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Analysis of No-Load Test on a Power Transformer: Case Study 2.5MVA 33/0.415KV Transformer in Law School Rivers State.

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ABSTRACT
No-load tests are tests that apply rated voltage on the primary side at the no-load state of the secondary side to determine the core loss (no-load loss) and the no-load current. Current only flows in the primary side in the no-load test, but this current causes excitation and iron loss of the iron core. The characteristics of this test are however extremely important to know the acceptable percentage of the no-load value and ascertain voltage drop. No-load tests were used to perform an analysis on power transformers with a rating of 2.5MVA 33/11/0.415KV transformers in the Law School of Rivers State. Since core loss/ iron loss is due to alternating flux in the core of the transformer, any transformer whose no-load current percentage exceeds 2-10% of the rated current of the transformer has to be evaluated. The core of the transformer must be made of high permeability and high resistivity materials to reduce the iron losses in the transformer.MATLAB software was the major tool used to adequately simulate the transformer with the parameters given from the name plate. The MATLAB simulation was analyzed to find out the percentage of no-load current to the rated primary current, and the result was used to ascertain the working condition of the transformer to be used at the law school in Rivers State.

KEYWORDS*:* No-Load Test, Open-Circuit Test,Power Transformer,Transformers, Transformer Test.

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I. INTRODUCTION

Transformers are known to be more reliable and of higher energy efficiency to the order of around 98% as of date. Transformers represent an important link in the generation, transmission, distribution, and utilization of electrical energy in power systems [1].

A transformer is an electromagnetic energy conversion device that transfers energy from one electrical circuit to another electrical circuit through the medium of a magnetic field without a change in the frequency. The electric circuit which receives energy from the supply mains is called primary winding and the other circuit which delivers electric energy to the load is called secondary winding. In a transformer, the electric energy transfer from one circuit to another circuit takes place without the use of moving parts it has, therefore, the highest possible efficiency out of all the electrical machines and requires an almost negligible amount of maintenance and supervision.

The transformer is a static device that transfers electrical energy from one circuit to another without changes in frequency [2].

Transformers alone cannotdo the following:

- Convert DC to AC or vice versa
- Change the voltage or current of the DC
- Change the AC supply frequency.

Based on the principle of electromagnetic induction, the transformer consists of cores and coils and makes the electrical energy turn into electrical energy components through magnetic energy [3].

Since in the no-load switching process, the iron core of the transformer saturates and generates an operating current several times higher than the inrush current, the no-load switching process is very normal but attracts much attention. However, the transformer’s no-load switching will generate over-voltage and its amplitude can reach several times or even more than the steady-state voltage [4],

No-load tests are tests that apply rated voltage on the primary side at the no-load state of the secondary side. Current only flows to the primary side in the no-load test, but this current causes excitation and iron loss of the iron core. No-load test data is used to characterize the core losses and magnetizing inductance and find out the acceptable percentage.This test is carried out to determine magnetizing reactance, core-loss resistance, and the fixed power loss of the transformer (core-loss). The power supply must be operated at the rated frequency of the transformer. In this test, one terminal is open-circuited while the other is connected to the power supply.

There is so much literature on transformertheory like its working principle, construction, operation, and maintenance in the form of textbooks [5] and handbooks [6]. Also, continuous research is going on globally on transformers design [7], construction, efficiency, smart transformers [8], maintenance, and modeling is being disseminated through various forms like journals and conferences/seminars.

The distribution transformer is one of the major pieces of equipment which connects the power supply to the customer[9]. Transformer tests as a means to ascertain the working capacity of a power transformer [10].

It is safer to excite the low-voltage side of the transformer even though either side can be excited [11].The low-voltage power supply is always available in laboratories while the high-voltage supply might not be so.Sincethe secondary terminal is open-circuited, there is no current flowing through it. Ideally, there is no current flowing through the primary terminal under open-circuit conditions. The primary winding impedance is much smaller than the equivalent impedance of the excitation branch.

It is important to note that this work is based on the need to analyze the characteristics of the no-load test in a power transformer to know the acceptable percentage of the no-load current in relation to the rated current of the transformer. This is essential to know the voltage drop of the transformer.

The open-circuit test, or no-load-test, is one of the methods used in electrical engineering to determine the no-load impedance in the excitation branch of an excitation transformer.

1.1 The Aim of This Research Work

The goal is to perform an analysis of a no-load test in a power transformer.

1.2 Objective of this Research Work

- Data obtained from the transformer main plate for simulation,.
- Develop mathematical relationships that describe the no-load test for power transformers
- Solve the mathematical equations to determine no-load magnetizing reactance, core-loss resistance, and the fixed power loss of the transformer (core-loss)
- Analyze results of mathematical equations
- Simulation and comparison of results using MATLAB.

II. MATERIALS AND METHOD

2.1 Materials

The materials used for this research work are: 2.5KVA, 400V mobile generator set, high voltage multi-meter (Avometer: with range -1000ACV, recording templates (tabular chart, etc.), live tester (with range: 100-1000V or 100-500Vac), fastening toolbox (with pliers sets range: 1000Vac), testing lamp(s), etc. The method used to carry out this analysis was a MATLAB simulation using the ratings of the parameters of the transformer. Model equations developed are used to solve for the core loss resistance, magnetization reactance, and efficiency. The results are compared with the measured results of the transformer.

2.2 Circuit Diagram of Open Circuit Test Connection

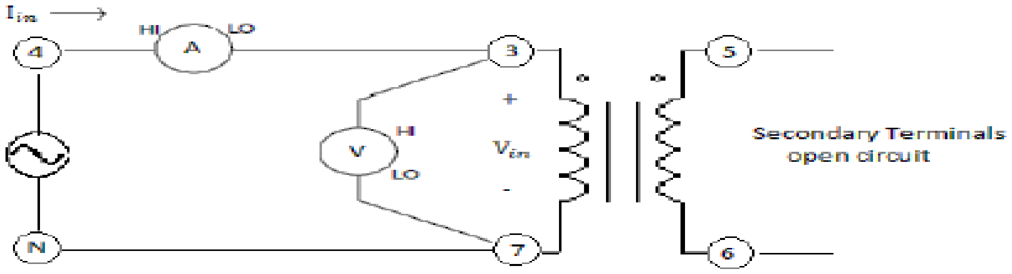

Figure 1: No-load test Circuit

Where, 4-N is the AC power supply terminals; Iin is the input current (on the primary side); Vin is the voltage applied to the primary side; 3-7 is the low-voltage terminals of the single-phase transformer unit; 5-6 is the high-voltage terminals with a rated voltage of 240V AC.

Table 3.1: Rating of 2500KVA 33/0.415KV Three-Phase Transformer

Descriptions	Values	Descriptions	Values
Rated Power (KVA)	**2500**	**Rated Primary Current (A)**	43.739
Rated Frequency (Hz)	**50**	**Rated Secondary Voltage (V)**	400
Rated Primary Voltage (V)	**33000**	**Rated Secondary Current (A)**	3808.44

2.2 MATLAB Model for Open Circuit Test

The figure above shows the Simulink/Sim Power Systems realization of the open-circuit test. A single-phase transformer model whose equivalent circuit parameters could be specified using a transformer dialog box. An AC voltage source is applied to the primary side. Since in the Simulink environment, all elements must be electrically connected, the secondary side of the transformer cannot be left open, and a voltmeter and RMS mask are connected to view the secondary voltage.

On the primary side, current, and voltage measurement blocks are used to measure the instantaneous current and voltage. The output of each meter is connected to a root mean square (RMS) block/ mask to determine the RMS values of primary current and voltage. The RMS block computes the RMS value of its input signal over a running window of one cycle of the fundamental frequency. The display boxes read these RMS values of the open-circuit Current, $I_{OC,}$ and Voltage, V_{OC}.

The outputs of the current and voltage measurement blocks are connected to a power measurement block that measures the apparent power, active power, P_{OC}, and reactive power, Q_{OC}, of the primary side. The output of this block is connected to a display box to read P_{OC} and Q_{OC}.

The output of the open circuit voltage, V_{OC}, is connected to a math function block which squares the value of the

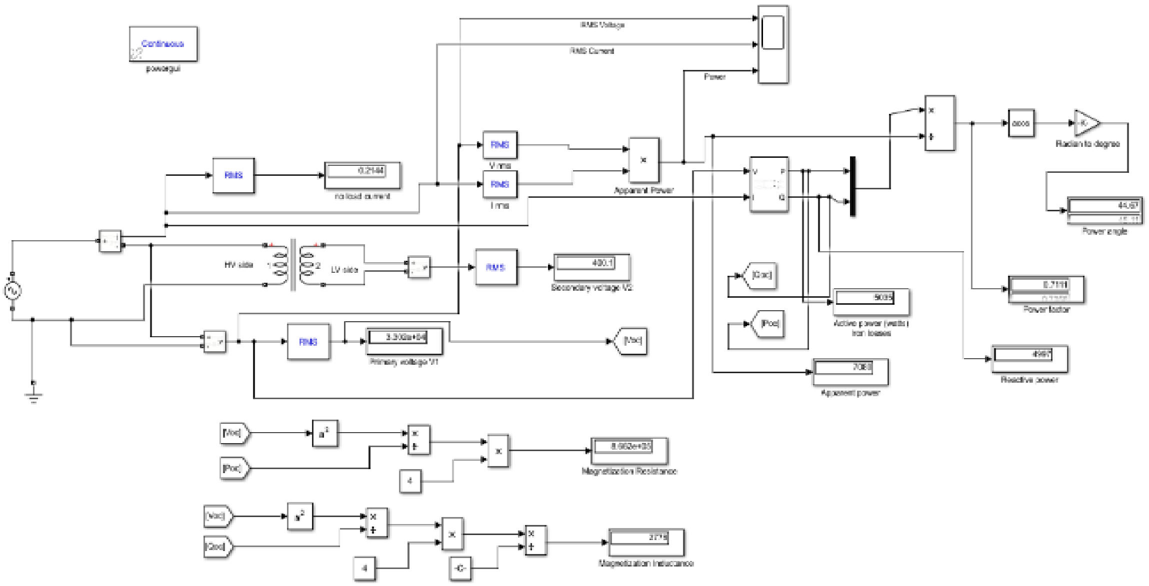

Figure 2: Simulink Model of the Open Circuit Test

V_{OC} and divides it by the active power, P_O. The value is multiplied by 4 to get the magnetization resistance.

The output of the open circuit voltage, V_{OC}, is connected to a math function block which squares the value of the V_{OC} and divides it by the active power, Q_{OC}. The value is multiplied by 4 and the product is divided by a constant ($2\pi f$) to get the magnetization inductance.

2.3 Mathematical Expressions for Core Loss Resistance and Efficiency

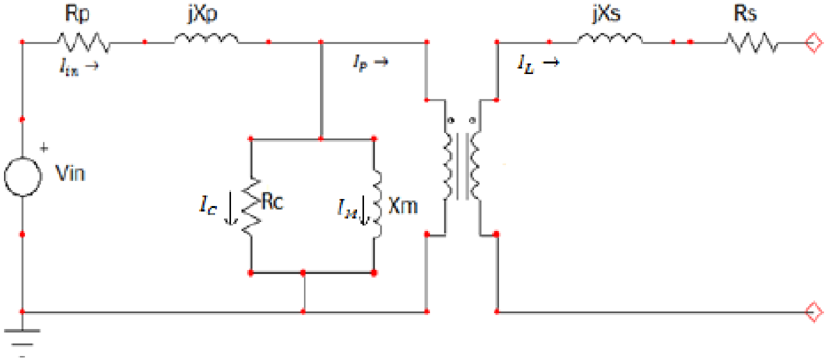

Figure 3: Transformer Exact Equivalent Circuit Open-circuited

Where:

Vin is the input voltage to the primary side; Iin is the input current; IL is the secondary current flowing through the load; RP and RS are the primary and secondary winding resistance; XP and XS are the primary and secondary winding reactance; RC is the core-loss resistance; XM is the inductive reactance.

Since the secondary terminal is open-circuited, there is no current flowing through it (IL=0). Ideally, the primary current (IP) equals the secondary current (hence IP=0) [12]

Therefore, all the input current flows through the excitation element [13].

The two components of no-load current can be given as $I_\mu = I_o Sin\theta$

An $I_w = I_o Cos\theta$

Where Cos θ = no-load power factor

I_μ= magnetizing component of no-load current

I_w = Core loss component of no-load current

$$Cos\theta = \frac{W}{V_{in} * I_o} \quad (1)$$

W = wattmeter reading (Iron loss)

From this, shunt parameters of an equivalent circuit of the transformer (X_o and R_o) can be calculated as:

$$Xo = V_{in}/I_\mu \quad (2)$$

$$Ro = V_{in}/I_w \quad (3)$$

Xo = pure inductance

Ro = non-induction resistance

The primary winding impedance is relatively negligible compared to the excitation branch [14]

$$|RP{+}jXP| \ll |RC//jXM|$$

Hence, RC is the only resistance dissipating power in this case. The input voltage and the input power can be used to calculate RC as shown ins (4) below

$$.R_c = \frac{V_{in}^2}{P_{in}} \quad (4)$$

The current flowing through this resistor can be calculated as shown in (5)

$$I_c = \frac{V_{in}}{R_c} \quad (5)$$

Iin is the phasor sum of IC and the current through the magnetization reactance, IM. Since XM is an inductive reactance, the current through it lags the input voltage (and IC) by 90°. IM can be calculated:

$$I_M = \sqrt{I_{in}^2 - I_c^2} \quad (6)$$

Finally, XM can be calculated using Ohm'slaw:

$$X_M = \frac{V_{in}}{I_M} \quad (7)$$

For calculating efficiency;

Let, Copper Loss = $Io^2 * X_M$

Iron Loss = W

$$efficiency = 1 - \frac{losses}{input} = 1 - \frac{I_o^2 X_m + W}{V_{in} I_o * cos\theta} \quad (8)$$

The efficiency of the no-load test is expected to be zero as there is no power output.

Using the model equations developed to solve on MATLAB,

```
clc
clear all
```

```
W = zeros(0,3);
Io = zeros(0,3);
theta = zeros(0,3);
Pin = zeros(0,3);
Vin = 400; %Vin is input voltage (in volts)
Iin = 43.739; %Iin is input current
VT = 5;
fori = (1:3)

Io = [4.56 4.22 3.74];
 W = [21.8 63.4 28.8];
Pin = [21.8 63.4 28.8]; %Pin is input Power (in watts)
theta(i) = acosd(W(i)/(Vin*Io(i))) %cos theta is the no-load power factor
Iu(i) = Io(i)*sin(theta(i)) %Iu and Iw components of no-load current
Iw(i) = Io(i)*cos(theta(i))
Xo(i) = Vin/Iu(i)
Ro(i) = Vin/Iw(i)
Rc(i) = (Vin^2)/Pin(i) %Rc is core loss resistance,
Ic(i) = Vin/Rc(i) %Ic is the current flowing through resistor
Im(i) = sqrt((Iin^2)-(Ic(i)^2)) %Im is the magnetizing reactance
Xm(i) = Vin/Im(i) %Xm is inductive reactance
efficiency(i) = 1-((((Io(i)^2)*Xm(i))+W(i))/(Vin*Io(i)*cos(theta(i))))
end

No-load loss = (W(1)+W(2)+W(3))*VT
```

```
theta = 89.3152
Iu = 4.4499
Iw =0.9960
Xo = 89.8896
Ro = 401.6139
Rc = 7.3394e+03
Ic = 0.0545
Im = 43.7390
Xm = 9.1452
Efficiency = 0.4680

theta = 89.3152   87.8475
Iu = 4.4499   -0.4930
Iw = 0.9960    4.1911
Xo = 89.8896 -811.3963
Ro = 401.6139   95.4402
Rc = 1.0e+03 *(7.3394    2.5237)
Ic = 0.0545    0.1585
Im =   43.7390   43.7387
Xm = 9.1452    9.1452
Efficiency = 0.4680    0.8650

theta = 89.3152   87.8475   88.8969
Iu = 4.4499   -0.4930    3.0032
Iw = 0.9960    4.1911    2.2289
Xo = 89.8896 -811.3963 133.1899
Ro = 401.6139   95.4402 179.4570
Rc = 1.0e+03 *(7.3394    2.5237    5.5556)
Ic = 0.0545    0.1585    0.0720
Im = 43.7390   43.7387   43.7389
Xm =   9.1452    9.1452    9.1452
Efficiency = 0.4680    0.8650    0.8242
No-load loss =   570
```

III. RESULTS AND DISCUSSION

Figure 4 shows the graphical representation of the RMS voltage, RMS current, and apparent power after the model has been run for ten (10) seconds.

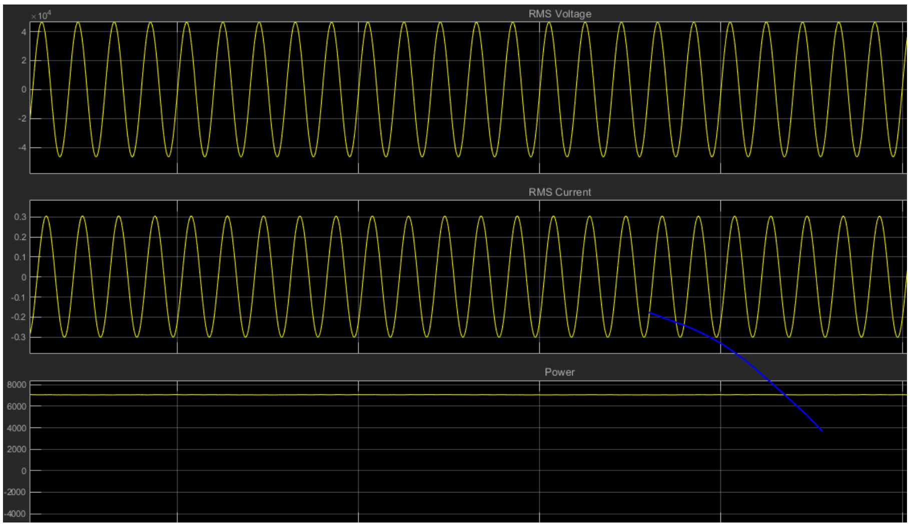

Figure 4: Graph Showing RMS Voltage, RMS Current, and Power

From the graph above, the apparent power remains constant since there is no load attached to the transformer.

Table 2: Simulated Results for No-Load Test

	No load current	No load loss	Power factor	Power angle	Active power	Reactive power	Apparent power	Magnetization resistance	Magnetization inductance
Transformer	1.8	6000						2.178 * 10^5	693.28
Simulation	0.6145	5008	0.7119	44.61	5042	4992	7083	8.648*10^5	2778

From the simulation,
The No-Load current is 0.6145. Taking the percentage of the simulated no-load current from the nominal current of the transformer from table 3.
No-Load current = 0.6145 A
Rated current = 43.739 A
Taking the percentage,

$$\frac{0.6145}{43.739} x\ 100 = 1.474\%$$

From the data collected from the transformer:

Table 3: Measurement of No-load Losses and Current

Applied Voltage(V)		Sec. Voltage	No Load Current (A)			Wattmeter (W)			Multiply			Avg. Current
HV	LV		A	B	C	A	B	C	W	V.T	C.T	
70	28	400	4.56	4.22	3.74	21.8	63.4	28.8	1	5	1	4.17

Table 3 shows the ammeter reading of the no-load current I_o. As no load current I_o is quite small compared to the rated current of the transformer, the voltage drops due to this current can be taken as negligible.
Since the voltmeter reading V_1 can be considered equal to the secondary induced voltage of the transformer, the input power during the test is indicated by the watt-meter reading. As the transformer is open-circuited, there is no output, hence the input power here consists of core losses in the transformer and copper loss in the transformer during no load condition. But as said earlier, the no-load current in the transformer is quite small compared to the full load current, so copper loss due to the small no-load current can be neglected. Hence, the wattmeter reading can be taken as equal to core losses in the transformer.
The results of the developed model for transformer testing are shown in table 4 below:

Table 4: Calculated Results for No Load Test Result

Desc.	1st Reading	2nd Reading	3rd Reading
θ	89.3152	87.8475	88.8969
Iu	4.4499	-0.493	3.0032
Iw	0.996	4.1911	2.2289
Xo	89.8896	-811.396	133.1899
Ro	401.6139	95.4402	179.457
Rc = 1.0e+03 *	7.3394	2.5237	5.5556
Ic	0.0545	0.1585	0.072
Im	43.739	43.7387	43.7389
Xm	9.1452	9.1452	9.1452
Efficiency	0.4680	0.8650	0.8242
No load loss	570		

The model equation was used to calculate the result three times and three readings were generated as above.From the result, the current lags the input voltage at approximately 90^o. The efficiency of the no-load test is greater than zero, which means that power is being lost hence the transformer needs to be checked on, even though small, the efficiency is expected to be zero since the load is not connected across the secondary of the transformer.

IV. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

From the calculations, the percentage of the no-load test is less than 10% (1.47%), hence, the transformer is working in optimal function and can serve the consumer adequately well. The lesser the percentage of no-load current the better the efficiency of the transformer

The acceptable percentage of the no-load test to the nominal current/ rated current of the transformer is ≤ 10%. The no-load current value should not be greater than 10% of the rated current so as the ensure the transformer serves the consumers adequately well.

It is essential no-load tests are properly carried out on transformers before use to avoid damage to the transformer and consumers’ properties.

4.2 Recommendations

The research gives the entire practical basis required to carry out performance tests on Distribution Transformers in-service (along a Street or Road or within a complex) for electricity consumers; however, proper inspection/testing of transformers whether power or distribution should be undertaken on routine maintenance or preventive maintenance to avert the cause(s) of transformer failure due to:

- Incorrect use of insulation materials in the transformer.
- Thief on apparatus Consumer’s wrong connection
- Poor earthing system
- Absent of lightning Arresters.
- Overloading of a transformer.
- Lightning Surge

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