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Review

Distribution Transformer Failures In Port Harcourt

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Seventy-five percent of power consumed in Rivers State is within Port Harcourt city and about four thousand distribution transformers are spread within various distribution areas. These transformers range from 200KVA to 1.5MVA. Most of the transformers that have been installed about 25 years are usually taken out of service due to damage of various parts. Transformers have no moving parts and are designed to last for over 40 years. It is therefore necessary to look at the reasons of failures of the transformers. This will enable engineers to regulate and monitor the transformers for better performance. From the study it was clear that the problems were as a result of lack of care, unscheduled loading, and unbalance operation of the transformer and activity of the vandals (transformer oil). If good maintenance programmes is provided it will increase the life span of the transformer.

Keywords: Insulating oil, magnetostriction, Pressboard, Dielectric strength, radial and axial stress.

INTRODUCTION

A transformer is a static piece of apparatus and used for transferring power from one circuit to another without change in frequency. The physical circuits linked by a common magnetic flux through a path of low reluctance. According to the Faraday law of electromagnetic induction

$$e = M\frac{di}{dt} \qquad - \quad - \quad - \qquad (1)$$

Where M = mutual inductance, e = induced emf.

If the second circuit is closed, a current flows in it and electric energy is transferred (entirely magnetically) from the first coil to the other (Primary to Secondary). The instantaneous value of counter electromotive force (Lawson et al., 1977).

$$e_1 = -N_1 d\emptyset/d2$$

To obtain the rms values of counter emf e_1, the maximum value is divided by $\sqrt{2}$. Therefore, the result is

$$E_1 = \frac{2\pi}{\sqrt{2}}.fN_1\emptyset_m$$

It could finally be expressed generally as

$$E = 4.44fN\emptyset_m - \quad - \quad - \qquad (2)$$

(1 and 2 describe the primary and secondary).

Apart from active materials like copper and cold rolled grain-oriented silicon steel, a number of ferrous and nonferrous insulating materials are employed for building up of a transformer. Optimum utilization of all materials in consonance with their electrical, mechanical, physical, chemical and thermal characteristics is necessary for obtaining a compact size and efficient transformer operation (Sokolov and Vanin, 1974). These characteristics of transformer are given in table 1.

These characteristics determine the life of the solid and liquid insulations. In fact the life of the transformer is actually the life of the internal insulation system.

Another area of consideration is the electromagnetic forces in power transformer. The most sever mechanical stress occurs in a transformer when it is subject to a sudden short circuit.

Since the current flowing through the windings at that time is enormous, the forces generated are also enormous (Oommen and Lindgren, 2001 ; IEEE, 2007 ; Cigre, 2009).

Two main forces vectors are the radial force and the axial force.

Radial forces are those that act in the radial direction and are generated by the interaction of the current and the axial component of the leakage flux density. They tend to sequeeze the inner winding and burst the outer winding. The simple formula for radial force could be derived from the basic formula.

$$f = \bar{\imath} \times \bar{B} \times \bar{l}$$

The average radial force is

$$F_r = {}^{1}/_{2u_0} \times \frac{(NI)^2}{l} \times \pi D_m N \quad \text{---------} \quad (3)$$

The maximum force per turn will occur at the inner-turn of inner most layer of the outer winding and the outer turn of the inner winding and is

$$f_m = 2fr/N \quad \text{--} \quad \text{-} \quad \text{-} \quad (4)$$

Axial forces are those that act in the axial direction and are generated by the interaction of the current and the radial component of the leakage flux density.

The electromagnetic forces arising due to a short circuit are oscillatory in nature and act on an electric system immersed in oil and consisting of winding conductors, insulation components and clamping structures.

Attempts have been made to obtain empirical equations for the effective length of path of the radial leakage flux. The simplest of all these approaches is that of waters (Oommen and Lindgren, 2001). Considering that there is an unbalance of Ampere-turns (NI), the mean radial flux density (B_r) and is given by

$$B_r = \frac{u_0}{2} \cdot a \cdot \frac{NI}{l_{eff}} \quad \text{----------} \quad (5)$$

The axial force on the winding f_a is

$$f_a = \frac{\mu_0}{2} \cdot a \cdot (NI)^2 \frac{\pi D_m}{l_{eff}} \; Newton \quad \text{----------} \; (6)$$

A short circuit can result in severe radial and axial forces which can damage the insulation integrity. Axial forces are controlled by the proper preloading of the transformer coil during manufacture. The windings are preloaded to a pressure which is at least as high as the maximum calculated axial short circuit force. As long as the transformer clamping system maintains pre-load pressure the winding will remain tight during a short circuit event and should therefore not sustain any damage due to movement of the conductors (Kers, 2011), (Griffin, 1996).

Any change in the thickness of the materials in the winding and associated end insulation will change the pressure on the winding. The thickness of the conductor material will not change except for the thermal expansion and contraction during load cycles. The cellulose insulation material, being organic will change in thickness and elasticity over time resulting from the effect of moisture, temperature and aging (Kers, 2011), (Jalah and Abdallah, 2011)

It is known that materials which are purely elastic according to Hooke's Law bear a relationship between compression in materials and the pressure. This can be defined by the Modulus of Elasticity as

$$E = (\rho \times L)/\Delta L \quad \text{----------} \; (7)$$

Where E = modulus of elasticity (N/mm^2)
ρ = pressure (N/mm^2)
L = thickness of the material – mm
ΔL = change in thickness of material – mm

Electrical and Environmental Factors

It can be seen that insulation suffers mainly from processes caused by environmental factors such as thermal degradation, oxygen in oil, and moisture in the oil.

Moisture consist of free water that exist in three states

When the oil temperature changes several other parameters change as well. If temperature increases, there is an increasing number of water molecules that can dissolve in the oil before saturation occurs.

Besides that, the viscosity decreases and the conductivity of transformer oil increases.

The degradation of transformer paper has besides electrical stressing many other causes. Other degradation factors are temperature, oxygen, acids and contamination. Due to these factors, the state of the paper changes (Du et al., 2011).

In transformer insulation, moisture exists in the capillaries of cellulose. The conductivity of paper changes as the moisture content increases. This change in conductivity subsequently increases its tanδ (Du et al., 2011), (Doble, 1946) There is a balance between the moisture in the paper and the moisture in the oil. Moisture can dissolve better in hot oil than in cold oil. Combined with the hot conductors in a transformer, this will drain the moisture out of the paper into the oil. When the transformer cools down again moisture will go back from the oil into the paper. This is in fact a temperature

Table 1

Electrical	Mechanical	Physical	Chemical	
❖ Electric strength (Breakdown volt) ❖ Dissipation factor of unimpregnated paper at 105^{0}C ❖ Conducting paths	Tensile strength Enlongation at break % Internal tearing resistance Heat stability	Substance g.m^2 Moisture content Water absorption Air permeability Oil absorption Density g/cm^3	Mineral Ash Conductivity of 5% aqueous extract pH value chloride content of aqueous extract conductivity of organic extract	

dependent equilibrium reaction. Absorption of moisture by the paper does not occur in an equal measure and as such the moisture will diffuse in the oil, thus lowering the concentration gradient.

The water solubility for oil can be expressed in Arrhenius form as

$$log r_s = A - B/\tau \quad \text{---------- (8)}$$

Where, r_s is the saturation solubility of water in oil in ppm a

τ is the temperature in Kelvin

A and B are different coefficients

Insulating oil undergo oxidative degradation in presence of oxygen to give a number of oxidation products. The final products of oxidation are acidic materials that can affect the characteristics of insulating fluid as well as damage the components of electrical unit. The high temperature in due course causes the fluid to oxidize and ultimately produce sludge and soluble acid in sufficient quantity to impart its heat transfer and dielectric efficiency (Waters, M.), (Roth, 1936).

Sludge formation is the terminal stage of the determination process.

Common Faults Of Transformers In Port Harcourt District

These common faults are put in the following categories:

- ❖ Damage to winding (HT or LT or both)
- ❖ Failure of winding insulations
- ❖ Ingress of moisture or water
- ❖ Loss of phase
- ❖ Low voltage on a phase or all the phases
- ❖ Drying up of oil or leakage of oil

These faults were identified as faults due to external or internal causes or both. More than fifty (50) percent of the existing transformers are as old as twenty-five years or more. Presently, several distribution transformers were installed to reduce the load on the existing ones and to take care of the incoming load. This is a welcome development but it was identified that the causes of failure was contributed by relatively lack of proper maintenance or neglect. The other factors were excess overloading and short circuits within and near the transformer.

In overloading the temperature rises due to the resistive losses (I^2R), stray, and eddy current losses. The increasing temperature greatly influences the properties of the insulation and the oil surrounding it. The heating up of the oil have consequences for multiple parameters:

- ❖ Moisture goes from the paper to the oil
- ❖ Increasing solubility
- ❖ Increasing conductivity
- ❖ Decreasing viscosity of oil

Due to the heating, the decreasing moisture level of the paper and the increasing moisture level of the oil cause the following:

(i) Increase tanδ of oil
(ii) Decrease breakdown strength of the oil
(iii) Increasing breakdown strength of the paper.

In short circuit condition whether external or internal, depending on the severity of the short circuit and the effectiveness of the protective devices may cause damage to the transformer winding. Also in certain cases, it may cause electrodynamic vibrations which may results to lose ends.

The electromagnetic forces arising due to a short circuit are oscillatory in nature and act on winding conductors, insulation components and clamping structures. Such forces dynamically transmitted to various parts such as conductors, and supports, press plate and clamps.

Failures due to these forces (axial and radial) could cause loss of a phase(s).

Ingress of moisture or water to the transformer is a regular occurrence in most transformers in the district. This is due to weather condition and the Algae growth on insulating rubbers gasket, bushing and the external contacts. The ingress of moisture, combined with high temperature in the paper insulation reduces the dielectric strength of both the cellulose materials and transformer oil. Excessive moisture in the insulation causes partial discharges within the moisture-soaked cellulose paper reducing its effective life.

Drying of oil is a clear indication of lack of care or it may be as a result of theft but such act is possible to cause a transformer life to be shortened. Several experiments have be done regarding mixing of oils. The results indicate that the oil of two different sources though conforming to the same standards should not be mixed as the sludging properties of the oil are considerably affected by mixing. Another pit fall is the opening of the winding to air as it absorbs moisture from the air. This is possible even with oil opened to the air. The dielectric strength of oil is appreciably diminished by even minor quantities of solid impurities and dirt present in the oil. Therefore proper storage facility as well as care is needed in handling the transformer, oil and other accessories.

CONCLUSION

Due to the climatic conditions of the Niger Delta the life of a transformer could be reduced if proper maintenance programme is not adopted. Normally, the causes of damage transformers could be any one of the following – surge voltage, heavy leakage of oil loose connection, ingress of moisture by loose gasket or non replacement of silica gel, poor earthing, overloading, LT. line faults, inadequate protections against overload, short circuit and lightning.

Failure of transformer can also take place if proper care has not been taken during its erection. While receiving the transformer unloading, storing and assembling, the instructions of the manufacturer should be followed strictly. If the transformer is received with oil inside, all care as if the transformer is in service, is required with nitrogen gas. A strict watch is required on maintenance of pressure and purity of gas, all the time the transformer is stored. The auxiliary equipment such as radiators, conservator, piping explosion vent are to be stored with proper care.

If the erection and commissioning is done properly, maintenance is required on the transformer to judge the performance in service. It consists of regular inspection, testing and reconditioning whenever necessary.

RECOMMENDATIONS

- Oil level should be checked at frequent intervals and if necessary conservator should be topped up. Dielectric strength does not give a true indication of the correct condition of the oil, it is therefore necessary to carry out the required chemical test.
- The inside of the conservator should be cleaned periodically. A detachable end plate is provided to facilitate cleaning on all power transformers. Oil indicator glass should be kept clean and its holes at top and bottom be kept cleaned so that oil level is clearly and correctly visible.
- Breather should be inspected frequently especially in this environment that temperature and humidity changes considerably, as transformer is subjected to fluctuating load. The oil level in the oil seal must be maintained at the level marked in the cap.
- The diaphragms fitted at the exposed end and inner end of the explosion vent should be inspected frequently and replace if damaged. Failure to replace the outer diaphragm quickly will allow ingress of moisture to the oil.
- Porcelain insulators and connectors should be cleaned at convenient intervals and minutely examined for any cracks or other defects.
- There should be regular yearly maintenance.

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