 1 that the hazardous level of transformer increased with respect to year and the average failure rate was 1.04% per year.
Various factors were identified for reducing the accuracy of the model, including; limitation of available failure data, unavailability of some condition data and measurement uncertainties in some of the data that were used. However, a model better suited for the asset management model could be developed with various improvements made with availability of more data. Failure of power transformer needed to be restored as quickly as possible. The sooner it was restored, the lesser the risk of power outage, damage of equipment of grid, loss of revenue, customer complaints and repair crew expenses.

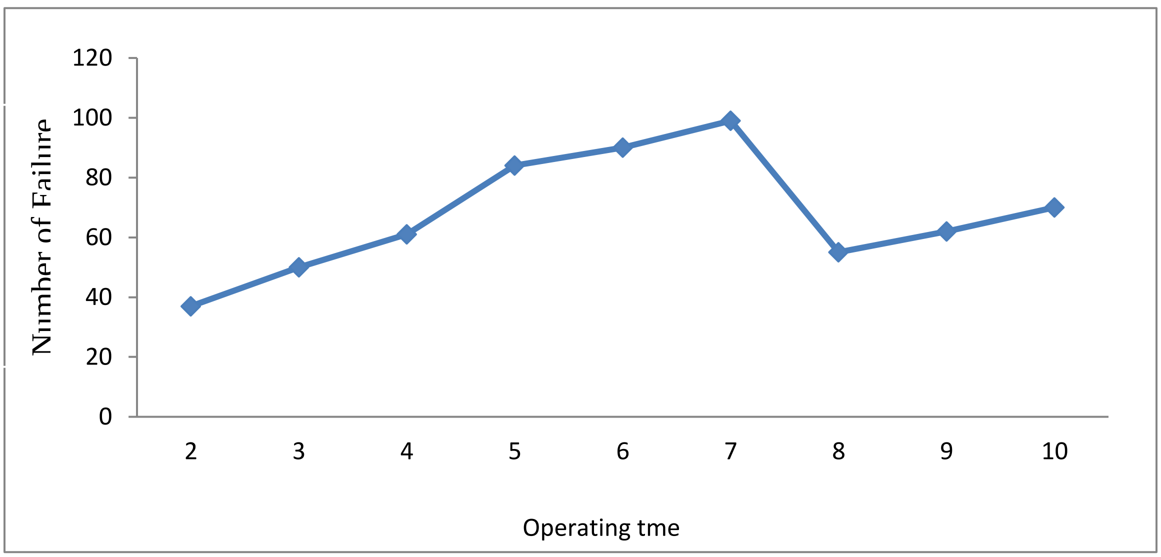

Figure 2: Number of Failure versus Operating Time

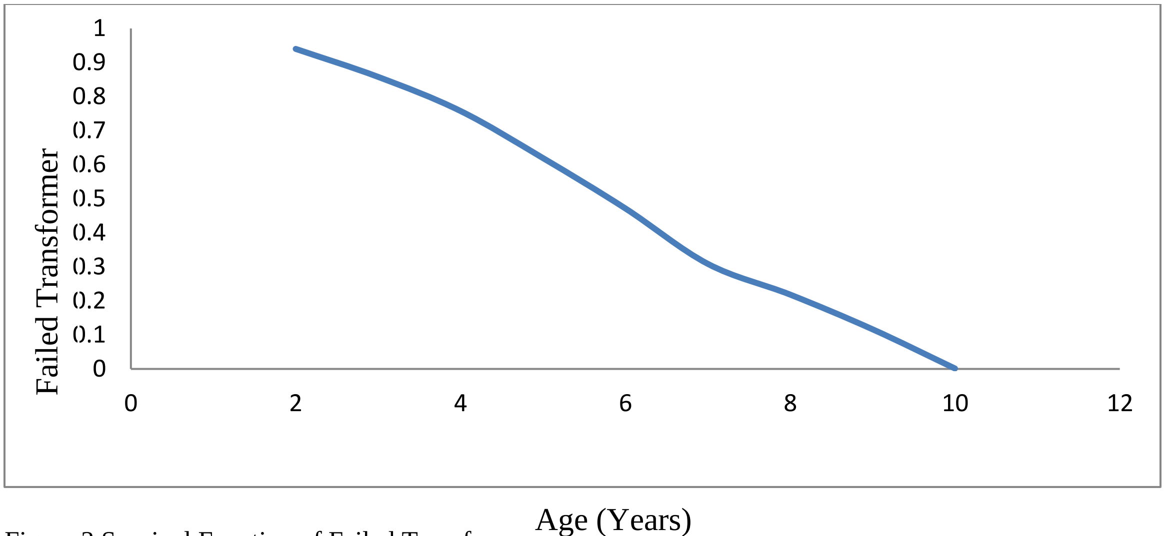

Figure 3 Survival Function of Failed Transformer

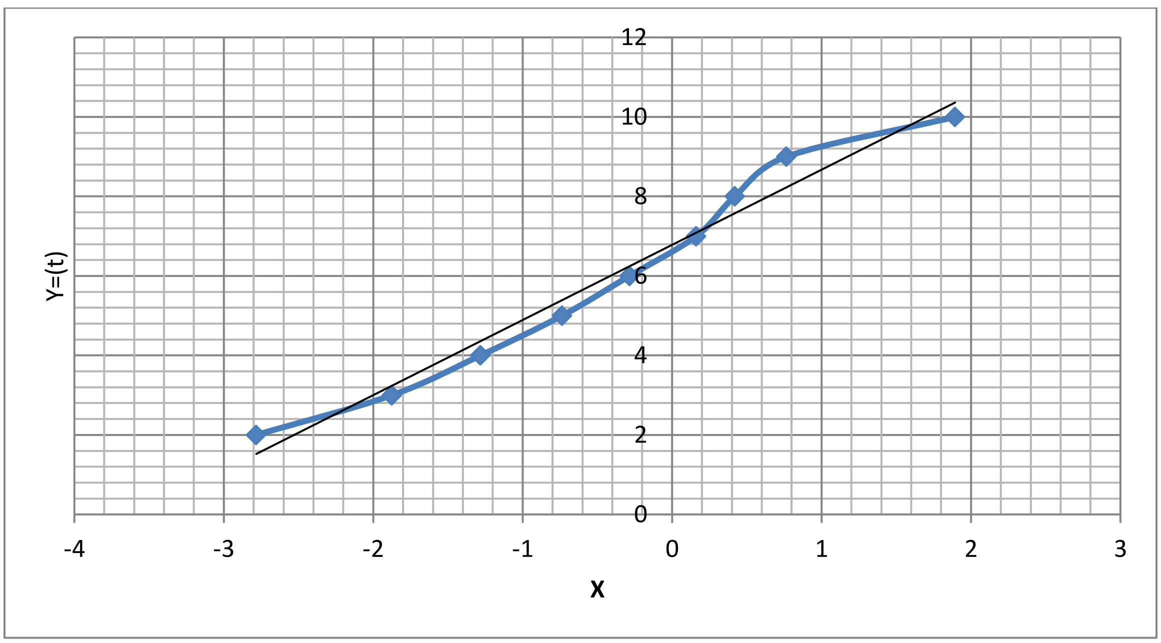

Figure 4: Relative Cumulative Functions of Failed Transformer

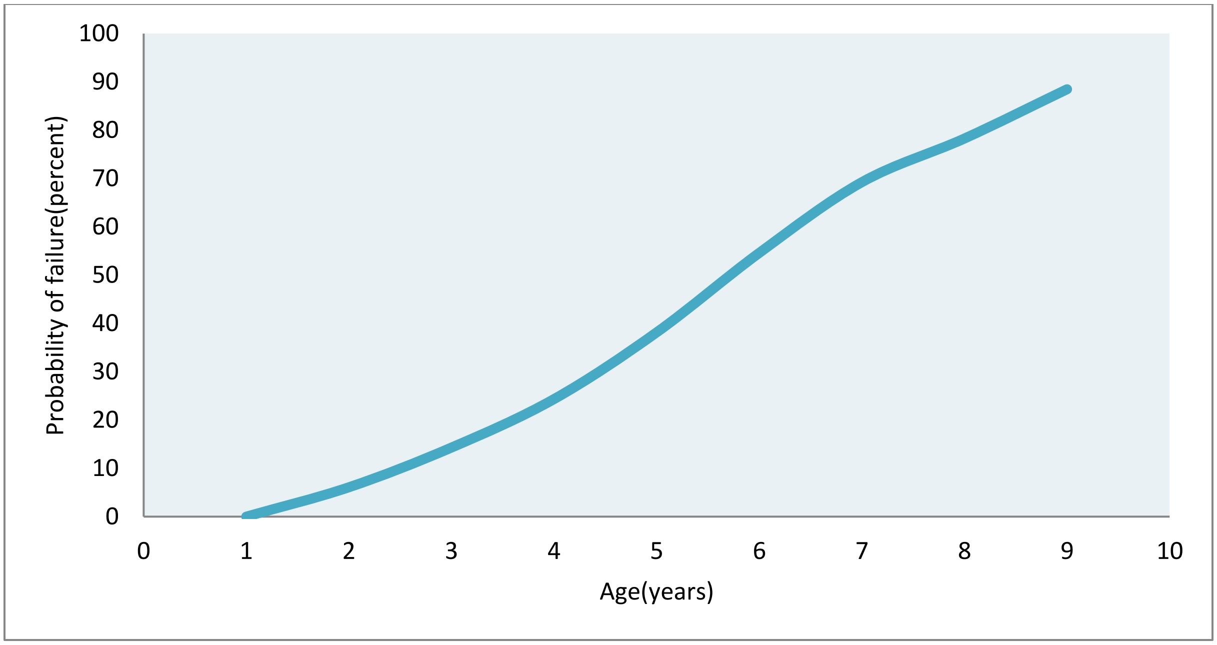

Figure 5: Theoretical Distribution Curve of Operating Time of Failed Transformer

XI. CONCLUSION

Analysis of power transformer has been presented in this research paper. Based on the statistical analysis it was concluded that the failure of power transformer increased with ageing. With the help of statistically linked mathematical model, it could predict the future failure of power transformer previously installed and the existing one to be installed. Unscheduled outage of transformer could cause huge power system problems**,** social disorder and financial losses. The only way to prevent this is through adequate maintenance processes. In this paper, the use of data obtained to predict failure financial resource can be properly utilized and future planning of procurement could be done for power transformer failure. The failure of transformer could be represented by Weibull distribution. For most transformers, the empirical Cumulative frequency ($F^{i}_{(t)}$) versus Age (t) on the weibull probability exhibit a remarkable linearity.

XII. RECOMMENDATION

The following recommendations were made to enhance a high level of reliability and low level of failure in Ogbomoso sub-station.

i. Periodic preventive maintenance and schedule maintenance rather than corrective maintenance should be practiced on transformers.
ii. Appropriate maintenance of newer and refurbishment of the older unit could minimize general ageing and significantly extended life of transformers.
iii. Transformer should not be kept on site for too long.

XII. REFERENCES

[1] Anderson(2017): Analysis Techniques for system reliability procedure for failure mode and effect analysis (FMEA), International Journal of Engineering Research, Volume 4, Number 6, Pp. 1-10.

[2] Anna F,. and Sabina, K. (2007) Failure Modes and Effects Analysis of Transformers

[3] Josep, F. S. (2013). Failure analysis of power transformer based on fault tree analysis, Pp. 1-10.

[4] Chao, W., Yun-Cai, L., Bi-jun, C., You-yuan, W. (2014):"A multi-layer power transformer life span evaluating decision model based on information fusion". In international conference on high voltage engineering and application, Pp. 1-4.

[5] Da Silva, A. C., Castro, A. R. and Miranda, V. (2018). Transformer failure diagnosis by means of fuzzy rules extracted from Kohonen self-organizing map. International Journal of Electrical Power & Energy Systems. 2018; 43(1), Pp. 1034-42.

[6] Da N. T., De Oliveira, T. F., Da Silveira, A. M., Da Silva, R. R. and Saraiva, A. C. (2017): "Knowledge acquisition of vibrations in high-power transformers using statistical analyses and fuzzy approaches–a case study". Electric Power Systems Research. 104, Pp. 110-5.

[7] Duan, R. and Wang, F. (2015): "Mechanical condition monitoring of on-load tap-changers using chaos theory and fuzzy c-means algorithm". In power and energy society general meeting, Pp. 1-5.

[8] Ehsan, A. (2017): "Developing practical method for ageing and failure probability modeling of mineral oil immersed power transformer using smart utility data, Pp. 1-8.

[9] Ghoneim, S. S and Taha, I. B. (2016):"A new approach of DGA interpretation technique for transformer fault diagnosis". International Journal of Electrical Power and Energy Systems. 81, Pp. 265-74.

[10] Islam, M. M., Lee, G. and Hettiwatte, S. N. (2017): "Application of a general regression neural network for health index calculation of power transformers". International Journal of Electrical Power and Energy Systems, Pp. 1-10.

[11] Josee, M. (2016): "Analysis of transformer failure due to lighting in Haugland power line distribution network". Thesis, Pp1-4.

[12] Keri, P. (2015): Determination of probability of failure of power transformer using statistical analysis". Pp 1-7.

[13] Malik, H., Yadav, A. K, Mishra, S. and Mehto, T. (2015): "Application of neuro-fuzzy scheme to investigate the winding insulation paper deterioration in oil-immersed power transformer". International Journal of Electrical Power and Energy Systems, Pp.53:256-71.

[14] Malik, H, Singh, S. M. and Jarial, R. K. (2014). "UV/VIS response based fuzzy logic for health assessment of transformer oil. Procedia Engineering". 2014; 30, Pp. 905-102..

[15] Pengfei, J., Chao, W., Jianxin, G., Xinru, Y., Shaojun, C. and Ting, R. (2016). " The condition assessment of transformer bushing based on fuzzy logic". In international conference on condition monitoring and diagnosis, Pp. 469-72.

[16] Porth, R. (2015): "Distribution transformer future failure using extreme value model". International journal of engineering research and develop, Pp. 68- 74.

[17] Ramesh, K. and Sushama, M. (2018). "Inter-turn fault detection in power transformer using fuzzy logic". In international conference on science engineering and management research, Pp. 1-5.

[18] Rigatos G, Siano P (2016):"Power transformers' condition monitoring using neural modeling and the local statistical approach to fault diagnosis". International Journal of Electrical Power and Energy Systems. 80, Pp. 150-9.

[19] Rajamani, P., Dey, D. and Chakravorti, S. (2010). "Classification of dynamic insulation failures in transformer winding during impulse test using cross-wavelet transform aided foraging algorithm". IET Electric Power Applications. 2010; 4(9), Pp. 715-26.

[20] Rao, U. M., Reddy, M. V. and Jarial, R. K. (2018). "Fuzzy logic based system to diagnose internal faults of power transformer". In international conference on communication and industrial application 2018 Pp. 1-5.

[21] Siontorou, C. G, Batzias, F. A. and Tsakiri, V. (2017). "A knowledge-based approach to online fault diagnosis of FET biosensors". IEEE Transactions on Instrumentation and Measurement. 2017; 59(9), Pp. 2345-64.

[22] Tang, S., Peng, G., Zhong, Z. (2016):"An improved fuzzy C-means clustering algorithm for transformer fault". In China international conference on electricity distribution, Pp.1-5.

[23] Žarković, M. and Stojković, Z. (2017):"Analysis of artificial intelligence expert systems for power transformer condition monitoring and diagnostics". Electric Power Systems Research. 149, Pp. 125-36.