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Insulation Deterioration and its Effects on Power System

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Abstract: Insulation deterioration occurs on power system when insulators are subjected to abnormal stresses. The overall effect is the failure or breakdown of power system. The research is the investigation of the causes and effects of insulation deterioration in power system with particular reference to transformer mineral insulating oil. Fifteen samples of transformers insulating oils were collected from various sub-station distribution locations in Ilorin metropolis in Nigeria, through Power Holding Company of Nigeria (PHCN), Ilorin district office. Two major tests, dielectric and acidity tests were carried out on all the collected samples to access their level of deterioration. The authentication of the results was determined by comparing the experimental values with American Society for Testing and Mineral (ASTM) and British Standard (BTA4705) pre-requisites. While only four of the fifteen samples failed acidity tests, about ten samples failed dielectric tests. The overall results indicated that the distribution sub-stations of Nigeria Electricity Supply System lacked adequate routine checks despite stresses being experienced by some of the transformers due to overloading.

Key words: Insulation, deterioration, power system, ASTM, PHCN

INTRODUCTION

One of the major causes of failure of power system is the insulation breakdown. Insulation is the isolation between conductors of electrical power system. It may be solid, liquid, gas or vacuum. The insulation deterioration and its effects are two phenomena that must be familiar with by any Electrical or Maintenance Engineer if adequate safety of equipment and personnel and continuous service to consumers are to be maintained.

Deterioration of insulators occur as a result of ageing and stresses imposed on them during their normal working life. The end result of the occurrence is the damaging or shortening of the life span of electrical equipment being protected by these insulators. Occasionally personnel and environment in which such system is being operated are negatively affected. Also, the cost of replacement of the equipment is another effect that must not be overlooked.

Over the years, faults on power system have been increasing as a result of insulation failure. More so the failure causes various hazards among which are (Bello, 2004):

- Fire outbreak on power system.
- Back feeding on transmission and distribution system.
- Damage to equipment and properties.
- Personnel injury, fatal accident and loss of life and
- Unplanned expenses due to replacement.

In this research, insulation deterioration with particular reference to distribution transformer oil insulator will be considered. Distribution system serves as the major link between power supply authority and consumers of the electricity.

INSULATORS AND INSULATING MATERIALS

Insulator can be solid, liquid, gas or vacuum. A substance through which conduction of electrical current does not take place or is negligible and in which electric field can be maintained with minimum loss of energy is called a dielectric or insulating material (Mohammed, 2004; Smith, 1995). Polyvinyl Chloride (PVC) and Polyethethylene (PE) are examples of solid insulating materials used for cables and conductors. Ceramic is another insulating material used mainly for post-insulators and bushings. Their useful properties being high dielectric strength, high insulation resistance, low thermal conductivity, high tensile strength, etc (Looms, 1988).

Mineral oil and silicon liquid are common high viscosity liquid insulators used in transformers, circuit breakers, bushings and voltage cable. Also, there are Air (dry) and sulphur Hexa-flouride (Sf6) which are gaseous insulating materials used as insulating and arc-extinguishing medium. The non-flammability and non-poisonous characteristic of SF6 makes it more advantageous as arc-quenching medium in switchgears (Mohammed, 2004; Looms, 1988).

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INSULATION BREAKDOWN

The deterioration of insulation is one of the primary causes of electrical equipment failure. The breakdown of insulation occurs when there is a breakdown of dielectric. Few among major causes of insulation failures are (Bello, 2004; Mohammed, 2004; Ravi, 2005) cracks on solid insulators, contamination, moisture, humidity, corrosive vapour on liquid and gas insulators, excessive load, excessive voltage, stress due to overloading, vibration, etc.

Insulation breakdown in oil insulation: Two of the major factors responsible for the deterioration of insulating oil with particular reference to transformer oil will be considered. These are electrical stress due to persistent overloading of the transformer and chemical attack due to environmental contamination.

Determination of insulating oil due to electrical stress: Persistent overloading of the transformer results in the excessive heating of the oil. This usually results in reducing oil volume in the conservation tank or in particular, the burns of transformer oil. The effect of the later is the carbonization i.e., formation of carbon sediments inside the transformer oil. This process is explained using chemical Eq. 1 (Institute of Petroleum, 1987; Robert, 1997; Adejumobi, 2004).

$$2CH+O_2 \rightarrow CO+H_2O+C \qquad (1)$$

The hydrocarbon CH represents the transformer oil reacting with oxygen during burns. Equation (2) is another way of presenting Eq. 1, i.e.,

$$\begin{array}{l} H-C\ \ -C+O_2 \rightarrow CO+H_2O+C \\ \quad\ || \\ \quad\ H \end{array} \qquad (2)$$

From Equation (1) and 2, it is observed that CH reacts with Oxygen (O_2) which support the burns. These burns eventually result in the formation of Carbon-monoxide (CO) gas, water (H_2O) and Carbon (C) which are all dissolved inside the oil (Institute of Petroleum, 1987). The carbon acts as semi conductor which results in the reduction of the dielectric (Herald and Willism, 1992).

Deterioration due to chemical stress: Another major cause of deterioration of the mineral insulating oil is the chemical attack. The presence of oxygen and water due to moisture from the surrounding environment is another instrument responsible for the production of chemical substance in the oil.

When oxygen present in the atmosphere comes in contact with the oil, oxidation takes place which results in the formation of acid and sludge in the oil and hence loss of dielectric strength (Turan, 1998). Equations 3 and 4 explain the process of oxidation in dibutyl sebacate which is one of the additives (chemical components) used in the manufacturing of the transformer insulating oil (Institute of Petroleum, 1987).

$$\begin{array}{l} C_4H_9OOC(CH_2)_nCOOC_4H_9 \xrightarrow{O_2} \\ \quad \text{(Diibutylsebacate)} \\ HOOC(CH_2)COOH + 2C_4H_7OH \\ \text{(Sebacic acid)} \qquad \text{(Bu tan ol)} \end{array}$$

Or

$$\begin{array}{l} \quad O \qquad\qquad O \\ \quad || \qquad\qquad || \\ B_uO-C-(CH_2)_n-C-OB_u \xrightarrow{O_2} HO \\ \quad O \qquad\quad O \\ \quad || \qquad\quad || \\ -C(CH_2)_n-C-OH+2C_4H_7OH \\ \text{(Sbacic acid)} \qquad \text{(Bu tan ol)} \end{array} \qquad (4)$$

Where Bu is butyl and n is the number of molecules of Dibutyl sebacate. When reacts with water the transformer insulating oil additive dibutyl sebacate is hygrolysed (Institute of Petroleum, 1987) as in Eq. 5 and 6. i.e.,

$$\begin{array}{l} C_4H_9OOC(CH_2)_nCOOC_4H_9 \xrightarrow{H_2O} \\ HOOC(CH_2)_nCOOH + 2C_4H_7OH + 2H_2 \\ \text{(Sbaacic acid)} \qquad \text{(Bu tan ol)} \end{array} \qquad (5)$$

Or

$$\begin{array}{l} \quad O \qquad\qquad O \\ \quad || \qquad\qquad || \\ B_uO-C-(CH_2)_n-C-OB_u \xrightarrow{H_{2}0} \\ \quad O\ \ O \qquad\quad O \\ \quad ||\ \ || \qquad\quad || \\ HO-C-C(CH_2)_n-C-OH \\ \quad \text{Sebacic acid)} \end{array} \qquad (6)$$

Again, the formation of Sebacic acid if allowed to continue reduces the dielectric strength of insulating oil hence resulting to insulation voltage breakdown.

Determination of breakdown voltage and dielectric strength on transformer insulating oil: The dielectric strength of an insulator is the minimum voltage at which electrical failure or breakdown occurs under prescribed condition (Herald and Wilism, 1992). Or, it is the voltage at which breakdown occurs when applied between standardized electrodes at a specific temperature. The relationship between dielectric strength and Breakdown voltage of an insulator is given by Herald and Wilism (1992).

$$D_s = \frac{V_{bk}}{d} \quad (7)$$

Where D_s = Dielectric strength
V_{bk} = Breakdown voltage of insulator
d = Thickness of dielectric between the test electrodes, or Distance between test electrodes (usually in mm). The breakdown voltage value is usually dependent on the level of the amount of contaminant (usually moisture) that is present in the insulating oil.

Various tests are usually conducted on insulating oil by electricity supply authority (Turan, 1998) to ascertain the capacity level of the insulation. Two of these tests that describe the relationship in the Eq. 1-8, have been considered in this research. These are dielectric and acidity tests. Acidity test measures the amount of acid contents present in the insulating oil.

Dielectric test on transformer insulating oil: For the purpose of this test, the motor driven insulating oil tester was used. The machine is an analogue, consisting of test cell covering an electrode-holder holding two test electrodes 2.5 mm apart. The oil to be tested is carefully poured on the glass cylinder where 2 electrodes are inserted. The system is to be powered with 220-230 d.c. supply voltage.

A push button connected with the system to the voltmeter is provided to measure breakdown Voltage (V_{bk}). When the breakdown voltage has been reached, spark occurs between test electrodes, which is also accompanied by the tripping of H.V circuit breaker connected. The Dielectric strength is therefore calculated using expression (7).

It should be noted that for insulating oil to be effective when in service, it has been recommended that (Instittute of Pertroleum, 1987; Turan, 1998).

- For the 11/0.415 kV transformer, the minimum breakdown voltage of its insulating oil should not be less than 25 kV ; and
- For 33/0.415 kV transformer, the minimum breakdown voltage of its insulating oil should not be less than 45 kV.

Acidity test on transformer insulating oil: The acidity test measures the amount of the acidic contents presents in the oil. For the purpose of this analysis, the British Standard 4705 method (Insititute of Petroleum, 1987) is used hoping that acidic contents might be organic or inorganic. Seven steps are involved in this method of determining the acidity of the oil, with the following reagents used (Insititute of Petroleum, 1987).

- Standard Potassium hydroxide (kOH) solution, (alcohol, 0.1N); purity- 95% ethanol with silver oxide alloy.
- Phenolphthalein solution-0.5% alcohol and indicator.
- Ethyl alcohol 95% by volume as solvent.

Following the seven steps the acidity of the oil is determined using Eq. 8 (Insititute of Petroleum, 1987).

$$A_T = \frac{56.1NV}{W} \quad (8)$$

Where
A_T = Total acidity in mgkoH/g of the sample
V = Volume of Potassium hydroxide (KOH) solution in milliliters required to titrate the solutions of the above and the acidic oil.
N = Normality of potassium hydroxide solution
W = Weight of sample of oil in gramme
56.1 = Molar mass of KOH

For a functional insulating oil, it is required that (Institute of Petroleam, 1987) the molar gramme of KOH that will neutralize one gramme (1 g) of acidic insulating oil be equal to or less than 0.2 mg, otherwise the oil need reconditioning or replacement.

RESULTS AND DISCUSSION

Fifteen samples of transformer insulating oils were collected at different distribution substation locations in Ilorin metropolis through the Maintenance and Construction department of PHCN of Ilorin Distribution station. The collection were randomly done on old, fairly old and new transformers both on 11kV and 33KV distribution transformers. The dielectric and acidity tests were carried out by following the procedures described in section 3.1.3 to 3.1.5. Results of the tests were used to calculate the dielectric strength and acidity of the test samples, using expression (7) and (8). The results of the analysis showing the oil sample, the corresponding transformer types and ratings, measured breakdown voltage, calculated dielectric strength and the acidities are presented in Table 1.

From the results obtained it was observed that only samples A,C,H,K and L passed the two tests, i.e., are in good condition. Each one of the remaining 10 samples failed either of the 2 test or both.

Table 1: Results of dielectric and acidity tests

Oil sample	Transformer type (kV)	Transformer rating (KVA)	Breakdown voltage (kV)	Dielectric strength kV mm^{-1}	Total acidity mgkoH g^{-1} of oil	Remark
A	33/11/0.415	300	49.8	19.20	0.00	In good condition
B	33/11/0.415	300	41.3	16.52	0.06	To be reconditioned
C	11/0.415	100	33.3	13.3	0.06	To be reconditioned
D	33/0.415	200	37.5	15.0	0.10	To be reconditioned
E	11/0.415	100	14.5	5.80	0.20	To be replaced
F	11/0.415	250	27.2	6.90	0.30	To be replaced
G	11/0.415	100	36.6	5.50	0.35	To be reconditioned
H	11/0.415	100	27.8	11.12	0.10	In good condition
I	11/0.415	100	8.3	3.30	0.45	To be replaced
J	33/0.415	300	28.7	11.50	0.45	To be replaced
K	33/0.415	500	49.8	19.90	0.00	In good condition
L	11/0.415	300	30.0	12.0	0.06	In good condition
M	11/0.415	300	27.2	10.88	0.11	To be reconditioned
N	33/0.415	300	9.80	3.92	0.45	To be replaced
O	11/0.415	200	13.8	5.52	0.35	To be replaced

To be sure the results from the test were reliable, tests were repeated and the average value where used to obtain Table 1.

CONCLUSION

Insulation deterioration had been identified as one of the major causes of power system failure. The safety of power system equipment and its personnel would depend among other on the quality of insulation provided.

The transformer insulating oil deterioration and its effects had been presented in this research. Two major components, dielectric strength of the oil and its breakdown voltage for the fifteen collected samples of transformer insulating oil from various substation distribution locations in Ilorin metropolis, Nigeria have been observed.

Two major tests, dielectric and acidity were carried out on the collected samples.

Determination of the level of the quality of the insulating oil was measured by comparing the experimental results values with the recommended ones by the American Society for Testing and Minerals (ASTM) and the British standard (BTA 4705). While five out the fifteen samples passed both tests i.e., met the standard requirements, each of the remaining ten failed either or both.

The overloading of the transformers and lack of regular routine checks were two major factors identified as the causes of the reduction in breakdown voltage and the development of the acidic contents inside insulating oil. Most often checks were done only when there were faults.

Preventive maintenance and regular checks on the insulating oil and regular replacement of the oil as at when due possibly six month interval as it has been recommended (Bello, 2004) will go along way prolonging the life span of power system and providing quality service to consumers of electricity.

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