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ANALYSIS OF LOAD TEST, TRANSFORMATION, TURNS RATIO, EFFICIENCY AND VOLTAGE REGULATION OF SINGLE PHASE TRANSFORMER

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Abstract: This paper presents analysis obtained for the design of single phase transformer. The method is simple, efficient and accurate, by an exhaustive analysis. The following constraints are imposed: excitation current, load fractions, efficiency and voltage regulations. The methodology of this paper requires only two input data: primary side of the transformer and the secondary side of the transformer. The input side of the transformer include the following parameters; voltage, current and power while the secondary side of the transformer includes; voltage, current, efficiency, voltage regulation. These data are included in the transformer nameplate. In this paper, the minimization of the following four objective functions is considered: total owing cost, mass, total losses and material cost was considered. The consideration of these four objective functions is implemented automatically by running the analysis several times without intervention of a designer. Consequently, transformer manufacturers save design man-hours and increase capacity. The optimized solutions of transformer design are validated with laboratory and process measurements. In this paper the simulation of single phase transformer with different supplies such as Load Test and efficiency of voltage regulation are carried out.

Keywords: Exhaustive Analysis, Load Test, Ratio Test, Excitation Current, Voltage Regulation.

1. INTRODUCTION

Transformer is an electromagnetic energy conversion device that transfers energy from one electrical circuit to another electrical circuit through the medium of magnetic field and 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 the secondary winding. [1]

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 possible efficiency out of all the

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electrical machines and requires almost negligible amount of maintenance and supervision [2].

Transformer is a static device which transfers electrical energy from one circuit to another without change in frequency [3]. Most of the cases we see that the inputs given are sinusoidal wave only. In modern electrical distribution system, there has been a sudden increase of nonlinear loads, such as power supplies rectifier equipment, domestic appliances, adjustable speed drives, etc. These nonlinear electronic loads draw non-sinusoidal currents from ac mains and cause a type of voltage and current distortion called as 'harmonics' [4]. The primary effect of harmonic currents on transformers is the additional heat generated by the losses caused by the harmonic contents generated by the nonlinear loads [5]. There are three effects that result in increased transformer heating when the load current includes harmonic components.

1. **Rms current:** If the transformer is sized only for the kVA requirements of the load, harmonic currents may result in the transformer rms current being higher than its capacity [6];
2. **Eddy-current losses:** These are induced currents in a transformer caused by the magnetic fluxes. [7]
3. **Core losses**: The increase in nonlinear core losses in the presence of harmonics will be dependent under the effect of the harmonics on the applied voltage and design of the transformer core [8]. Therefore harmonic analysis with calculations plays an important role in transformers to reduce harmonics effect. To show importance of these problems, we consider provides experimental data for the development of power quality mitigating devices. Lack of previous studies; the detail of the tested transformer parameters and collected data during experimental analysis was given but limited. However, this study gives the detail of the tested transformer. For this, a conventional shell type transformer was designed and manufactured. Collected data gives the opportunity to the researchers to understand the effect of the harmonics. Moreover, the data presented here can be used in future studies and simulations. The obtained data is sufficient for the analysis of the losses caused by load harmonics. [10] [11].

2. Materials and Methods

Shell type transformer was designed to use in this study as shown in Fig. 1.

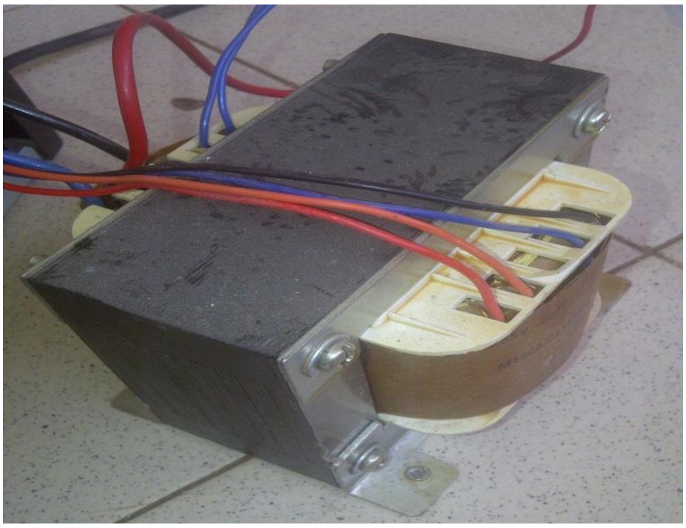

Fig.1. shell type transformer

The following materials were used for the analysis of load test, efficiency and voltage regulation of single phase transformer

- Voltmeter
- Ammeter
- Wattmeter)
- Connecting leads
- Load (60W, 100W, 200W) bulbs

2.2. TRANSFORMATION AND TURNS RATIO TEST ON A SINGLE PHASE TRANSFORMER

1. Insulation Test (with 5kV megger at room temp. 350c)

- L.V. winding to earth - 982 m
- H.V. winding to earth – 743m
- H.V. winding to L.V. winding 736 m

2. Short Circuit Current Test

Supply given to H.V. side (single phase from 220 – 250 volts) & L.V. side short circuited with an arrangement to measure neutral current. From table1 it is seen that primary transformer current varies with respect to its Loads [12].

3. Ratio Test

Single phase (240 volts) L.T. supply is given to H.V. sides & all voltages are measured from Table.1. test result the variation in Ratio is calculated from table 3 if Ratio is deviated from required value then transformer is declared as faulty.

4. Magnetic Balance Test

Two phase supply given to H.V.

2.3. TRANSFORMER FAULT ANALYSIS

Internal Faults [13]

i. Phase-to-phase (HV winding) fault

ii. Phase-to-phase, (LV winding) fault

iii. Phase to earth fault (HV / LV winding)

3. Results and Discussion

To verify the effectiveness of proposed analyzes. The transformer was subjected to different voltages 220V – 250V, the design specification of the secondary current, Voltage and transformers rating for each load rating were measure and recorded, these values obtained are shown in Table 1.

However the transformer was tested on load rated as follows 60W, 100W, 120W, 160W, 200W, 300W.

Table.1 Distributions of Primary winding and Secondary windings when subjected to various voltages

	Primary side of transformer			Secondary side of the transformer				
n	Voltage $V_0(V_P)$ (V)	Current $I_A(I_P)$ (A)	Power (W)	Voltage $V_2(V_S)$ (V)	Current $I_2(I_S)$ (A)	Efficiency (%)	Voltage reg. (%)	E_2 (V)
1	256	0.2	60	250	0.1	41.67	0.79	252
2	254	0.3	100	251	0.2	50.2	0.40	252
3	259	0.4	120	253	0.4	84.33	2.32	259
4	225	0.8	160	219	0.5	68.43	1.35	223
5	231	1	200	223	0.8	89.2	1.33	229
6	246	1.42	300	239	1.21	96.40	1.24	244

The efficiency and the voltage regulation of the transformer were calculated [14];

Efficiency (η) = $\frac{V2\ I2}{W} * 100$

Voltage Regulation= $\frac{E2 - V2}{E2} * 100$

Where E2 is the No load voltage

Load fraction;

n = $\frac{\text{Load}}{\text{transformer rating}}$

Table.2 Calculation result for transformer rating, load fraction analysis

Load(W)	Transformer Rating(V)	Load Fraction(W/V)
60	270	0.22
100	270	0.37
120	270	0.44
160	242	0.66
200	246	0.813
300	250	1.2

Fig.1. Demostation of load to efficiency characteristics

The fraction at which the efficiency is maximum is 6/5= 1.2 w/V.

We confirmed that at 60W the efficiency is at minimum and at 300W the efficiency is maximum, however; an increased in load leads to increase in efficiency and vise vasa [15].

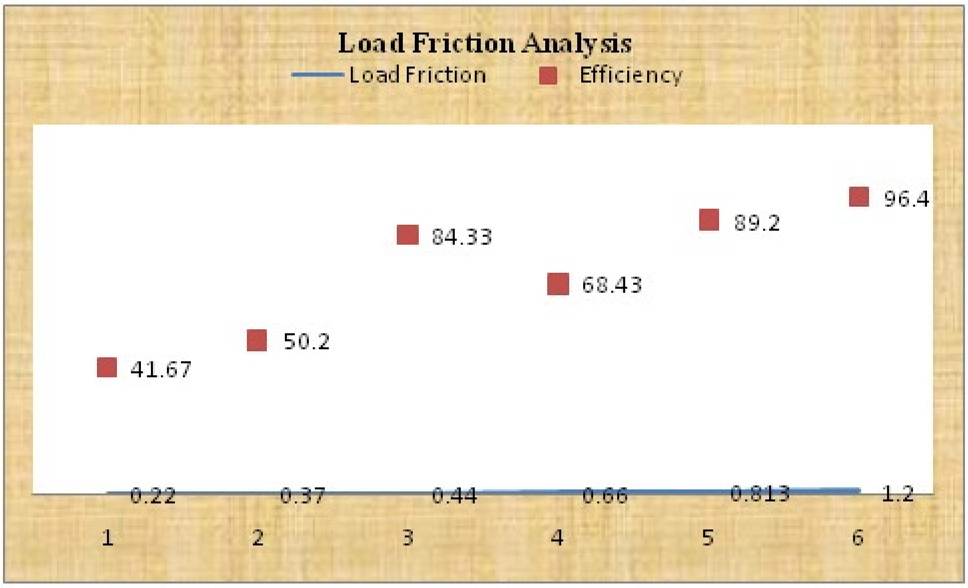

Fig.2 Load friction analysis

Comparing the load friction and efficiency, our analysis shows that there are increase and decrease of efficiency as the load friction changes, in general, the higher the load the higher the efficiency of the transformer and the lower the load the lower the efficiency of the transformer.

Table.2 Distributions of Primary winding and Secondary windings when subjected to various voltages

S/N	Primary side of the transformer			Secondary side of the transformer	
	Voltage V_0 (V)	Current I_0 (A)	Power W_0 (W)	Voltage V_1 (V)	Current I_1(A)
1	230	0.1	40	210	0.1
2	235	0.1	60	228	0.1
3	230	0.1	80	220	0.1
4	232	0.2	100	221	0.3
5	241	0.4	120	235	0.5
6	238	0.5	140	228	0.7
7	240	0.6	160	230	0.7
8	230	0.8	200	219	0.8
9	230	1.1	240	219	0.9
10	230	1.2	260	219	1.0
11	230	1.3	300	214	1.2

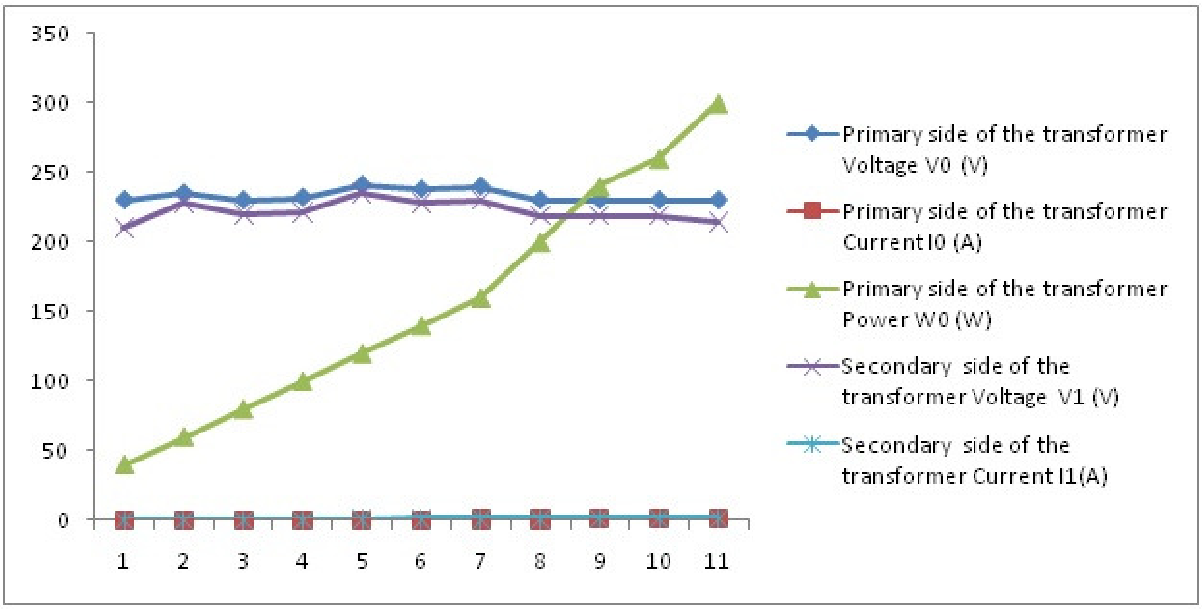

Fig.3. Demostation of primary and secondary current voltage and power characteristics

Calculation

$Cos\Phi_0$ = Power factor of the transformer, W_0/V_0I_0

R_{IE}= Equivalent resistance of the transformer (as calculated before)

X_{IE}= Equivalent reactance of the transformer (as calculated before)

P_1= Iron Loss (As recorded in Open Circuit test)

P_{CU}= Full load copper Loss (as recorder in short circuit test)

VA rating of transformer = 1 KVA (1000VA)

n=- Load Wattage/ VA rating of transformer

Hence, Efficiency and voltage regulation at n load:

P_1= 46W; as recorded in OC test

Pcu= 110W; as recorded in SC test

$Cos\Phi_0$ =0.9167

R_{IE} = 4.4 Ω

X_{IE} = 1.918 Ω

Efficiency and voltage regulation at n load

For 40W load

$$n = \frac{\text{Load voltage}}{\text{VA rating of transformer}} = \frac{40}{1000} = 0.04$$

$$\%\ \text{efficiency} = \frac{0.04*1000*0.9167}{(0.04*1000*0.9169)+(46+0.04^2+110)} * 100$$

$$= 44.26\%$$

$$\%\ R = \frac{(0.04*5*4.4*0.9167)-(0.04*5*1.918*0.9167)}{210} * 100$$

=0.216%

For 100W load

$$n = \frac{\text{Load voltage}}{\text{VA rating of transformer}} = \frac{100}{1000} = 0.1$$

$$\%\ \text{efficiency} = \frac{0.1*1000*0.9167}{(0.1*1000*0.9169)+(46+0.1^2+110)} * 100$$

$$= 66.059\%$$

$$\%\ R = \frac{(0.1*5*4.4*0.9167)-(0.1*5*1.918*0.9167)}{210} * 100$$

=0.542%

For 200W load

$$n = \frac{\text{Load voltage}}{\text{VA rating of transformer}} = \frac{200}{1000} = 0.2$$

$$\%\ \text{efficiency} = \frac{0.2*1000*0.9167}{(0.2*1000*0.9169)+(46+0.2^2+110)} * 100$$

$$= 78.437\%$$

$$\%\ R = \frac{(0.2*5*4.4*0.9167)-(0.2*5*1.918*0.9167)}{210} * 100$$

=1.08%

For 300W load

$$n = \frac{\text{Load voltage}}{\text{VA rating of transformer}} = \frac{300}{1000} = 0.3$$

$$\%\ \text{efficiency} = \frac{0.3*1000*0.9167}{(0.3*1000*0.9169)+(46+0.3^2+110)} * 100$$

$$= 83.107\%$$

$$\%\ R = \frac{(0.3*5*4.4*0.9167)-(0.3*5*1.918*0.9167)}{210} * 100$$

=1.63%

Efficiency and voltage regulation at full load

$$\%\ \text{efficiency} = \frac{1*1000*0.9167}{(1000*0.9169)+(46+110)} * 100$$

$$= 85.44\%$$

$$V_1 = \frac{1000}{5*0.9167} = 218.17V$$

$$\%\ R = \frac{(5*4.4*0.9167)-(5*1.918*0.9167)}{218.17} * 100$$

= 5.21%

3.1. ISOLATION TRANSFORMER

Table 4 Secondary and primary isolation voltages

Transformer	Voltage,V1(V)	Voltage, V2 (V)
Isolation	225	217

Calculation

Transformation ratio of transformer is $K = \frac{V2}{V1}$

Turns ratio of a transformer is $T = \frac{V1}{V2}$ or $\frac{N1}{N2}$

Where V_1=225 V and V_2= 217 V.

Hence, $K= \frac{217}{225}$ and $T= \frac{225}{217}$

3.2 Step down Transformer and Step up Transformer Transformation

In other to measure the step up voltage, an adjustable AC power supply was connected to the primary side of the transformer and was adjusted to 125V [16] [17].

The readings for V1 and V2 were measured and recorded. The values obtained are recorded in the table below.

Table 5 Step up and step down transformations

Transformer	Voltage,V1(V)	Voltage, V2 (V)
Step-down	228	114
Step-up	120	240

Calculation:

For step down transformer

Transformation ratio of transformer is $K = \frac{V2}{V1}$

Turns ratio of a transformer is $T = \frac{V1}{V2}$ or $\frac{N1}{N2}$

Where V_1=228 V and V_2= 114V.

Therefore $K= \frac{114}{228} = \frac{1}{2}$ and $T= \frac{228}{114} = \frac{2}{1}$

For step up transformer

Transformation ratio of transformer is $K = \frac{V2}{V1}$

Turns ratio of a transformer is $T = \frac{V1}{V2}$ or $\frac{N1}{N2}$

Where V_1=120V and V_2= 240V.

Therefore $K= \frac{240}{120} = \frac{2}{1}$ and $T= \frac{120}{240} = \frac{1}{2}$

4. CONCLUSION

In each test results the appropriate remarks are given. Since the results are not satisfactory, this transformer was declared as faulty. However the required correct results are mentioned thereby. Since the fuses provided on H.V. and L.V. were found blown off at the time of failure. This transformer was failed due to overload condition. The insulation strength of other windings gets deteriorated due to fault. It was also concluded that the;

- Transformation and turns ratio of isolation transformer are $\frac{217}{225}$ and $\frac{225}{217}$ respectively.
- Transformation and turns ratio of step down transformer are $\frac{1}{2}$ and $\frac{2}{1}$ respectively.
- Transformation and turns ratio of step up transformer are $\frac{2}{1}$ and $\frac{1}{2}$ respectively

RECOMDTATIONS

- The transformer should not be overloaded the fuses of appropriate capacity on each H.V./L.V. circuits should be provided.
- It is advisable to keep transformer loading up to 90% of their rated capacity

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