American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-10, Issue-8, pp: 285-291
www.ajer.org
Research Paper Open Access

Improving the Insulation System of Service Transformers Using Artificial Intelligence Technique.

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***Abstract**: This research work performed analysis on fifty (50) transformers of Port Harcourt metropolis. The insulation oil samples of distribution transformers were collected on the network. American Society for Testing of Materials (ASTMD 923) standard method was used for testing the samples. The samples were allowed to stand in tightly sealed containers for 24 hours prior to testing. The result showed that twenty-six (26) test samples of transformer insulating oil passed acidity test whilst twenty-four (24) test samples of transformer insulating oil fail acidity test.*

***Keywords**: Insulation, Transformers, Insulation System, Artificial Intelligence Technique*

Date of Submission: 07-08-2021 Date of acceptance: 21-08-2021

I. STATEMENT OF THE PROBLEM

One of the major challenges in the power system network that often paralyze the system to its passive state for a short or long period is insulation failure or insulation breakdown in the power service transformer which renders the entire network dead even when other power equipment and accessories are intact and steady.

II. INTRODUCTION

The major insulation consists of the insulation between the windings, between windings and the limb/yoke, and also the insulation between the high voltage leads and the ground. While minor insulation system includes external insulation within the windings that is the inter-turn and the inter-disk insulation. The end insulation design of a transformer is one of the factors deciding the window height of transformers; hence optimization of the insulation will permit a reduction in the clearances to the core and thus reducing the amount of steel and transformer oil (Balinth, et al., 2010). The objective of the course is to improve the insulation system strength of the service transformers. Whereas for either corrective, preventive or replacement maintenance to take place it may take a long time by the utility company (PHED) because such may require a huge amount of money, technical know-how; all accompanied with extreme inconveniences to the consumers over time especially when there is no means to cascade the load to nearby active network meanwhile the utility company (PHED) also losses huge part of their revenue from such areas over the period they are out of supply hence this insulation failure must be proper care for to safe cost (AJES., 2012).

Improving the insulation system of the service transformers would be a good means of controlling insulation failures such as to improve efficiency and stability of the power distribution network of Port-Harcourt metropolis. The goal is designed to help determine good operating function which will improve the stability and availability function of the entire network.

III. PAST REVIEW

To measure moisture in oil, coulometric Karl Fischer titration is commonly performed in accordance to IEC 60814.There are three quantifications of moisture in oil, which are absolute moisture content, corrected moisture content, and relative moisture content (relative humidity, RH). Measurements obtained from Karl Fischer titration are indicative of the absolute moisture content and are expressed in mg H_2O/kg oil or otherwise parts per million (ppm), (Fofana et al., 2010).

Sludge is formed by polymerization or combination of components with large molecular weight arising from insulation degradation which if the solubility limit is exceeded, sludge will precipitate and contribute as an additional element of sediment.

Particle count addresses the number of particles that could arise from manufacturing, storage, or handling, as well as operation related sources like metal wear, operation of on-load tap changer (OLTC), localized overheating, and insulation ageing (Duarte et al., 2010).

The electrical and mechanical properties of such wood pulp are found acceptable for meeting the standards of electrical insulation. They contribute more than just mechanical separation between windings or support, it contributes to the total dielectric properties of any composite insulation of which it may be part. The cellulose insulation has effects on voltage distribution in heterogeneous dielectric systems; to a reasonable extent, the life of the total insulation system (Borsi, et al., 2005).

However, (Balinth, et al., 2010) stated that it that during optimization, the insulation design rules must be true under all circumstances for reliable insulation, thence the electrostatic analysis done was by Finite Element Method (FEM), using the software 'Electnet' with the areas of study selected for optimization as the thickness of clamping ring and size of oil gaps.

IV. METHOD

This research work examined the acidity of distribution transformer oil in service through field and laboratory tests using a case study of installed distribution transformers at Port-Harcourt metropolis network comprising ten Feeders. The study covers part of the commercial place in the city where regular and continuous supply of electricity is desired.

Prior to the testing of distribution transformer insulation oil, a detailed sampling was carried out on installed distribution transformers at Port-Harcourt metropolis distribution network to arrive at the selected transformers, samples were not taken from energized transformers. The transformers have no external sampling valve; hence, the units were first de-energized and the samples were taken internally. The adopted method of obtaining liquid samples follows ASTM D 923 standard. Oil samples were fetched from the bottom of the transformers, since less-flammable liquid samples were the ones recommended to be taken from the top.

The samples were allowed to stand in tightly sealed containers for 24 hours prior testing. Five oil samples each from ten distribution transformers making a total of fifty samples were taken from different installed distribution transformers all from the Port-Harcourt metropolis distribution network, Rivers state. The acid neutralization number is a measure of the amount of acid materials present in the oil, as the transformer ages, the oil will oxidize and increase in acidity. An automatic potentiometric titration system Titrino SM 702 was used to measure the acidity of the oil samples. The system involves determination of the Total Acid Number TAN by a volumetric titration with potash to neutralize the carboxylic acids. Ten gramme (10g) of the oil sample were dissolved in 40 ml of solvent ethanol in a ratio of 5 to 4. Then 0.1mol/litre of Potassium hydroxide (KOH) was added as titre with volume increments of 0.001 ml.

The system detects, when the acid-base equivalence-point EP is reached by a voltage measurement in the solution. The acidity test for each sample was carried out four times and the average total acid number recorded. From the volume of potassium hydroxide at the equivalence point for each experimental run, the total acid number was calculated from equation (1):

$$T_A = \frac{(E_X - C_Y) N_{KOH} M_{KOH}}{W} \quad (1)$$

T_A is the total acid number, E_x is the equivalent point, C_y is the blind value of solvent ethanol.

N_{KOH} is the concentration of the titre (mol/L), M_{KOH} is the molar mass of titre = 56,106g/mol and W is the weight of the oil sample.

The Test Methods in accordance by the American Society for Testing of Materials (ASTM) provides that the acidity of oil in a transformer should never be allowed to exceed 0.2mg KOH/g oil, this is the Critical Acid Number and deterioration increases speedily once this level is exceeded.

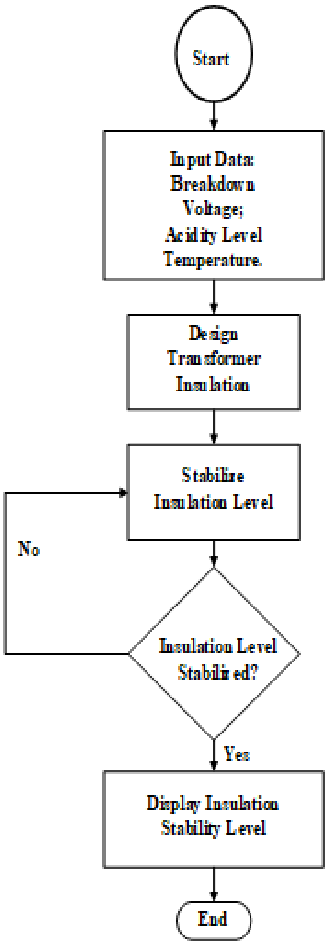

Figure 1: Fuzzy flow Algorithm

Table 1: IEC 60422 condition classification (Linhjell, et al., 2007)

Parameter	Voltage (kV)	Condition Classification Good	Fair	Poor
Colour and appearance	All	Clear and without visible contamination	Not Applicable	Dark and/or turbid
Moisture (ppm at operating temperature)	>170	<15	15 – 20	>20
	72.5– 170	<20	20 – 30	>30
	≤ 72.5	<30	30 – 40	>40
BDV (kV, 2.5 mm gap)	>170	>60	50 – 60	<50
	72.5– 170	>50	40 – 50	<40
	≤ 72.5	>40	30 – 40	<30
Acidity (mg KOH/g oil)	>170	<0.1	0.1 – 0.15	>0.15
	72.5– 170	<0.1	0.1 – 0.2	>0.2
	≤ 72.5	<0.15	0.15 – 0.3	>0.3
DDF (40Hz– 60 Hz at 90 °C)	>170	<0.1	0.1 – 0.2	>0.2
	≤ 170	<0.1	0.1 – 0.5	>0.5
Resistivity (GΩm, at 90 °C)	>170	>10	3 – 10	<3
	≤ 170	>3	0.2 – 3	<0.2
IFT (mN/m, uninhibited)	All	>25	20 – 25	<20

The recommended value ranges, condition classification, and suggested actions as described in IEC 60422 are possible through progressive accumulation of operational experience over the years by electrical utilities and authorities worldwide. There have been three past versions of IEC 60422, in 1973, 1989 and 2005 before the current 2013 edition.

V. RESULTS AND DISCUSSION

A. Simulation Term and Conditions

The organic acids are detrimental to the insulation system and can induce corrosion inside the transformer when water is present. An increase in the acidity is an indication of the rate of deterioration of the oil with sludge as the inevitable by-product of an acid situation which is neglected. It has been reported that the acidity of oil in a transformer should never be allowed to exceed 0.20mg KOH/g oil.

As shown in Equations, E_o and Ep are mainly affected by the parameters of A and C when η is high, whereas they are mainly affected by the parameters of B and D when η is low. This indicates that the electric field distribution is significantly affected by the resistivity when the DC content is high and by the relative permittivity when the DC content is low. The breakdown of insulating material is mainly affected by the maximum value of the voltage waveform. The fuzzy logic controller was applied for the improvement of transformer health condition. There are three inputs which are Breakdown Voltage (BDV), oil acidity and Temperature with one output which indicate the stability level of transformer insulation.

Table 2: Corrected in-service Transformer insulation

S/N	Transformer Name	Transformer Code	Transformer oil Acidity (mgKOH/g)	Breakdown Voltage (BDV) kV/mm
1.	Olu-Woji S/S	T2	0.0945	56
2.	Clamorgan S/S	T3	0.0954	52
3.	Erijoy S/S	T4	0.09855	50
4.	MTN Lord Emm S/S	T7	0.0963	48
5.	Elem Oil S/S	T8	0.0954	54
6.	Rumuodaolu Cluster 1	T14	0.0972	40
7.	Market Road S/S	T20	0.099	52
8.	Hospital S/S	T21	0.09675	48
9.	Anglican Relief S/S	T22	0.0981	54
10.	Anglican S/S	T25	0.0981	46
11.	Rumuprikon S/S	T28	0.0981	56
12.	Red Cross S/S	T30	0.09855	50
13.	Community1 /Cluster 1	T33	0.099	52
14.	N.E.W S/S	T34	0.099	42
15.	Mini Jeje S/S	T36	0.1008	54
16.	Service & Smile S/S	T39	0.09585	48
17.	Genesis S/S	T40	0.1013	44
18.	EFCC S/S	T41	0.09855	52
19.	Casablanca S/S	T42	0.1035	50
20.	Rumuomasi S/S	T43	0.104	42
21	Abacha S/S	T45	0.09855	40
22	GTB S/S	T46	0.09945	42
23	Restopark S/S	T48	0.09585	40
24	Azungugu S/S	T49	0.09765	44

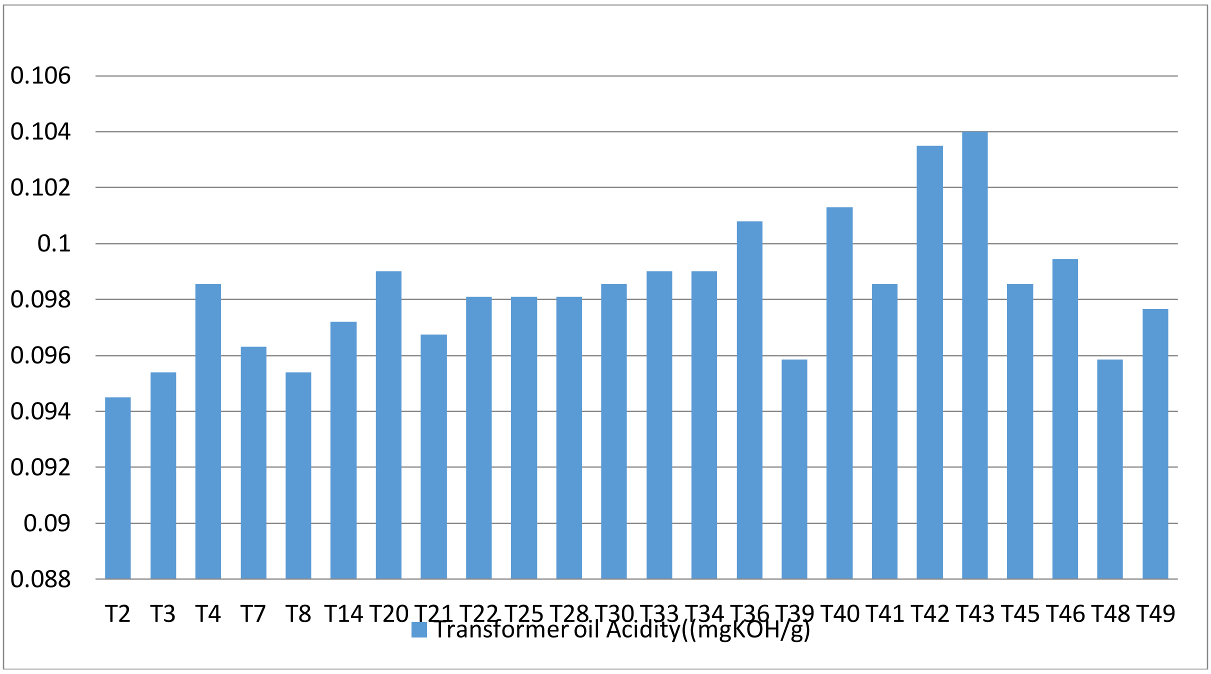

Figure 2: Corrected Transformer oil Acidity Level with Fuzzy logic

Figure 2 shows the corrected transformer oil acidity level when fuzzy logic controller is incorporated. The results correct the fail transformer due to oil acidity level and also stabilize the level of oil. The corrected transformers are T2, T3, T4, T8, T14, T20, T21, T22, T25, T28, T30, T33, T34, T36, T39, T40, T41, T42, T43, T45, T46, T48, T49 and oil acidity level are 0.0945, 0.0954, 0.09855, 0.0963, 0.0954, 0.0972, 0.99, 0.9675, 0.0981, 0.0981, 0.0981, 0.09855, 0.099, 0.099, 0.1008, 0.09585, 0.1035, 0.104, 0.09855, 0.09945, 0.09585, 0.09765 respectively. According to Test Methods by the American Society for Testing of Materials (ASTM) provides that the acidity of oil in a transformer should never be allowed to exceed 0.2mg KOH/g oil. Therefore, from the result achieved, it was shows that the acidity level of transformer did not exceed 0.2mgKOH/g.

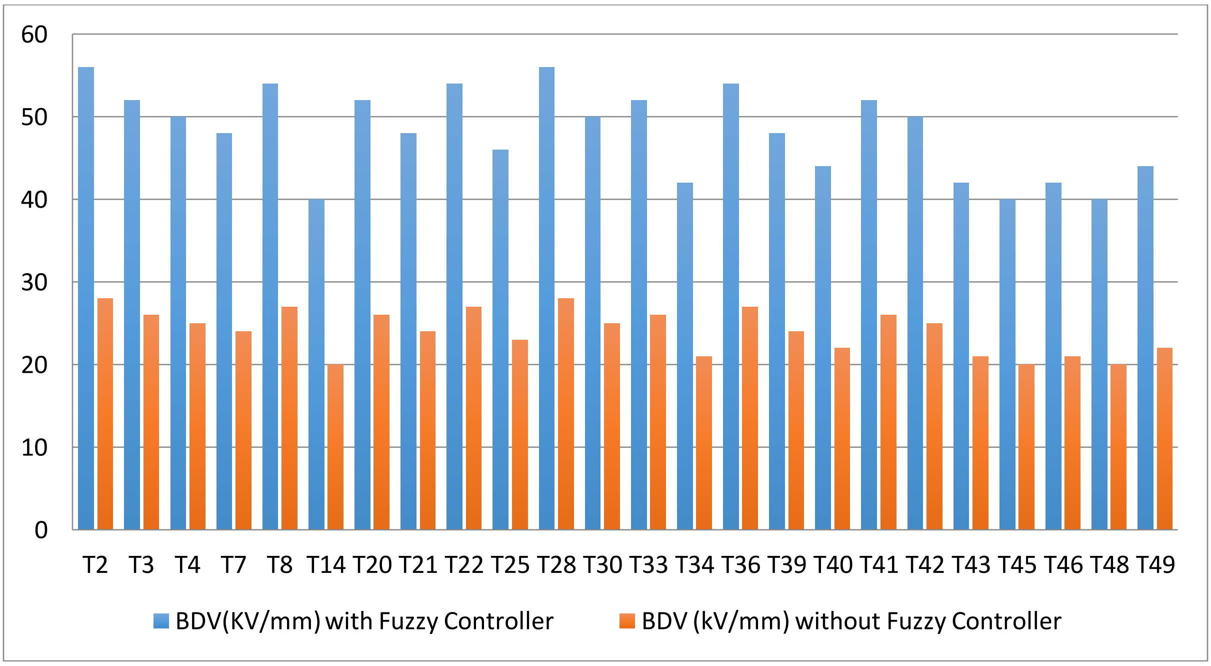

Figure 3: Comparison of Insulation Breakdown voltage with and without fuzzy controller

B. Simulation Scenarios

I. Stability Level of Transformer insulation

Figure 3 shows the three input which are: Breakdown Voltage, Oil Acidity and Temperature, also the stability in oil level which shows output of the system. The rules are program in oil dialogue box which shows the controller of the system.

II. Transformer Oil Acidity Indicator

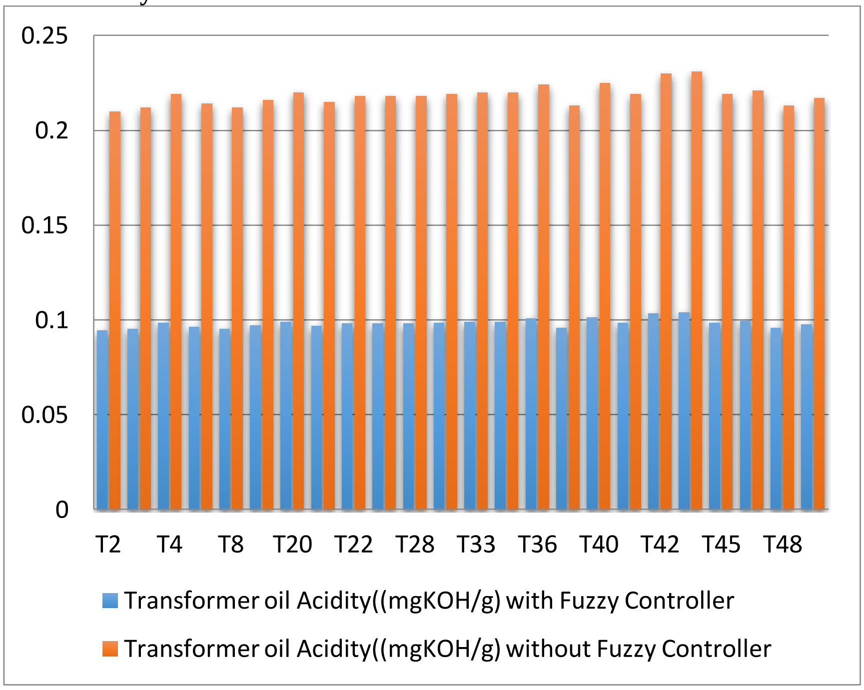

Figure 4: The transformer oil Acidity with and without fuzzy controller.

The result of Figure 4 shows that if oil Acidity greater than 0.2mg the state of health is poor, if oil Acidity falls between 0.11 to 0.2mg the condition is fairly good and if oil Acidity falls within 0 to 0.1 the condition is good.

III. 3D Surface of Transformer Oil

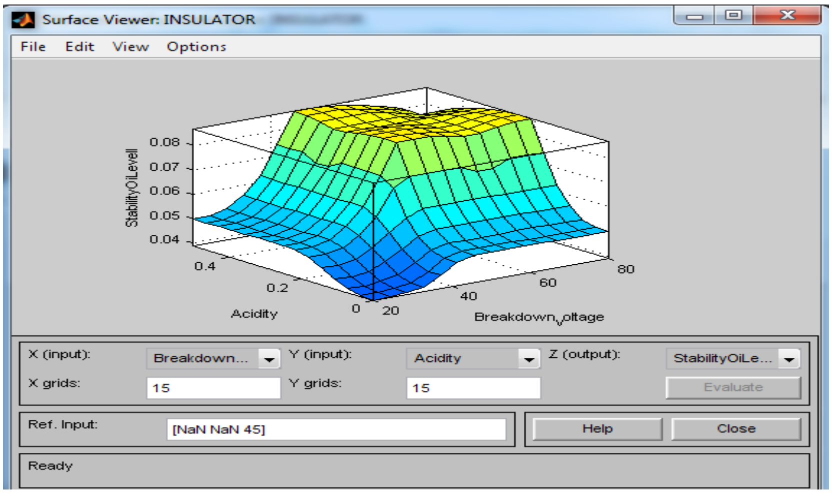

Figure 5: The 3D surface of transformer oil Acidity using fuzzy logic Controller

Figure 5 results shows the 3D surface of transformer oil Acidity with three inputs and three membership function each which generates 19 rules, this shows the stability system of Acidity level of transformer oil and Breakdown voltage of transformer insulation. The Acidity level of transformer oil stabilizes at the increase in Breakdown voltage; therefore, the effect of Acidity level of oil transformer determines the productivity and gravity of Insulation Breakdown voltage. The breakdown voltage began to stabilize at 40kV/mm and Acidity began to stabilize below 0.2mgKOH/g.

IV. CONCLUSION

The research work analyzes fifty (50) transformer samples within Port Harcourt metropolis. The result shows that twenty six (26) test samples of transformer insulating oil passed acidity test and twenty four (24) test samples of transformer insulating oil failed acidity test, this indicates that the transformer insulating oil from distribution transformers T2, T3, T4, T8, T14, T20, T21, T22, T25, T28, T30, T33, T34, T36, T39, T40, T41, T42, T43, T45, T46, T48 and T49 are in failed condition, which implies that oxidation leading to acidity of the oil has commenced in the transformers, the samples failed acidity test. This shows that contaminants, like sludge, were present in the oil from these transformers and reconditioning or replacement of the insulating oil is necessary for these sets of transformers.

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ADEBODUN, et. al. "Improving the Insulation System of Service Transformers Using Artificial Intelligence Technique."*American Journal of Engineering Research (AJER)*, vol. 10(8), 2021, pp. 285-291.