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Evaluation and Analysis of Frequency of Transformer Failures.

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Abstract

The frequency of failed distribution transformers in Power Holding Company of Nigeria Plc, Akpakpava Business Unit network, Benin City, for a period of two years have been investigated in this work. The frequent power outages recorded in our communities resulting in customers dissatisfactions, economic losses, frustration, complains and demonstrations and wanton destruction of government properties call for concern and investigation. Transformers that dropped J&P fuses causing electric power supply interruption were tested to ascertain if the incipient or thorough fault that must have resulted in open-circuit or short-circuit fault current flowing through the device has damaged it so as not to reclose on fault which could be catastrophic. Logbooks containing complains at the different service units dispatch office were used for the study. The study revealed that in 2005, out of the 390 transformers in the network on load, 26 representing 6.67% failed, while in 2006 out of the 460 transformers in the network on load, 28 representing 6.10% failed the essential tests conducted and so they could not be energized to restore power to the customers connected to them. On opening the failed transformers to ascertain the level of damage, 53 representing 99.00% of the total 54 transformers that failed in the period under review had burnt-coils, while the remaining 1 representing 1.00% had burnt tap changer. The work also revealed that 30 representing 56.00 % of the failed transformers were operating in the wear-out period of their useful-life, 10 representing 19.00% of the failed transformers had no name plate, while the remaining 14 representing 26.00% failed in their useful life period. Since the transformers failed the essential tests the insulating medium (i.e., oil) were not tested in all the cases to ascertain the degrading level of its dielectric strength. The investigation also showed that the failure rates fell within the failure rates accepted in developing nations in the world.

Keywords: Practical Transformers, Frequency of Failure, Failed Transformer, Power Supply, Failure Rate, Stress, Losses, and Reliability.

Nomenclature

ASAI: Average System Availability Index
BIL : Basic Insulation Level
CAIDI:Customer Average Interruption Duration Index
DGA :Dissolved Gas Analysis
GDP :Gross Domestic Product
GNP : Gross National Product
HV : High Voltage
LV : Low Voltage
MTBF: Mean Time between Failures
MTTR: Mean Time to Restoration
PHCN: Power Holding Company of Nigeria
SAIDI: System Average Interruption Duration Index
SAIFI: System Average Interruption Frequency Index
SM : Safety Margin

List of Symbols

$\bar{\phi}_m$ = alternating maximum magnetic flux in the laminated iron core, which is constant at all load

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V_p; V_s = primary applied voltage fixed by a.c. supply voltage; secondary terminal voltage
R_p = resistance of primary coil of the actual transformer
R_s = resistance of secondary coil of the actual transformer
X_p = primary self-inductance (reactance)
X_s = Secondary self-inductance (reactance)
I_p = current draw from the supply to produce a flux $\bar{\phi}_m$ equal and opposite to $\bar{\phi}_2$
I_o = no-load current in the primary which is the phasor sum of I_m and I_c (I_o = constant and independent of the load, usually 3-5% of the full-load primary current)
I_c = power-loss component in phase with V_p
I_m = Magnetising or reactive current which produce the magnetic flux $\bar{\phi}_m$ which Lag V_p by 90^o
R_c = Resistance of the core-loss component
R_m = Magnetising inductance (or inductive reactor)
I_p^1 = Current flow in the primary of the ideal transformer (= $I_s\left(N_s/N_p\right)$), also called the secondary current referred to the primary.
N_p = number of turns in the primary circuit
N_s = number of turns in the secondary circuit
I_s, I_L = secondary or load current respectively
B = magnetic flux density
l = mean length of path
H = magnetic intensity
μ_o = relative permeability
$\bar{\phi}_o$ = no-load phase angle
$Cos\phi_o$ = no-load power factor (=I_c/I_0), which is usually very low
ϕ_s = Secondary phase angle
$Cos\phi_s$ = load power factor
$\bar{\phi}_p$ = primary phase angle
$Cos\phi_p$ = primary power factor
$R_{es} = R_s + R_p\left(\frac{N_s}{N_p}\right)^2$; Equivalent resistance with primary winding resistance referred to the secondary per phase
$X_{es} = X_s + R_p\left(\frac{N_s}{N_p}\right)^2$; Equivalent resistance with primary winding resistance referred to the secondary per phase
V_{Tap} = test applied voltage at the transformer primary,
V_{RP} = transformer rated primary voltage,

1. Introduction:

Electricity is generated in most parts of the world using conventional methods such as; nuclear fission, geothermal, hydro schemes and thermal plants etc., in bulk form. The Nations owned hydro schemes and thermal plants and the independent power plants are all located in the remote parts of the country where the generated power cannot all be utilized or conserved, thus arise the need to evacuate the surplus power at suitable voltages to various load points for consumption. In Nigeria electric power is made available to end users using either underground or over head lines supported by steel towers called transmission lines motivated by technical and economic reasons. The nation's grid covers considerable distances for primary power transforming and/or switching substations (330/132/66/33kV switch yard) located at reasonable and suitable points considering lines congestion, economic costs and power security. From the various high voltage switch yards power is further transmitted and distributed at secondary voltages (33/11/6.6/3.3/0.415kV) to various points of utilization. Transmission and distribution of electric power involves primary and secondary transformation of high and low voltages in accordance to the nation's acceptable standard using appropriate equipment known as transformer. This equipment can be classified in different forms based on its mode of operation. Power and Distribution transformers are installed over the whole load areas so that the length of cables, cross section and losses are kept within economic limits [1].Transformer is a major power- system component that permits economic power transmission with high efficiency and low series-voltage drops [2]. This study is limited to the availability of power and distribution transformers in networks. The dependability on power systems for sustainable development also depends on other auxiliary equipment such as circuit breakers, wave traps, line switches, and the type of protection schemes put in place etc. For an electric utility provider to supply reliable, quality and secured electricity to end users trouble free functioning transformers and its associated auxiliary equipment has to be guaranteed, therefore their prompt and adequate maintenance can lead to huge energy savings and uninterrupted power supply the back-bone of gross national product (GNP) and gross domestic product (GDP) index values of a nation. In Nigeria experience has shown that most utilities provider do not maintain logbooks for the operation of its practical distribution transformers, but maintain skeletal routine/scheme maintenance records for the power Transformers with no reliable diagnostic test to asses the internal (incipient) condition of transformers except the dissolved gas analysis (DGA) test of the transformer oil resulting from either local overheating, partial discharge or arc discharge in high voltage transformer. Insulating materials decomposes into gaseous state such as hydrocarbon of (ethane, ethylene, and acetylene) and gases (hydrogen and carbon dioxide), which are high inflammables; this has resulted in several burnt transformers. Transformer is a system made of up of sub-systems assembled to obtain the desired objectives, therefore the overall reliability to a very large extent depends on the reliability of the individual parts that make up the static device. Transformer is characterized by a base MVA rating based on maximum-hot-spot temperature of a constant load at a specified ambient temperature, and by impedance expressed as a percentage rating [3]. Thus designers and manufacturers of this very important component in power system networks have to ensure the individual components can cope with the subjected stress. Therefore component load-strength model analysis and engineering variability process becomes very important in the system engineering reliability, such that, the safety margin (SM) is guaranteed [4]. Technically, the size, rating and operational capability of transformers depends on several factors which are also contributing factors to the system reliability. Transformer failure rate of the order of 6.00 – 8.00% is generally acceptable [5]. The dissatisfaction and both financial and economic confusions caused by failed transformers vital equipment in the nation's development to consumers calls for the study. Section 2 presents the device principles of operation, some equations that determine its practical certainty and stresses and losses that affect its operation. In section 3 faults and tests associated with practical transformers are highlighted, while in section 4 data's obtained from the tests results, analysis and minimising failure rate is presented. Section 5 of this paper concludes the case study.

2. Principle of operation

Transformers are static electromagnetic devices that transform electric energy from one level to another based on the transformation ratio. It operates on the principle of Faraday's Law of electromagnetic induction. Figure 1 presents the simplified equivalent circuits of a practical transformer.

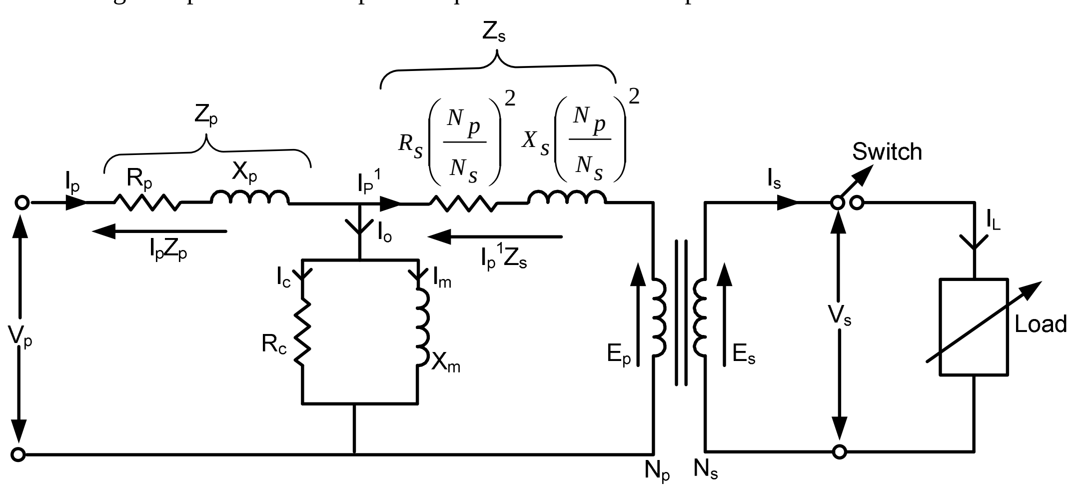

Figure 1: simplified (exact) equivalent circuit of a practical transformer

Some of the basic equations that ascertain the availability of this device whether of the core or shell type (less reactance, heavy currents used to supply electric furnaces) are [6, 7, 8, 9, 10, 11];

$$E_{p,}E_s \equiv E_{rms_{3-\phi}} = -N_p N_s \frac{d\overline{\phi}_m}{dt} = 444 f \overline{\phi} N_{p,s,} \text{ volts} \tag{1}$$

$$E_{p,}E_s \equiv E_{rms_{1-\phi}} = 2.22 f \phi N_{p,s,} \text{ volts} \tag{2}$$

Under ideal condition where there are no losses, no magnetic leakage, and infinite permeability requiring no magnetizing current, E_p and V_p are in phase. For all practical purposes, it can be said that the voltage and current ratios of a transformer is the same as the turn's ratio, thus;

$$\frac{V_s}{V_p} = \frac{E_s}{E_p} = \frac{I_p}{I_s} = \frac{N_s}{N_p} = n \tag{3}$$

Open-circuit and short-circuit tests enables the exact equivalent circuit parameters determination for its performance characteristics on-no load and load conditions. The difference between V_p and E_p is only about 0.05% when the transformer is on no load. The direction of induced e.m.f. in the secondary winding opposes the cause (Lenz's Law) and therefore, alternate at the frequency. Neglecting no-load current (excitation current), the total ampere-turns of primary winding are equal to the total ampere-turns of the secondary, meaning volt amperes remain constant. Therefore with extremely small loses, the output power is almost equal to the input power given by;

$$\sqrt{3} V_p I_p Cos\phi_p = \sqrt{3} V_s I_s Cos\phi_s \tag{4}$$

$$V_p I_p = I_s V_s \tag{5}$$

A highly permeable magnetic core, that the reluctance of the magnetic path is low results in efficient operation of a transformer. Under steady –state conditions, a single-three phase transformer operates exactly the same way as three single-phase transformers connected together [8]. For practical transformers the gross area of the core is about 10% greater than cross-sectional (net) area of the core to allow for the insulation between the insulations. The total magneto motive force (m.m.f) for the core (=Hl), the magnetomotive force for the equivalent air-gap (= $B/\mu_o l$), considered, the total m.m.f. to required produce the useful maximum flux density which remains almost independent of the load is given by the relationship;

$$Bmax = Hl + B/\mu ol \tag{6}$$

Depending on the rating (i.e. one, two or three ratings), transformers could be Oil Natural Air forced (ONAF) or Oil forced Air forced (OFAF) cooled, Water cooled, Air blast cooled [6, 7, 8, 9, 12]. The Insulation between the H.V. and L.V. windings and between L.V. winding and core, comprises bakelite paper cylinders or elephantide wrap, while the insulation of the conductors may be of paper, cotton or glass tape. All the tested power and distribution transformers have in built tap-changers which could be operated off-load and on-load depending on the engineering process put in place to control the network bus voltages. Table 1 shows the different tap positions at which the transformers were operated till they failed. The device percentage regulation can be selected using the relationships;

$$\text{Percentage regulation} = \frac{E_s - V_s}{E_s} \times 100 \tag{7}$$

$$= \frac{I_s \left(\mathrm{R_{es}} \mathrm{Cos}\phi_s \pm X_{es} \sin \phi_s \right)}{E_s} \times 100 \tag{8}$$

Since very good design make core loss (P_i) to be constant and the eddy current losses to be exceedingly small that it can be neglected, the only significant transformer losses (P_c) can be accounted for by the following expression;

$$P_c = I_p^2 R_p + I_s^2 R_s = I_s^2 R_{es} \tag{9}$$

In this wise, efficiency of the commonest commercial transformer can be determined using;

$$\text{Efficiency } (\eta) = 1 - \frac{losses}{input} = 1 - \frac{lossess}{output + losses} = \frac{P_c + P_i}{P + P_c + P_i} \tag{10}$$

$$= 1 - \frac{3I_{phs}^2 \mathrm{R}_{es} + \mathrm{P}_i}{1.732\mathrm{V}_s I_s \cos\phi_s + 3I_{phs}^2 R_{es} + P_i} \qquad (11)$$

Equation (11) is maximal when the variable $I^2 R_{phs}$ loss is equal to the constant core loss. The value of the apparent power at which the efficiency is a maximum is independent on the load power factor. Practical transformers continuously have a steady-core-loss rate. The annual cost of losses therefore depends on the hour-to-hour variation in the transformer loading. Thus the device energy efficiency depends on the load factor and the $I_{ph}^2 R_{es} / p_i$ ratio chosen in accordance with the type of load. The I_0 is usually less than 5% of the I_{FL}, so that the $I^2 R_{phs}$ loss on no load is less than 1/400 of the primary $I^2 R_{phs}$ on full load. The nearer the transformation ratio is to unity, the cheaper the cost of conductor material. The $I^2 R_{phs}$ loss in the auto-transformer is lower and the efficiency higher than in the two-winding transformer. Power transformers covered under IS 2026-1962 are designed to have considerable leakage reactance than is permissible in distribution transformer because of its inherent voltage regulation is not as much important as current – limiting effect of the higher leakage reactance's. Power transformers usually make use of flux density of 1.5 to 1.77; have percentage impedance ranging from 6-18%; and regulation 6-10% [5]. Any device subjected to loading conditions will experience some form of stress, which not controlled can result in one form of fault. Stresses associated with practical transformers are;

(a) **Dielectric stresses: resulting from;**

i. Continuous service voltage and occasional temporary over voltage,
ii. Occasional lighting surges, voltage spikes, line faults / flashovers,
iii. Occasional switching surges, and
iv. Sustained overloading and fault current level.

(b)Temperature stresses: arising from;

i. Losses during normal load cycle and occasional over load,
ii. High ambient temperature,
iii. Alternate temperature cycle,
iv. Undue harmonics,
v. Repeated external short circuits, and
vi. Failure of cooling system.

(c) Mechanical stresses: arising from;

i. During handling / transportation,
ii. When the system encounter, mechanical vibration,
iii. During tap-changing or tap-charger's / part failure, and
iv. During repeated external short circuits (on windings, core, and insulation system).

(d)Environmental stresses: due to;

i. Dust, moisture, chemical deposits, and
ii. Alternate/ External temperature.

For practical transformers to be highly efficient and reliable designers must plan and design them based on permissible stresses and required factor of safety. To reduce these stresses in order to elongate the useful life of costly transformers effective external means employed are:

i. Dynamic voltage regulation of the network buses voltage in times of temporary over voltages,
ii. Use of adequate protection devices such as circuit breaker, wave traps, surge arresters in cases of switching over voltage, lighting surges and thunder stroke,
iii. Use of effective cooling control systems to reduce temperatures stresses,
iv. Effective inspection, monitoring, and maintenance,
v. Incorporate into the network buchholz relays, over current, earth fault and differential protection schemes based on the rating and cost of the transformer and
vi. Ensuring appropriate system design and manufacture so as to reduce short circuit fault levels.

Transformers static by its design is one of the most efficient energy converter, and like every other machinery experience losses which reduces their efficiencies, Ideal transformer with infinite permeability, no energy losses is said to be 100% efficient, but in practical transformers energy is dissipated in the windings (copper losses), core (iron losses) and surrounding structures. Larger transformers have been found to be more efficient (about 98%) than smaller transformers. Losses associated with transformer usage are [6, 7, 8, 10];

i. Copper losses; which are affected by the supply frequency, skin effect and proximity effect,
ii. Hysteresis losses; proportional to the supply frequency and it's a function of the device magnetic flux density,
iii. Eddy current losses; which is a complex function of the square of supply frequency and inverse square of the material thickness,

iv. Magneto-strict ion losses; due to frictional heating in susceptible core resulting from the magnetic flux,
v. Mechanical losses; due to vibrations of metal work as a result of the alternating magnetic field causing fluctuating magnetic force between the primary and secondary windings, and
vi. Stray Losses; resulting from leakage flux that intercepts nearby conductive materials such as transformers support structure and the give rise to eddy current and be converted to heat loss.

3. Faults and Tests Associated with Practical Transformers

Transformers on load and no-load are prone to normal and abnormal faults which often leads to its failure resulting in interrupted power supply. Early detection of faults results not only in large saving in both operation and maintenance costs but also prevents premature breakdown, besides improving the overall system reliability. Inspection and various tests are conducted during prototype design, manufacturing, delivering and installation stages of electrical equipments. Inspection, testing and / or maintenance of equipment ensure proper operation and minimize the probability of failures. Operational tests verify transformers capability to withstand thermal, dielectric, short-circuits, electro-dynamic and environmental stresses in conformity with the technical data and manufacturers specifications. During these test defects in the parts counts and materials reliability are established in conformity with known standards (electrical installation regulation 12 – 18 of the electricity act). For very complex systems such as power transformers risk and safety analyses are also integrated to guarantee their continuous availability in the network. For all the tested transformers to minimize Leakage flux the low-voltage windings were placed inside the high voltage windings. Depending on the electric power projects tests conducted could be any of the following [1, 10, 12, 13, 14, 15]:

i. Insulation resistance test; (to ensure the system capability in times of transient over voltages occurring due to switching, lighting strokes etc) of the windings and oil, feeder pillars, cables, lighting arresters etc., are not shorted to the earth portions,

ii. Short-circuit test; (enables the device actual capacity or rating in withstanding on due pressure/stress); the impedance of the transformer windings expressed in percentage is used in evaluating this capacity. Expressed mathematically it's given by;

$$Z\% = \frac{V_{Tap}}{V_{RP}} \qquad (12)$$

iii. Transformation ratio tests; (to ascertain their voltage ratio i.e. step-up/step-down so as to avoid over or under voltage which causes damage to the equipment within the grid/network and more importantly, in the consumers premises),
iv. Transformer oil, SF6 etc., dielectric strength test; (i.e. to ascertain the break down insulation level (BIL) of the insulating medium and thus ascertain its suitability for use in the transformer), transformer basic insulation level (BIL) is the peak transient voltage level that the device can withstand for a specified times (5-30 times the insulation class), while the insulation class of the transformer is the maximum root mean square (rms) working voltage of the transformer,
v. Excitation test; (to verify the true state of the insulation medium of the transformer winding),
vi. Earth Resistance test; (in the case of earth resistance test, earth resistance of below 2ohms is recommended for injection substations, while 5ohms is an acceptable value in the distribution network), this enable the effective operation of the protection schemes in order to avoid high step and touch voltages,
vii. Vector group verification test; (it confirms the name plate vector group as specified by the manufactures),
viii. Phasing and polarity (Flick) test; (confirm the correctness of the terminal marking of the transformers). This test is not applicable to zig-zag transformer windings,
ix. Leakage impedance and load loss or Circulating current (Impedance voltage) test; (its used to determine the efficiency and regulation of transformers),
x. Continuity test; (it confirm that there is no open circuit in the winding of the transformer),
xi. Temperature rise test (measured during the performance of a heat-run, to observe that the temperature – rises of the various parts conform to specification: B.S.171 1936, and
xii. Magnetising current and core loss test.

4.0. Data presentation/Analysis

The operational functionality of transformers installed in Akpakpava business unit for the period of 2005 to 2006 was used in this study. The data's gathered and tests results from the transformers that dropped J & P fuses are presented in Table 1. From Table 1, 30(thirty) out of the 54(fifty-four) transformers that failed test were found to be operating in the wear-out period of the device useful life span which is taken as 25years. 14 (fourteen) out these transformers were manufactured in the late nineties to 2004, while the remaining 10 (ten) transformers have no data (name) plate. From the several tests results and general remarks contained in Table 1 reasons while the transformers can not be energized to supply power to the consumers becomes very glaring. Table 2 presents the transformers failure characteristics and the frequency of failure, while Table 3 presents the financial implication to the utility body. From the tests conducted and results obtained the failures could be attributed to the following reasons:

- lightning surges,
- Failure of system component parts, (such as, cores, yokes, adjacent clamping structure, windings, terminal gears, structural defects etc)
- Deterioration of the transformer oil dielectric strength which samples were never tested to ascertain the present state of break-down insulation level,
- Oil leakage resulting in acute shortage,
- Sabotage and undetermined causes,
- Overloading above the full-load capability, especially in the cases of transformers without name plate,
- Lack of adequate maintenance,
- Undue noise resulting from magnetostriction, the degree of mechanical vibration developed by the laminations, the mechanical vibration of tank walls and the damping [12]
- Loose connections,
- Line surges/External short-circuits,
- Moisture accumulation,
- Poor workmanship/Manufacturer defects, abnormal operating conditions,
- Ageing in the component parts.
- Under the influence of the electric field, foreign substance, (dust, moisture or metallic particles, have a tendency to arrange themselves in radial lines, giving rise to paths of low dielectric strength, with consequent danger of breakdown [12]

The rate of failure of the loaded transformers in the network for the year 2005 and 2006 respectively was found to be;

For the year 2005; $$\frac{26}{390} \times 100 = 6.67\%$$

While for the year 2006; $$\frac{28}{460} \times 100 = 6.10\%$$

These figures 6.67% for 2005 and 6.10% for 2006 falls within the standard value of 6.00 -8.00%. To reduce this reliability index further the following points can mitigate the frequent failure of practical transformers drastically if the network operators adhered to them:

- Integrating maintenance schedule into the operation of transformers,
- Constrain the connected load within the design limit,
- Monitoring the top oil temperature, especially in power transformers,
- Frequent inspection of the silica-jar and treat accordingly to remove moisture which decrease dielectric strength of insulating mediums up to 50%,
- Operate transformers in line with technical and manufacturers guides; whether outdoor, indoor or pole mounted,
- Put in place the desire protection schemes for optimal operation of the transformers,
- Testing of the transformer oil, SF6, after certain hours of usage to ascertain their dielectric strength,
- Use of bakelite tubes to surround the conductor concentrically to break up radial chains of semi-conducting particles,
- Use of standard designed and manufactured components parts,
- Gas-in-oil analysis should be performed annually to measure the dissolved gases in the oil that are created by faults within the transformer. The specific gas and volume identify the type of fault,
- Tests such as; insolent, acidity, interfacial tension e.t.c., of the fluid should be conducted annually,
- Inspection and regular cleaning of the porcelain bushing and insulators,
- Regular check of the radiators, fins for leakage, rust, dust accumulation and any mechanical damage that could resist flow of oil or gas,
- Inspect and maintain the tap-changers and other ancillary equipment regularly,
- The transformer windings, bushings, arrestors should be tested at most every three years,
- Harmonics test should be conducted on the transformers regularly,
- Regular inspection of the grounded point connections and monitoring of the earth resistance value,
- Routine check of the electrical and mechanical tightness of connections and joints,
- Correcting the power factor of the network close to unity because this will reduce the total device losses this prolonging the insulation's useful life,
- Regular vegetation management (often referred to as tree trimming) on two to five year cycle, and

- Precautions to be taken in the application of transformers on load and the factors that can impair transformers performance are highlighted in [16].

- Electric power utility providers should put in place vibrant maintenance management system the can reduce reliability indices to standard acceptable values.

From Table 3 net financial loss to PHCN for the two years reviewed is #104,730,000.00 Million (one hundred and four million, seven hundred and thirty thousand naira only) using the prevailing market prices. This huge financial loss to replace the failed transformers in the network not check and control by management will defeat the essence of cost/benefit ratio greater than unity the bench mark for any financial establishment. This financial loss not properly matched with reliability indices such as; SAIFI, MTBF, MTTR, etc. will continue to result in energy lost, customers dissatisfaction and reduce cash collection.

Table 1: Summary of failed Transformers Test Results Carried out in Akpakpava Business unit, PHCN, Benin City, Nigeria

Date of Test	Name of substation	Transformer Data			Open Circuit (Continuity) Test (A)	Insulation Resistance Test (B)	Ratio Test (Single Phase) (C)	Single Phase (Excitation) Test (D)	Cable Text (E)	Feeder Pillar Test (F)	Earth Resi-stance (G)	Oil Sample Test (H)	General Remark
		Name	Year of Manu.	Rating									
11/03/05	Zomi-Zomi	Elin	1982	300KVA, 11/0.415KV	Continuity tested not okay	Insulation tested not okay	Unacceptable ratio test values	Unacceptable Excitation characteristics	HV/LV Cable tested Okay	-	-	Nil	The "TX" failed test A – D and cannot be energized
18/05/05	Amube	Mitsubishi	1980	500KVA, 11/0.415KV	Continuity tested okay	Insulation tested okay	okay	Okay	HV/ LV cables tested okay.	Nil	Nil	Nil	Oil leakage observed at both HV and LV sides of the "TX" crucial oil shortage. The "TX" cannot be energized
19/07/05	Stadium Road	Alstom	2001	500KVA, 11.415KV	Continuity tested okay	HV/LV Insulation tested not okay	Unacceptable ratio characteristics	Excitation characteristics not okay	HV and LV cables tested okay	-	-		The "TX" failed tests B – D and Feeder pillar need to be maintained. It cannot be energized
21/07/05	Aduwawa I	Nuova Conato	2002	500KVA, 11/.415KV	Continuity not okay	Insulation too low, not okay	Unacceptable ratio characteristics	Excitation characteristics Unacceptable	-	-	-	Nil	"TX" failed all tests cannot be energized.
26/07/05	Forestry II	Pauwel Trafo	Nil	300KVA, 11/0.415KV, No. of Taps (5),	Continuity tested okay	Insulation between HV/LV tested not okay	Unacceptable ratio characteristics	Excitation characteristics Unacceptable	HV and LV cables tested okay	Not okay	Nil	Nil	The "TX" failed tests B, C, D and F and cannot be

				Tap used (3)									energized.
03/08/05	Umagbae	Brush	1983	500KVA, 11/0.415KV No. of Taps (6), Tap used (2)	Continuity test not okay	LV/E Insulation not okay (grounded)	Unacceptable ratio characteristics	Unacceptable Excitation characteristics	LV Cable Blue Phase not okay, HV Cables Okay	The neutral bar not earthed	Okay	okay	The" TX" failed test A – D and LV Blue phase cable not okay. The TX cannot be energized

"TX" ; Transformer, HV; High voltage, LV; Low voltage, E; Earth, R; Red phase, Y; Yellow phase, B; Blue phase

Table 1 Contn

Date of Test	Name of substation	Transformer Data			Open Circuit (Continuity) Test (A)	Insulation Resistance Test (B)	Ratio Test (Single Phase) (C)	Single Phase (Excitation) Test (D)	Cable Text (E)	Feeder Pillar Test (F)	Earth Resis-tance (G)	Oil Sample Test (H)	General Remark
		Name	Year of Manu.	Rating									
05/08/05	Bins Hotel	Brush	1983	500KVA, 11/6.6/0.4, 15KV,50Hz No. of Taps (6), Tap used (2)	RY, YB phases of the primary side not continuous	Insulation Breakdown not okay	Unaccep-table ratio values	Excitation characteristics not okay	Both the HV and LV cables tested okay.	Nil	Nil	Nil	The "TX" failed all the tests carried out. It Gushed out oil from the Top and all the primary**
10/08/05	Idiado	Trafo Union	1986	200KVA, 11/0.415KV No. of Taps (6)	Continuity tested okay	Insulation tested not okay	Unacceptable ratio test values	Excitation characteristic not acceptable	HV/LV Cable tested Okay	-	-	Nil	"TX" failed test B, C & D. It cannot be energized
22/08/05	Water Board	Transfix	1997	500KVA, 11/415KV, No. of Taps (7), Tap used (5)	Continuity tested okay	Insulation resistance tested okay	Acceptable ratio test values	Acceptable excitation test values	HV cables insulation okay, LV cables insulation not okay	_	_	Nil	The "TX" tested okay, but the LV cables insulation too low. It cannot be energized.
25/08/05	Urora II	Mitsu-bishi	1978	300KVA, 11/.415KV No of Taps		Continuity tested okay	Insulation tested okay	Unacceptable ratio test values	Excitation	HV/LV cables	_	Nil	"TX" failed test C&D, so cannot be energized

				(5), Tap used (3)					characteristics unacceptable	tested okay			
03/09/05	Uyiosa	Minel	1979	300KVA, 11/0.415KV	Continuity Tested okay	Acceptable insulation values	Unaccep-table ratio character-istics	Excitation characteristic Unacceptable	HV Cable Red Phase value is low	-	-	Nil	"TX" failed tests C & D and cannot be energized.
03/09/05	Ogiemudia	Alsthom	1983	300KVA,11/ 0.415 KV, No. of Tap (6) Tap used (3)	Continuity tested not okay	HV/Earth insulation not okay (grounded)	Unaccep-table ratio test values	Excitation characteristics Unacceptable tripped the Generator Set.	HV/LV cables tested okay	-	-	Nil	Transformer failed test A-D. It cannot be energized.
04/09/05	Okah V	London	1962	500KVA, 11/0.415KV	Continuity tested not okay	Insulation tested not okay (grounded)	Unaccep-table ratio test	Excitation characteristic Unacceptable	HV and LV cables tested okay	-	-	Nil	"TX" failed tests A – D and the earthing needs to be improved on. It cannot be energized.

Table 1 Contn

Date of Test	Name of sub-station	Transformer Data			Open Circuit (Continuity) Test (A)	Insulation Resistance Test (B)	Ratio Test (Single Phase) (C)	Single Phase (Excitation) Test (D)	Cable Text (E)	Feeder Pillar Test (F)	Earth Resistance (G)	Oil Sample Test (H)	General Remark
		Name	Year of Manu	Rating									
27/09/05	Noma Relief S/S	Minel	1977	300KVA, 11/0.415KV	Continuity tested okay	Unacceptable LV/E insulation resistance values	Unacceptable ratio test values	Excitation characteristic unacceptable	HV/ LV cables tested okay.	-	-	Nil	"TX" failed test B, C & D. It cannot be energized
10/10/05	NEPA Guest House	Bonar Long	1983	200KVA, 11/0.415KV No. of Taps(7) Tap used (3)	Continuity tested okay	HV to earth insulation tested not okay (grounded)	Unacceptable ratio characteristics	Excitation characteristics not acceptable	HV/KV cables tested okay	-	-	Nil	The "TX" failed insulation tests ratio and excitation test. It

													cannot be energized
10/10/05	Air Force	Paulwels Trafo	-	200KVA, 11/0.415KV	Continuity Tested okay	HV to earth insulation tested not okay (grounded)	Unacceptable ratio test values	Excitation characteristics unacceptable	HV/LV Cables tested Okay	-	-	Nil	The "TX" failed HV/E insulation test (grounded). It cannot be energized.
12/10/05	Oghara Junction I	Koncar	1991	315KVA, 33/0.415KV No. of Taps (5) Tap used (3)	Continuity tested not okay	LV insulation Low and taking reading there was cracking noise	Unacceptable ratio characteristics	-	HV Copper Jumper okay. LV cable red phase grounded.	Feeder Pillar Tested okay	Needs improvement, only two L/A avai-lable	Nil	Failed test A, E(b) cracking noise heard, Earthing needs improvement. The "TX" cannot be energized
15/10/05	Forestry II	IEO	1976	300KVA, 11/.415KV No. of Taps (6), Tap used (6)	Continuity tested not okay	Insulation tested okay	Unacceptable ratio characteristics	Okay	HV/LV cables tested okay	Tested okay	Nil	Nil	"TX" failed continuity test and ratio test. It cannot be energized.
26/10/05	Chimara	Pauwels Trapo	2000	300KVA, 33/.415KV No. of Taps (5) Taps used (3)	Continuity Tested not okay	LV/E Insulation not okay	Unacceptable ratio characteristics	Excitation Characteristics unacceptable	HV/LV cables tested okay	_	Okay	Nil	Transformed failed test A,B & C. It cannot be energized.
31/10/05	Mission Road relief	Alstorn	2000	500KVA, 11/.415 KV		HV/Earth insulation tested not okay	Ratio test okay	Unacceptable excitation characteristics tripped the Gen. Set.	HV/LV cables tested okay	_	_	Nil	The "TX" failed tests B and D. It cannot be energized

Table 1 Contn

Date of Test	Name of substation	Transformer Data			Open Circuit (Continuity) Test (A)	Insulation Resistance Test (B)	Ratio Test (Single Phase) (C)	Single Phase (Excitation) Test (D)	Cable Text (E)	Feeder Pillar Test (F)	Earth Resis-tance (G)	Oil Sample Test (H)	General Remark
		Name	Year of Manu	Rating									
16/11/05	Urora II	Union	1988	500KVA, 33/.415KV No. of Taps (5) Taps used (3)		Continuity Tested okay	Unacceptable insulation resistance values	Unacceptable ratio test values	Unacceptable Excitation characteristics	HV/LV cables values. Acceptable	_	Nil	"TX" failed test B, C & D. Cannot be energized.
28/11/05	Mission Road Relief	Alstom	2001	500KVA, 11/0.415 KV, No. of Taps (5), Tap used (3)	Not okay, suspected open circuit on the Yellow phase.	Insulation tested okay	Unaccepted ratio test values	Excitation characteristics unacceptable tripped gen. set	HV/LV cables tested okay	_	_	Nil	The "TX" failed tests A, C & D. It cannot be energized.
5/12/05	Noma	Minel	1997	300KV, 11/.415KV	Continuity not okay, HV side continuous to the body	HV/E Insulation grounded	Unacceptable ratio test values	Excitation characteristics unacceptable	HV/LV cables tested okay.	_	_	Nil	The transformer failed tests A-D. It cannot be energized.
06/12/05	Omoigui Obasogie	Hyundai	1980	500KVA, 11/.415KV No. of Taps(5) Tap used (3)	Continuity tested okay	HV/LV insulation grounded	Unacceptable ratio test values	Excitation characteristic unacceptable	HV/LV Cables tested Okay	-	-	Nil	The "TX" failed ratio and excitation test. The HV/LV insulation is grounded. It cannot be energized
09/12/05	Inland Bank	Paulwels Trafo	2002	100KVA, 11/.415KV	Continuity tested okay	Insulation test not okay.	Unacceptable ratio test values	Excitation characteristic unacceptable	HV cables tested okay. And LV	-	-	Nil	"TX" failed test B, C & D, also the

				No. of Taps (5) Tap used (3)					cables insulation low.				insulation of the LV cables low. It cannot be energized.
14/12/05	Ugbor Road II	-	-	-	Continuity tested okay	Insulation tested okay	Ratio test okay	Unacceptable Excitation characteristics	HV/LV Cables tested Okay	-	-	Nil	Transformer failed test D, and cannot be energized

Table 1 Contn

Date of Test	Name of substation	Transformer Data			Open Circuit (Conti-nuity) Test (A)	Insulation Resistance Test (B)	Ratio Test (Single Phase) (C)	Single Phase (Excitation) Test (D)	Cable Text (E)	Feeder Pillar Test (F)	Earth Resis-tance (G)	Oil Sample Test (H)	General Remark
		Name	Year of Manu.	Rating									
16/01/06	Oko No. I	Elin	1982	300KVA, 11/6.6/.415 KV	Continuity tested okay	Insulation not okay	Ratio test okay	Excitation result unacceptable	HV/LV Cables tested Okay	-	-	Nil	"TX" failed insulation and Excitation tests. It cannot be energized.
22/01/06	Omoregbe	-	1980	300KVA, 11/0.415KV No. of Taps (5) Tap used (3)	Continuity on LV side not okay	LV Insulation resistance not okay	Unacceptable ratio test values	Excitation characteristics unacceptable	Cables tested okay	-	-	Nil	Transformer failed tests A – D. It cannot be energized.
22/01/06	Royal Marble	-	-	-	Continuity test okay	Insulation resistance tested okay	Unacceptable ratio characteristics	Excitation test result unacceptable. It tripped the Generator. Set.	HV/ LV cables tested Okay		-	Nil	Transformer failed C, & D. It cannot be energized.
02/02/06	Ministry of Works Sapele Road	-	-	200KVA, 11/0.415KV	Continuity tested okay	Insulation tested not okay (Low).	Ratio test results unacceptable.	Unacceptable Excitation characteristics	HV/LV Cables tested Okay	-	-	Nil	The "TX" failed ratio and excitation tests and the Red phase bushing of the HV side leaking oil. It cannot be

													energized
06/02/06	Ugbor II	-	-	-	Continuity tested okay	Insulation tested okay.	Unaccep-table ratio test values	Unacceptable Excitation characteristics	HV/LV Cables tested Okay	-	-	Nil	The “TX” failed ratio and excitation tests. It cannot be energized

Table 1 Contn

Date of Test	Name of substation	Transformer Data			Open Circuit (Continuity) Test (A)	Insulation Resistance Test (B)	Ratio Test (Single Phase) (C)	Single Phase (Excitation) Test (D)	Cable Text (E)	Feeder Pillar Test (F)	Earth Resi-stance (G)	Oil Sample Test (H)	General Remark
		Name	Year of Manu	Rating									
21/02/06	Omofonmwan	Alsthom	1983	300KVA, 11/6.6/.415KV	Continuity test not okay	LV/E Insulation not okay.	Unacceptable ratio test values	Excitation characteristics unacceptable	HV/LV cables tested okay.	-	-	Nil	Transformer failed A, B (LV/E), C & D. It cannot be energized.
23/02/06	Nekpenekpen	Elprom Trafo	1977	500KVA, 11/0.415 KV	Continuity tested not Okay	Insulation tested not okay	Unacceptable ratio test values	Excitation characteristic unacceptable	HV/LV Cables tested Okay	-	-	Nil	Transformer failed test A – D. It cannot be energized
07/03/06	St. Jude	Alsthom Atlantique	1983	300KVA, 11/.415KV	Continuity tested okay	Insulation tested okay	Ratio test results unacceptable	Excitation test result unacceptable	HV/LV cables tested Okay	-	-	Nil	“TX” failed C & D. It cannot be energized.
09/03/06	Factory Road	-	-	-	Continuity tested okay	Insulation tested not okay	Unacceptable ratio test values	Excitation characteristics unacceptable	HV/LV Cables tested Okay	-	-	Nil	“TX” failed Test B, C & D. It cannot be energized.
11/04/06	Edo State Library	Kure	-	300KVA, 11/.415KV	HV Continuity not okay	Insulation tested okay	Unacceptable ratio character-ristics	Excitation characteristics unacceptable	HV/LV Cables tested Okay	-	-	Nil	“TX” failed Test A, C & D and so it

													cannot be energized.
12/04/06	Ikhueniro I	Alsthom Atlantique	1983	300KVA, 11/6.6/.415KV	Continuity tested okay	Unacceptable insulation resistance values (Low)	Ratio test okay	Unacceptable Excitation results	HV/LV Cables tested Okay	-	-	Nil	Transformer failed test B & D. It cannot be energized.

Table 1 Contn

Date of Test	Name of sub-station	Transformer Data			Open Circuit (Conti-nuity) Test (A)	Insulation Resistance Test (B)	Ratio Test (Single Phase) (C)	Single Phase (Excitation) Test (D)	Cable Text (E)	Feeder Pillar Test (F)	Earth Resistance (G)	Oil Sample Test (H)	General Remark
		Name	Year of Manu	Rating									
21/04/06	Aibangbe	Elin	1982	300KVA, 11/0.415KV	Continuity test not okay	Unacceptable ratio test characteristics	Unacceptable excitation characteristics	Excitation characteristic unacceptable	HV/LV cables tested okay.	-	-	Nil	"TX" failed tests A – D. The blue phase of the HV bushing, the neutral red and Yellow phase bushing of the LV side leaking oil. The trans-former cannot be energized.
24/04/06	Odin Biscuit	Mitsubishi	1981	300KVA, 11/.415KV	Continuity tested Okay	Insulation tested okay	Unacceptable ratio test results	Excitation characteristic unacceptable	HV/LV Cables tested Okay	-	-	Nil	"TX" failed tests C & D. It cannot be energized
24/04/06	Lella Specialist Hospital	Bonar Long	1995	200KVA, 11/.415KV	Continuity tested okay	Insulation tested okay	Ratio test results Okay	Unacceptable excitation results	HV/LV cables tested Okay	-	-	Nil	"TX" failed test D, with cracking sound heard

													during excitation.
25/04/06	Idahosa II	Bonar Long	1983	200KVA, 11/.415KV No. of Taps(5) Tap used (2)	Continuity tested okay	Acceptable insulation resistance values	Unacceptable ratio characteristic	Unacceptable Excitation characteristic	HV/LV Cables tested Okay	-	-	Nil	"TX[I]" failed tests C & D. It cannot be energized

Table 1 Contn

Date of Test	Name of substation	Transformer Data			Open Circuit (Continuity) Test (A)	Insulation Resistance Test (B)	Ratio Test (Single Phase) (C)	Single Phase (Excitation) Test (D)	Cable Text (E)	Feeder Pillar Test (F)	Earth Resis-tance (G)	Oil Sample Test (H)	General Remark
		Name	Year of Manu.	Rating									
03/05/06	MTN Ugbor (Idogbie Str)	S.E.A.	2003	100KVA, 11/.415KV	Failed Continuity test	Failed Insulation test	Unacceptable ratio characteristics	Excitation tests results unacceptable	HV/LV cables tested okay.	-	-	Nil	"TX" failed A, B, C & D tests. It cannot be energized.
08/05/06	Piedmont Ologbo	Transfor-matore	1979	2500KVA, 33/11KV	Continuity tested Okay	Insulation resistance not okay	Unacceptable ratio characteristics	Excitation characteristics unacceptable	Cables tested okay after repairs	-	-	Nil	Transformer failed test B – D. Oil leakage from the top of Transformer. The upriser cable inside the compound exploded.
12/05/06	Odaro	Pauwels Trafo	1980	200KVA, 11/6.6/0.415KV No. of Taps (6) Tap used (3)	Continuity Tested okay	Insulation tested not okay	Unacceptable ratio characteristics	Excitation characteristics unacceptable	HV cables tested Okay LV cables not okay	-	-	Nil	Transformer failed B, C, D and the LV cables insulation very low. It cannot be energized.

15/05/06	Mobil Oghara	ABB	2004	300KVA, 11/.415KV	LV Continuity not okay	LV Insulation tested not okay	Unacceptable ratio characteristics	Excitation characteristics unacceptable	HV/LV Cables tested Okay	-	-	Nil	Transformer failed test A – D. It cannot be energized
15/05/06	Market Junction Oghara	Mitsubishi	1979	300KVA, 11/.415KV	Continuity Tested okay	Insulation resistance low, but accepted because of suspected moisture	Unacceptable ratio test results	Excitation characteristics unacceptable	Cables tested Okay, but B/E was replaced by neutral cable	-	-	Nil	Transformer failed C & D tests. It cannot be energized.
24/5/06	State C. I. D.	IEO Breda	1976	200KVA, 11/0.415KV No. of Taps (6) Tap used (5)	Continuity Tested okay	Insulation resistance too Low	Unacceptable ratio test	Tripped the Gen. Set.	HV/LV Cables tested Okay	-	-	Nil	It was observed that oil is leaking from the "TX" top cover. The Transformer failed C & D test. It cannot be energized.

Table 1 Contn

Date of Test	Name of substation	Transformer Data			Open Circuit (Continuity) Test (A)	Insulation Resistance Test (B)	Ratio Test (Single Phase) (C)	Single Phase (Excitation) Test (D)	Cable Text (E)	Feeder Pillar Test (F)	Earth Resistance (G)	Oil Sample Test (H)	General Remark
		Name	Year of Manu.	Rating									
08/6/06	Country Home Motel	Paulwels Trafo	1980	500KVA, 11/6.6/ 0.415KV	HV side continuous with the transformer body.	HV insulation not okay and others LV low	Ratio test results not acceptable	Excitation characteristics unacceptable	HV/LV cables tested okay.	-	-	Nil	The "TX" Blue phase of the HV and LV confirmed bad. It cannot be energized.
17/6/06	Ekae I	IEO	1976	300KVA, /0.415KV No. of Taps (6) Tap used (6)	Continuity tested Okay	Insulation resistance values okay	Unaccep-table ratio test values	Excitation characteristics unacceptable	HV & LV Cables tested okay	-	-	Nil	Transformer failed C & D test. It cannot be energized.
27/6/06	Akugbe	-	-	-	HV	Insulation	Unaccep-	Unacceptabl	Part of	-	-	Nil	Transformer

	Ova				Continuity not okay	resistance tested okay	table ratio test	e Excitation characteri-stics. Cracking sound was heard	HV cables was vandalized and LV cable okay				failed test A–D. It cannot be energized
28/9/06	Circle Palace	GEC	1973	300KVA, 11/0.415KV	HV Continuity test not okay	LV Insulation tested not okay	No. output on the LV side	Tripped the Gen. Set.	HV/LV Cables tested Okay	-	-	Nil	Transformer not okay. It needs to be repaired or replaced.
29/09/06	Otumara I	ABB	2004	300KVA, 33/0.415KV No. of Taps (5) Tap used (3)	Continuity tested not okay	Secondary side grounded (LV/E-0Mohms)	Unacceptable ratio test characteristic	Excitation characteri-stics unacceptable	HV/LV Cables tested Okay	-	-	Nil	Transformer failed test A – D and so it cannot be energized
16/10/06	Legislator Quarters	Kotsons	2002	500KVA, 11/0.415KV No. of Taps (7) Tap used (3)	Continuity tested okay	Insulation test not okay	Unacceptable ratio test results	Excitation characteri-stics unacceptable	Cables tested okay.	-	-	Nil	Transformer failed test B, C & D. It cannot be energized.

Table 2: Summary of Failure Characteristics of Transformers tested in Table 1

Month	Transformer Rating (KVA)	No. of Transformer that failed	Open Circuit Test	Insulation Resistance Test	Ratio Test	Single Phase Excitation Test	Cable Test	Feeder Pillar Test	Oil Sample Test	General Remark	Cause of Failure
Jan., 2005	–	–	–	–	–	–	–	–	–	–	–
Feb.	–	–	–	–	–	–	–	–	–	–	–
Mar.	300	1	bad	Bad	–	not okay	Okay	–	–	Failed	burnt coil
April	–	–	–	–	–	–	–	–	–	–	–
May	500	1	–	–	–	–	–	–	–	–	–
June	–	–	–	–	–	–	–	–	–	–	–
July	500(2) & 300(1)	3	okay	not okay	bad	not okay	Okay			Failed	burnt coil
Aug.	500(3), 300(1)	5	okay	not okay	bad	not okay	Okay			Failed	burnt coil

	& 200(1)										
Sept.	500(1) & 300(3)	4	–	–	–	–	–	–	–	–	–
Oct.	500(1), 300(2), 200(2) & 315(1)	6	not okay	Okay	bad	not okay	Okay			Failed	burnt coil
Nov.	500(2)	2	not okay	Okay	bad	not okay	Okay			Failed	burnt coil
Dec.	500(1), 300(1), 100(1) & xxx(1)	4	okay	not okay	bad	not okay	Okay			Failed	burnt coil
Total		**26**						–	–	–	–
Jan., 2006	300(2) & xxx(1)	3	okay	not okay	okay	not okay	Okay			Failed	burnt tap changer
Feb.	500(1), 300(1) 200(1) & xxx(1)	4	okay	not okay	not okay	not okay	Okay	okay		Failed	burnt coil
Mar.	300(1) & xxx(1)	2	okay	not okay	not okay	not okay	Okay	–	–	Failed	burnt coil
April.	300(4) & 200(2)	6	okay	Okay	not okay	not okay	Okay	–	–	Failed	burnt coil
May	2500(1), 300(2), 200(2) & 100(1)	6	okay	not okay	not okay	not okay	Okay	–	–	Failed	burnt coil
June.	500(!), 300(1) & xxx(1)	3	not okay	not okay	not okay	not okay	Okay	okay		Failed	burnt coil
July.	–	–	–	–	–	–	–	–	–	–	–
Aug.	–	–	–	–	–	–	–	–	–	–	–
Sept.	300(2)	2	okay	Okay	not okay	not okay	Okay	–	–	Failed	burnt coil
Oct.	500(1)	1	okay	not okay	not okay	not okay	Okay	–	–	Failed	burnt coil
Nov.	500(1)	1	okay	Okay	not okay	not okay	Okay	–	–	Failed	burnt coil
Dec.	-	-	-	-	-	-	-	-	-	-	-
Total		**28**									

Table 3 net cost of failed distribution transformers in 2005 and 2006

S/N0	Transformer rating (KVA)	Quantity (No.)	Unit cost (# :K)	Total cost (# :K)
1	100	2	910,000.00	1,820,000.00
2	200	8	1,375,000.00	11,000,000.00
3	300-315	24	1,815,000.00	43,560,000.00
4	500	15	2,700,000.00	40,500,000.00
5	2500	1	7,850,000.00	7,850.000.00
Gross Total				104,730,000.00

5. Conclusion

An integrated electric power system supplies electricity to end users at different transformation voltages with power and distribution transformers as the major link components for the period of 2005 to 2006 failure rates values investigated determined lies within the acceptable range of 6.00% - 8.00% for developing nations in the world. The possible causes of the failure and ways of minimizing the failure rates were highlighted and proposed in this work. The extent of damage to the failed transformers was also investigated and presented in the study. The study also revealed that if the huge financial loss is not check and control by management it will defeat the essence of cost benefit ratio which is the bench mark for any financial establishment. This financial loss not properly matched with reliability indices such as; ASAI, SAIDI, CAIDI, SAIFI, MTBF, MTTR, etc. will continue to result in energy lost, customers dissatisfaction and reduce cash collection. The frequency of failure of commercial transformers the vital link to sustainability of nations development and enhancement of the well being of the customers have been successfully investigated in this paper.

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