

Computer-Aided Teaching of Transformers for Undergraduates

Rajesh Kumar, Roopali Dogra, Puneet Aggarwal

Abstract—In the era of technological advancement, use of computer technology has become inevitable. Hence it has become the need of the hour to integrate software methods in engineering curriculum as a part to boost pedagogy techniques. Simulations software is a great help to graduates of disciplines such as electrical engineering. Since electrical engineering deals with high voltages and heavy instruments, extra care must be taken while operating with them. The viable solution would be to have appropriate control. The appropriate control could be well designed if engineers have knowledge of kind of waveforms associated with the system. Though these waveforms can be plotted manually, but it consumes a lot of time. Hence aid of simulation helps to understand steady state of system and resulting in better performance. In this paper computer, aided teaching of transformer is carried out using MATLAB/Simulink. The test carried out on a transformer includes open circuit test and short circuit respectively. The respective parameters of transformer are then calculated using the values obtained from open circuit and short circuit test respectively using Simulink.

Keywords—Computer aided teaching, transformer, open circuit test, short circuit test, Simulink.

I. INTRODUCTION

UNDERGRADUATE courses consists of intensive coursework of theoretical and laboratory exercises. Theoretical course work of machine includes steady-state operation of transformers used to compute various quantities such as losses efficiency and voltage regulation. The trials carried out during laboratory sessions include open circuit, short circuit tests conducted to determine no-load losses and equivalent circuit parameters, and load test to study transformer performance under various loading conditions. Since in the undergraduate course at Maharishi Markandeshwar University in the Electrical Engineering Department there is limited time allotted for laboratory sessions. Students have to perform the experiments within the stipulated time, which hinders students' ability to understand the experiment completely. Hence, to verify this survey was conducted, and around 92% of the students felt that there should be a virtual environment for electrical machinery course work. The advantage of the virtual environment being interactive learning and a boost to computer aided teaching. The shift towards computer aided teaching among students is

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due to availability of low cost personal computers with the required computation software readily available [1]. Due the familiarity of MATLAB/Simulink among the undergraduate students of Maharishi Markandeshwar University, the virtual environment used here is of MATLAB/Simulink. We can use other simulation software such as Maple and Math Cad also [2], [3]. Further advantage of the virtual environment include that student can have a check on their circuit and then proceed to perform the experiment. This in one way helps the students to recheck their circuit, and on the other hand, also helps students to apply their intuition logically and then check the viability of circuit. After the viability is checked, the students can now apply to hardware instruments, which would be great help for students in their projects at the undergraduate level. It should be also noted that software simulation cannot totally replace hardware due to modeling assumptions [4]. Here, the MATLAB/Simulink model is used for carrying out transformers open circuit and short circuit test, respectively.

II. OPEN- CIRCUIT TEST

The open circuit test of a transformer is performed using the circuit shown in Fig. 1.

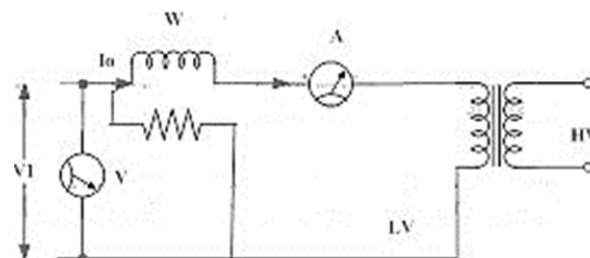


Fig. 1 Experimental Set Up For Open-Circuit Test

As illustrated in Fig. 1, the high voltage (HV) side of the transformer is open circuited and Voltmeter (V), Ammeter (A) and Wattmeter (W) are shown connected to low voltage (LV) side on transformer. The rated frequency voltage applied to primary [5]. When voltmeter reading is equal to the rated voltage of the LV winding, all the three instrument readings are recorded [5]. The ammeter records the no load current or the exciting current I_{oc} [5]. The input power is illustrated using wattmeter. The wattmeter reading consists of core and ohmic losses [5]. The exciting current being 2% to 6% of the full load current, hence ohmic loss during open circuit test is negligible [5]. Hence, wattmeter reading can be taken equal to transformer core loss. A negligible amount of dielectric loss may also exist.

A. Open-Circuit Test Using Simulink

The open-circuit test for calculation of parameter can be done using Fig. 2 [4]. The linear transformer block in the

Simulink diagram, as shown in the figure, can be modeled according to the values as shown in the table given below:

TABLE I
PARAMETER SPECIFICATIONS

PARAMETER	VALUES
Nominal Power and Frequency [Pn(VA) fn(Hz)]	[50e3, 50]
Winding 1 Parameters[V1(Vrms) R1(ohm) L1(H)]	[120 36.3 0.03]
Winding 2 Parameters [V2(Vrms) R2(ohm) L2(H)]	[2400 0.0047 3.18]
Magnetizing Resistance and Inductance [Rm(ohm) Lm(H)]	[57600 183.35]

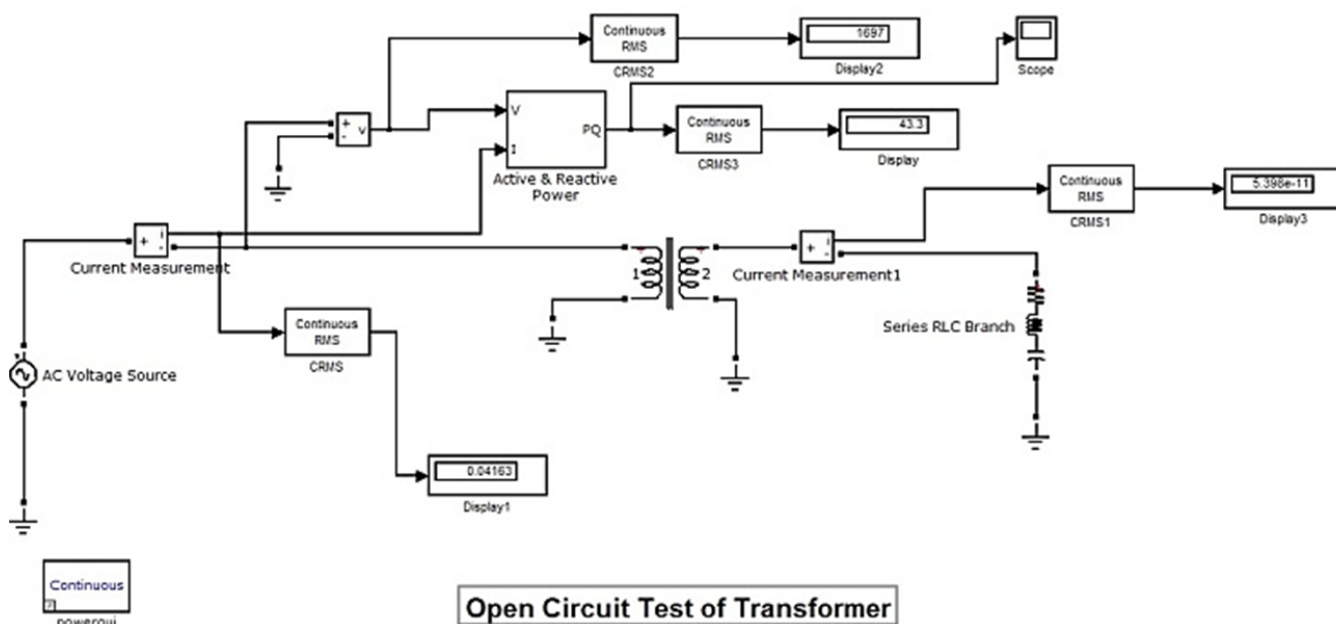


Fig. 2 Open-circuit test Using Simulink

The measurements either from experimental or simulation enables us to compute resistance (R_c) and reactance (X_m) approximately of the excitation branch referred to the primary side [4]. The magnitude of the excitation impedance from the open circuit voltage and current is computed as:

$$|Z_E| = R_c + jX_m = \frac{V_{OC}}{I_{OC}} \quad (1)$$

where R_c is the core resistance and X_m is the magnetizing reactance. The phase angle of admittance can be computed from the knowledge of power factor. The power factor PF_{OC} is given by,

$$PF_{OC} = \frac{P_{OC}}{V_{OC}} * I_{OC} \quad (2)$$

Once the power factor is computed, angle ϕ is known, R_c and X_m can be computed as follows [4]:

$$R_c = |Z_E| * \cos \phi, \quad (3)$$

$$X_m = |Z_E| * \sin \phi$$

III. SHORT CIRCUIT TEST

The short circuit is performed using the circuit as shown in Fig. 3 [5].

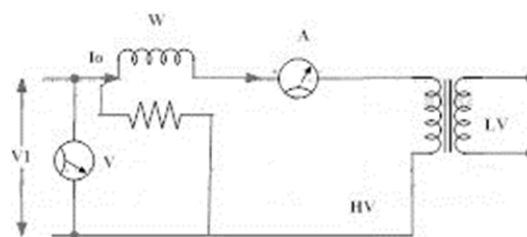


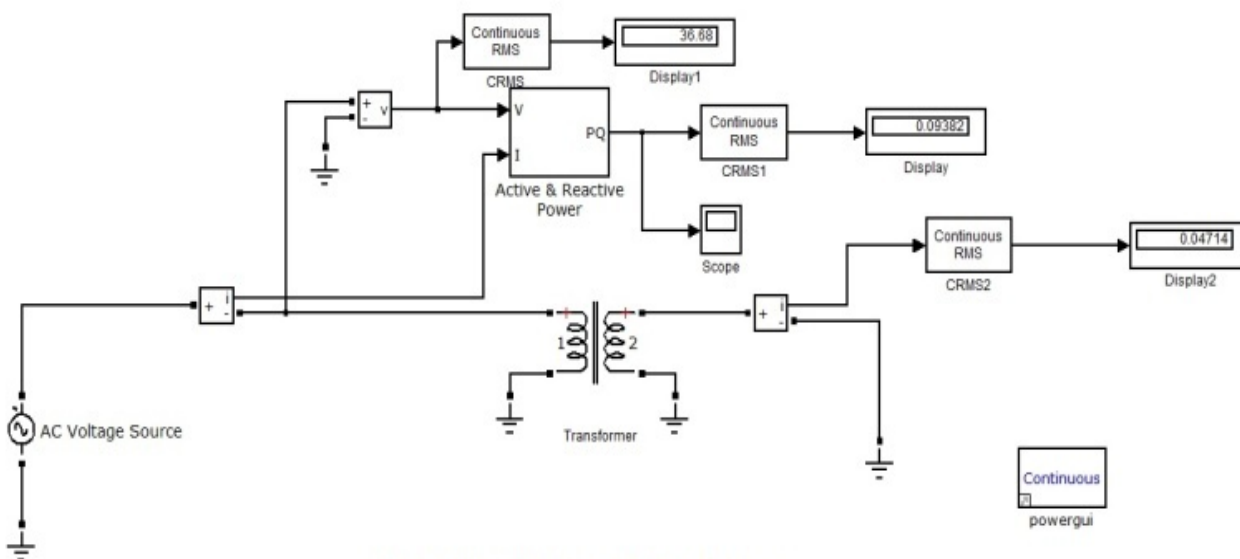
Fig. 3 Experimental Setup for Short-Circuit Test

In the following test, the LV side of transformer is short circuited and the instruments are placed on high voltage side, as illustrated in Fig. 3 [5]. The applied voltage is adjusted such that rated current flows in the circuit. A primary voltage of about 2% to 12% of rated voltage is sufficient for the flow of rated current in both primary and secondary windings [5]. The wattmeter in short circuit test of transformer reads ohmic loss in both the windings [5].

A. Short- Circuit Test Using Simulink

The short-circuit test of transformer can be performed using Simulink model shown in Fig. 4 [4]. The linear transformer

block in the Simulink diagram can be modeled according to parameters as shown in Table I.



Short Circuit Test of Transformer

Fig. 4 Short-circuit test using Simulink

The input voltage, short circuit current and real power are measured. A negligible current flow through the excitation branch since a reduced voltage is applied to the primary of the transformer [4]. The magnitude of series impedance referred to primary side of transformer can easily be computed by neglecting this current as:

$$|Z_{eq}| = |Z_{sc}| = \frac{V_{sc}}{I_{sc}} \quad (4)$$

Neglecting the core loss at the low value of V_{sc} , the equivalent leakage reactance and resistance can be found by,

$$\begin{aligned} X_{eq} &= X_{sc} = \sqrt{|Z_{eq}|^2 - R_{eq}^2} \\ R_{eq} &= R_{sc} = \frac{P_{sc}}{I_{sc}^2} \end{aligned} \quad (5)$$

The equivalent resistance and reactance are the sum of resistance and reactance of the primary and secondary referred to primary side. The primary and secondary windings have

equal contribution to total resistance and reactance is general assumption [4].

IV. HYSTERESIS IN SATURABLE TRANSFORMER

The simulation of saturable transformer is carried using Fig. 3 [6].

The transformer in Fig. 3 consists of three coupled windings wound on a same core [6]. Winding resistance and the leakage inductance as well as the magnetizing characteristics of the core are taken into account in this model. The magnetizing characteristic of the core is modeled by a resistance R_m simulating core active losses and saturable inductance L_{sat} . With the help of the hysteresis design tool of powergui, block hysteresis is carried out. Eddy current losses are modeled by a linear resistance R_m . The transformer block is modeled according to the parameters as given in Table II [6].

TABLE II
 SATURABLE TRANSFORMER PARAMETERS

PARAMETER	VALUES
Nominal Power and Frequency[Pn(VA) fn(Hz)]	[150e6 50]
Winding 1 parameters[V1(rms) R1(pu) L1(pu)]	[500e3/sqrt(3) 0.002 0.08]
Winding 2 parameters[V2(rms) R2(pu) L2(pu)]	[230e3/sqrt(3) 0.002 0.08]
Winding 3 parameters[V3(rms) R3(pu) L3(pu)]	[181.87e3 0.002 0.08]
Saturation Characteristic[i1 phi1; i2 phi2;...](pu)	[0 0; 0.0 0.85; 0.015 1.2; 0.03 1.35; 0.06 1.5; 0.09 1.56 ; 0.12 1.572]
Core loss resistance and initial flux[Rm phio] or [Rm] (pu)	[200 0]

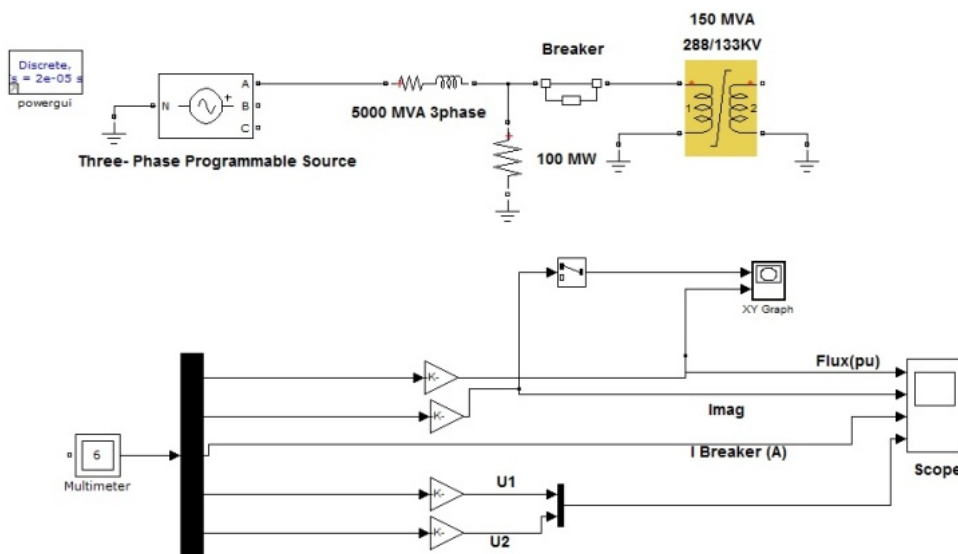


Fig. 3 Hysteresis in Saturable Transformer

V.RESULTS

Using the Simulink diagram as shown in Figs. 1 and 4, respectively, the open circuit and short circuit parameters of transformer is noted in Table III:

TABLE III
SIMULATION RESULTS

Test	V(V)	I(A)	P(W)	Q(VAR)
Open-Circuit	1697	0.041	42.05	43.3
Short-Circuit	36.68	0.047	0.0481	0.093

Using the results obtained from Table II, transformer parameters are calculated using (1), (2), (3), (4) and (5), respectively. After the calculations, the values are tabulated in Table IV. After obtaining the parameters from the calculations, the simulations results are compared with the

experimental value, and hence, the error is tabulated in Table V.

TABLE IV
PARAMETER CALCULATIONS

Rc(Ω)	Xm(Ω)	Req(Ω)	Xeq(Ω)
32975.87	433.42	18.10	780.21

TABLE V
ERROR IN SIMULATION

Rc(Ω)	Xm(Ω)	Req(Ω)	Xeq(Ω)	
Error (%)	1.188	0.835	0.1002	0.0399

After simulating Fig. 3, the hysteresis curve is obtained, as shown in Fig. 4. The other related waveforms obtained after the simulation of Fig. 3 are shown in Fig. 5.

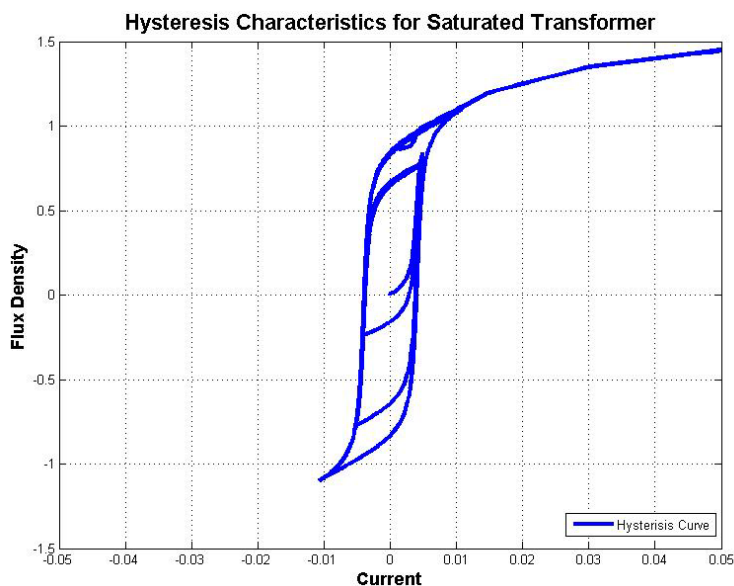


Fig. 4 Hysteresis Characteristics for Saturated Transformer

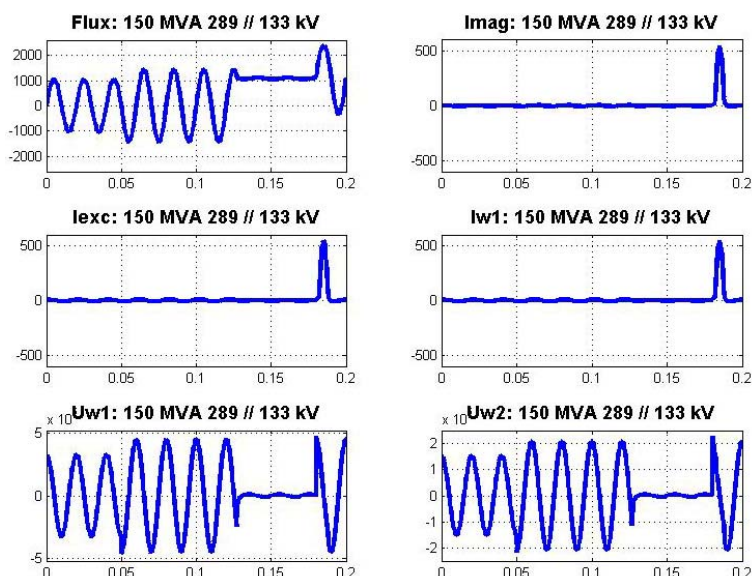


Fig. 5 Waveforms for Saturated Transformer

VI. CONCLUSIONS

Since the error lies within the range of 1%, the simulation model for the transformer so made using Simulink is appropriate. This helps the students to check and perform the virtual tests using simulation at their personal computer any time and then proceed to laboratory experiment. The virtual environment, hence, makes the learning more interactive and helps student to get a clearer view of working of transformer. After successful implementation of these tests the students are asked to perform further experiments as an assignment to boost up their simulation skills. The virtual environment implemented at undergraduate courses at Maharishi Markandeshwar University helped students to understand the gap between simulations and hardware, and they drew conclusions. That is, we cannot replace an exact model of hardware in simulations due to hardware limitations, which gives an explanation to the error so obtained in comparison of the modeling and laboratory results.

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