

## Experimental-Simulation Analysis for Transformer Single Phase in Resistive Load Condition.

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**Abstract** -Transformer is one of main components in electrical power system which role to increase or reduce voltage. Characteristics of transformer would be vital to ensure the voltage is fully transferred. This paper is presenting the study of transformer characteristics by using different approaches in experimental and simulation. This study focus on the output voltage, output current, the real power, the reactive power, the voltage regulations and efficiency resulting form different type of transformer in single phase system. Type of transformer been using in this experiment are the shell type, the toroidal type and the cut core type transformer in the resistive load condition. The analysed data are obtained from experiments as well as simulated model based on PSPICE Software. The result found that the shell type, the toroidal type and the cut-core transformer have produced 92%, 93% and 97% efficiency respectively in the resistive load condition.

**Keywords:** transformer, efficiency, PSPICE, resistive-load, apparent power.

### I. INTRODUCTION

The core of the first practical transformer, built by William Stanley in 1885, was made of carbon steel sheets [1]. Later, these materials were substituted

by silicon steels and today most distribution and power transformer cores in service are of grain oriented silicon steel laminations. However, this trend has been changed since the introduction of the amorphous alloys in the transformers of the U.S.A, Japan and European power distribution systems.

In the 21<sup>st</sup> century energy market, competition continues to accelerate in the electric industry. As a result, utilities will try to further improve system reliability and quality, while simultaneously being cost effective. The transformer manufacturing industry must improve transformer efficiency and reliability while reducing cost, since high quality, low cost products have become the key to survival [2]. Transformer efficiency is improved by reducing load and no-load losses. Transformer reliability is mainly improved by the accurate evaluation of the leakage field, the short-circuit impedance and the resulting forces on transformer windings under short-circuit, since these enable to avoid mechanical damages and failures during short-circuit tests and power system faults.

This paper represented the experimental and PSPICE simulation analysis for shell type, the toroidal type and the cut core type transformer. These two approaches will focus on the output voltage, output current, real power, reactive power, voltage regulations and efficiency for each type of transformer in single phase system. PSPICE has been chosen as it offers a user friendly interface. Over the years, many simulations for different aspects of a power system and engineering application using PSPICE have been demonstrated by different researchers [3]–[9].

## II. THEORY

### Operation, Voltage and Current of transformations.

The most common function of a transformer in a power system is to change voltage (and implicitly current) levels on the system. A transformer consists of one or more electrical windings linked or coupled together magnetically by a magnetic circuit or core. Since all transformers perform similar functions, the theory of two winding transformers may easily be extended to multi-winding transformers and one-winding transformers.

In order to understand the operation of a transformer, and to obtain certain basic relationship for an ideal transformer, consider the simple model shown as Figure 1 below;

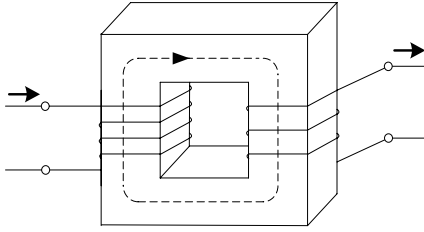


Figure 1: Basic single-phase two-winding transformer.

A fundamental parameter of the transformer is the turns ratio, defined as

$$a = \frac{N_1}{N_2} \quad (1)$$

The relationship of the windings to the instantaneous voltage  $E_1$  and  $E_2$  induced by the changing flux can be stated by Faraday's law as below,

$$v_1 = E_1 = N_1 \frac{d\phi}{dt} \quad (2)$$

$$v_2 = E_2 = N_2 \frac{d\phi}{dt} \quad (3)$$

Dividing both equations, yield,

$$\frac{v_1}{v_2} = \frac{E_1}{E_2} = \frac{N_1}{N_2} \quad (4)$$

Then, to find the relationship between the current  $I_1$  and  $I_2$  in the winding, the line integral of the magnetomotive force (*mmf*) is given by

$$\oint H_c \cdot ds = I \quad (5)$$

where

$I$  is the current passes through the bounded area in a closed path

$H$  is magnetic field intensity

$H \cdot ds$  is the product of the tangential component of  $H$  and the incremental distance  $ds$  along the path.

Note that, the current  $I_1$  and  $I_2$  contributes flux with different direction, thus the line integral can be written as,

$$\oint H_c \cdot ds = N_1 I_1 - N_2 I_2 \quad (6)$$

Converting the currents to phasor form, yield,

$$N_1 I_1 - N_2 I_2 = 0 \quad (7)$$

$$\frac{I_1}{I_2} = \frac{N_2}{N_1} \quad (8)$$

The equivalent circuit of single-phase transformer referred to the primary winding is shown in Figure 2. The resistances and reactance are determined from the open and short-circuit test. In power transformer, the current taken by the shunt branch is usually a very small percentage of the load current and can be neglected.

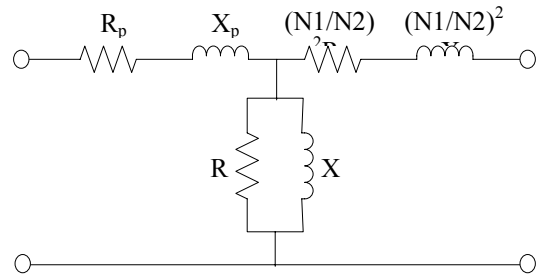


Figure 2: Equivalent circuit of single-phase two-winding transformer

The power delivered from the source passes through the transformer and fed to the load. Although no physical connection exists between the primary and secondary circuits, a connection does exist via a magnetic linkage between the coils. Transformers are in general very efficient

devices and its losses will seldom exceed 1 to 2% of load.

### Transformer losses

Transformer losses consist of no-load or core loss and load losses. This can be expressed by the equation below.

$$PT = Pc + PLL \quad (9)$$

where

$Pc$  core or no-load loss, watts;

$PLL$  load loss, watts;

$PT$  total loss, watts.

Core or no-load loss is due to the voltage excitation of the core. For nonsinusoidal load currents the primary voltage waveform is assumed to be sinusoidal.

Load losses consist of  $I^2R$  loss, eddy loss, and stray loss, or in equation form core or no-load loss, watts;

## II. EXPERIMENTAL SET-UP

The Experimental Set-up was commissioned in the Electrical Technology Laboratory, Faculty of Electrical and Electronics, University of Tun Hussein Onn Malaysia, Johor. Two experimental set up were used to determine voltage regulation and efficiency of the transformer correspondingly. The first experimental set-up is as given in Figure

$$PLL = I^2R + PEC + PSL \quad (10)$$

Where

$I^2R$  loss due to load current and dc resistance of the windings, watts;

$PEC$  winding eddy loss, watts;

$PSL$  stray losses in clamps, tanks, etc., watts

The  $I^2R$  loss is due to the currents in and the dc resistance of the windings. The ohmic loss is affected by the magnitudes of the harmonic currents but not the frequency.

The ohmic loss is determined by measuring the dc resistances using a dc current and voltage then a calculation is performed using the winding currents. There is no test method to determine individual winding eddy loss or to separate transformer stray loss from eddy loss.

3(a). For field-testing, a single-phase circuit is implemented. Meanwhile, 220Vac, 50Hz single-phase supply is connected to 200VA 220/2x110 V transformer with variable resistive load of 150W 210Ω – 1000Ω attached, is used as the second experimental set up (as shown in Figure 3(b)).

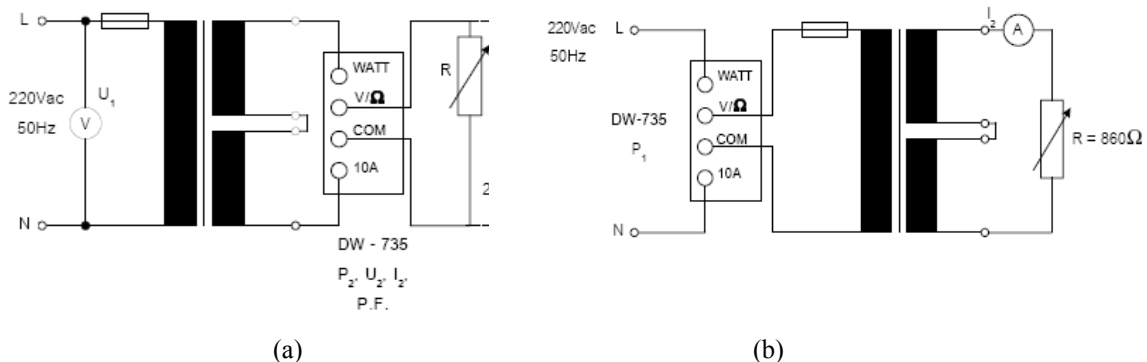


Figure 3: Schematic Diagram of Experimental Set-up for (a) determining voltage regulation (b) determining efficiency of the transformer



Figure 4: Photograph of the Experimental Set-Up

Three types of experimental transformer used are the shell type, the toroidal type and the cut core type as shown in Figure 5. The variable resistive

load used is 220 Vac max, 150W, 210Ω – 860Ω as shown in Figure 6.

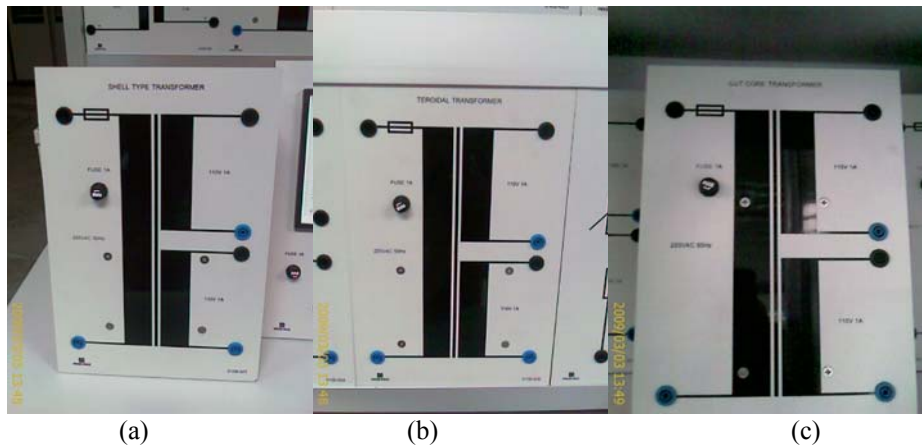


Figure 5: Photograph of (a) Shell type (b) Toroidal type (c) Cut-core type transformer



Figure 6: Photograph of resistive load (210, 390, 470 and 860Ω)

To measure the 220Vac 50Hz input voltage, Digital Multimeter GW with Model GDM 8034 is used. Meanwhile, for measuring the value of

voltage, current, active power and apparent power, the power analyzer DIGICON with DW 735 as shown in Figure 7 is used.



Figure 7: (a) The Power Analyzer DIGICON (DW-735) (b) The Digital Multimeter GW (GDM-8034)

#### IV. PSPICE SCHEMATIC

The schematic in Figure 8 is used to represent the experimental circuit for PSPICE simulation. During simulation, the circuit topology used is based on the experimental set up. Design parameters are fix to  $V_{sin} = 220V_{ac}$ , 50Hz from SOURCE:Libraries, XFRM\_NONLINEAR form BREAKOUT: Libraries, and  $R_{load} = 210\Omega - 860\Omega$ . Figure 9 (a) - (c) shows the waveforms of voltage, current, real power, apparent power and ratio of transformer from the PSPICE simulation.

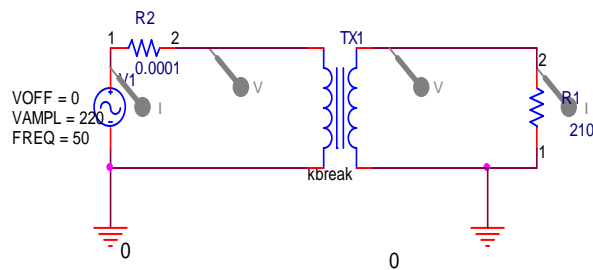


Figure 8: Schematic of transformer with resistive load.

The transformers voltage ratio is given by

$$a = \frac{V_1}{V_2}$$

where ( $V_1$  is the primary voltage and  $V_2$

is the secondary voltage). It is obvious that, the output voltage and the output current for this circuit are in phase due to its resistive load. The system also posses unity power factor pf. The active power can be expressed as  $P = RMS(V(R1 : 2)) * RMS(-I(R1))$  in watt (W) and the apparent power is  $S = RMS(V(TX : 1)) * RMS(-I(R1))$  in VA.

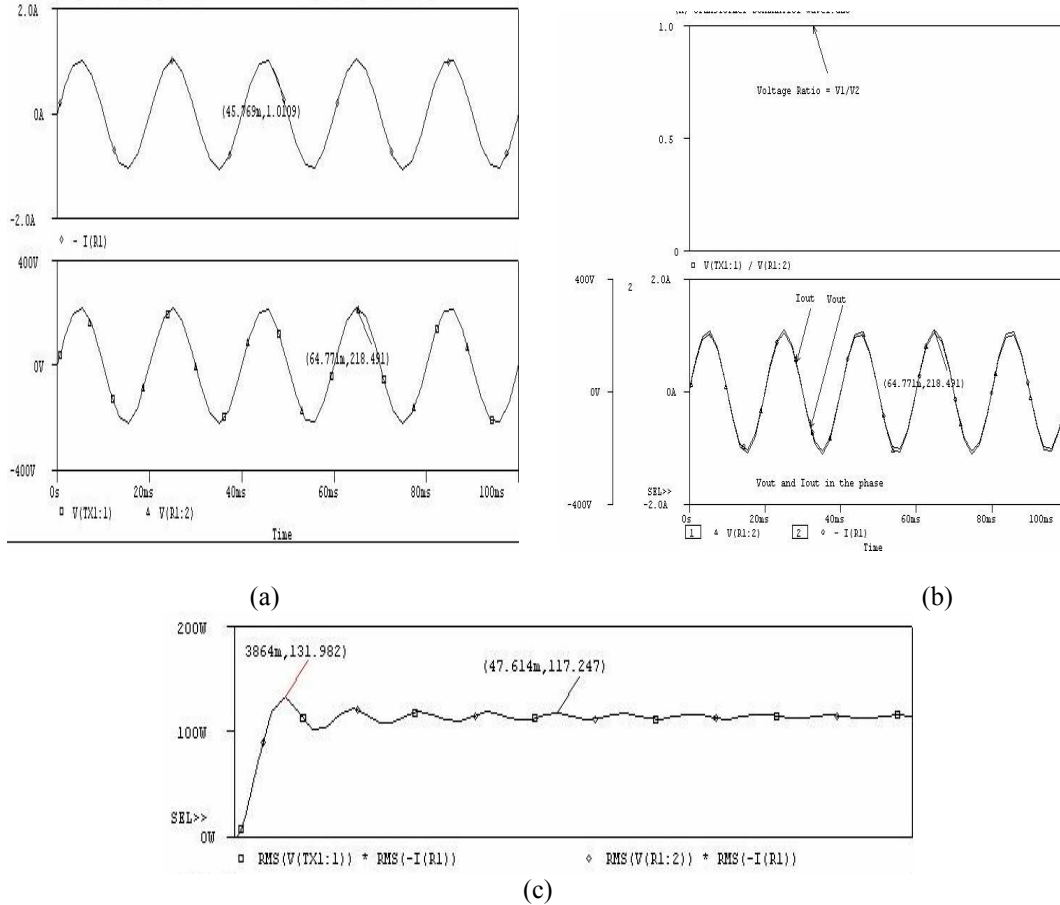


Figure 9(a) Waveform of voltage and current (b) Waveform of ratio is  $a=1$ , voltage and current in the phase (c) Waveform of real (P) and apparent power (S)

## V. RESULT AND ANALYSIS

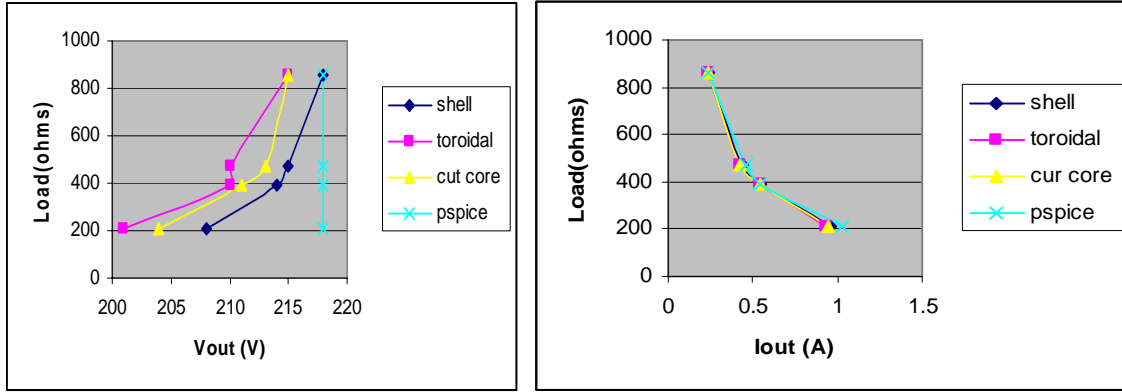
When the resistive load increased from  $210\Omega$  to  $860\Omega$ , the output voltage was increased from 200V to 220V as shown in Figure 10(a). Though, increment in resistive load would decrease the output current from 1.0 A until 0.3A as shown in Figure 10(b). Similar trend is experienced by each of the transformer used. Those trend are match with the Ohms Law which states that *the voltage  $v$  across a resistor  $\Omega$  is directly proportional to the current  $i$  flowing through the resistor*. [10]. Though, value obtained from PSPICE is equal the input voltage because no losses or no internal resistance in transformer and equipment of measurement is considered.

Changes in voltage and current when R load is increased, gives impact to the active power and the apparent power of the circuit. Theoretically, the active and apparent power are given by,

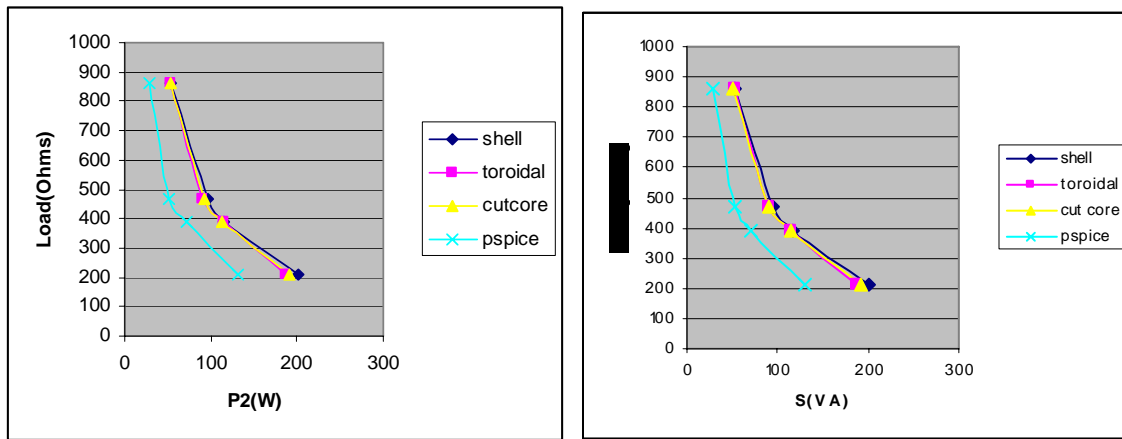
$$P = VI \cos \theta \quad (11)$$

$$S = VI \quad (12)$$

Since the transformer is solely connected to resistive load, unity power factor is achieved. Experimental results reveal that enhancement in resistive load magnitude, with constant voltage supply, would cause the active and apparent power would to decrease from 200W / 200VA to 50Watt / 50VA as shown in Figure 11(a) and (b).



(a) (b)  
Figure 10: Graph of (a) Vout versus Resistive Load (b) Iout versus Resistive Load



(a) (b)  
Figure 11: Graph of (a)  $P_2$  versus Resistive Load (b) S versus Resistive Load

The Voltage Regulation of the system is given by:

$$\%VR = \frac{V_1 - V_2}{V_2} \times 100\% \quad (13)$$

where ( $V_1$  is fixed and  $V_2$  varies on load, is no load transformer ratio).

Toroidal and cut core type transformer undergoes changes in voltage regulation from 8% to 2.5% since  $V_2$  decreased when R load is raised. In contrast, shell type transformer increased to 9% when R load being elevated beyond 500Ω. The complete plotting of voltage regulation for each type of transformer, at various values of load is as shown in Figure 10(a).

Mathematically, the efficiency is defined by:

$$\eta(\%) = \frac{P_{out}}{P_{in}} \times 100\% \quad (14)$$

(where the  $P_{in}$  is

$P_{out} + \text{core losses} + \text{copper losses}$  )

By changing the value of resistive load from 210Ω - 860Ω, different trend of efficiency is achieved for each type of transformer. The shell type transformer experience reduction in efficiency from 92% to 87%. This phenomenon occurs due to high transformer core loss which is near to 8W. Meanwhile, the toroidal type and the cut core type experience efficiency intensification up to 98% as shown in Figure 12. This situation occurs due to the low or nearly zero core losses in both of the transformer. For unity power factor condition, the highest efficiency achieved for the shell type, the toroidal type and the cut core type transformer are 91.99%, 92.9% and 97.2% respectively.

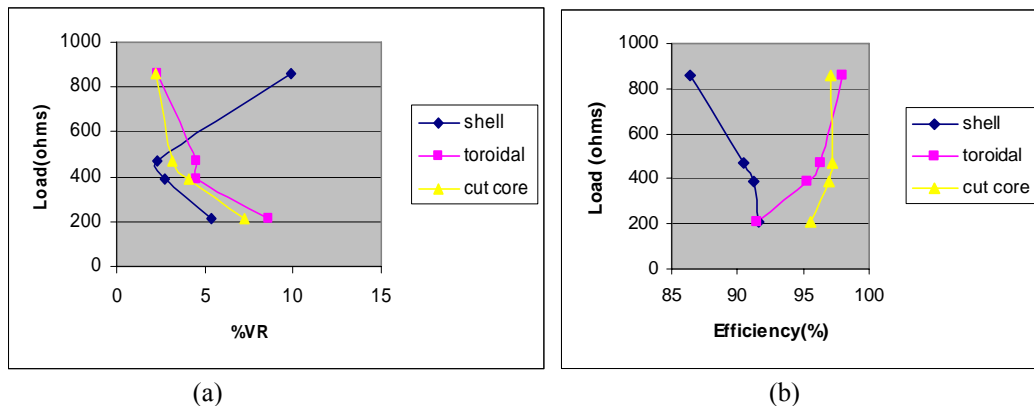


Figure 12: Graph of (a) %VR versus Resistive Load (b)  $\eta$  versus Resistive Load

## VI. CONCLUSION

The implementation for designing and analyzing transformer circuit using PSPICE of student version was described. This method was presented in electrical technology class to facilitate students to understand theoretical concepts and characteristics of electrical components, and on the other hand, students were asked to implement a different circuit as their class project or assignments. The experiment received a positive response. The technique presented in this paper can be extended for undergraduate mini projects design in electrical technology class and other courses.

## ACKNOWLEDGEMENTS

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