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# Modeling the base tests of monophase transformer

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**Abstract**

The paper develops a model created in Simscape – SIMULINK to study the monophase transformer behaviour. The equivalent circuit topology of a typical transformer needs to implement a procedure to determine the values for equivalent circuit elements based on performance criteria. The preliminary tests need in study of behaviour ‘s transformers are open-circuit and short-circuit tests.

The paper implements a model realised with Simscape block offered by MATLAB library used for modelling the transformer ‘behaviour described on laboratory tests.

**Keywords**: modelling, open-circuit test, short-circuit test

# 1. Introduction

## 1.1 Transformer. Construction and Electromagnetic Structure

The transformer has a relatively simple electromagnetic structure and represents a very useful tool in developing relationships of real value in the analysis of more complex electromagnetic structures. The transformer is extremely important as a component in many different types of electric circuits, the usual functions of a transformer being:[1]

i) to change the voltage and current level in an electrical system
ii) to assure an electrical separation between different circuits
iii) to match impedance

The construction of transformers varies greatly, depending on their applications, windings voltage and current ratings, and operating frequencies. Usually, power transformer consists of following main parts: iron core and the windings, forming together the electromagnetic structure and a housing or case of safety and protection. The space surrounding the electromagnetic structure is, in several types of transformers, filled with transformer oil. This one prevents damages to the electromagnetic structure, assures an electrically insulation and facilitates heat transfer between the electromagnetic structure and the case. In most power oil-filled transformers the oil circulates through cooling fins or tubes outside of the case to improve further the heat transfer characteristics.

The transformer core is the sheet steel laminations system which forms the magnetic circuit. The interleaved construction of transformer magnetic core leads to smaller air gaps that means lower no-load current and better mechanical stability but is more complicated.
The cross-section of a column is a stepped polygon inscribed in a circle with diameter Dc, Figure 1. The yoke is of square type section increased 5 to 10 per cent compared to the column section. Because of column stepped section the yoke sheets are unequal in length.

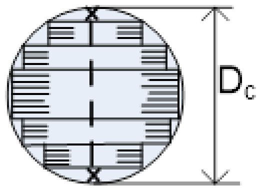


Figure 1 Stepped column cross section

The transformer's windings are cylindrical windings. High and low voltage windings can be disposed as concentric windings, which in each cross section are circle with common center, and sandwich when coils of the high and low voltage windings alternate along the height of the column.

## 1.2 Principle of Operation, Ideal Transformer.

The transformer is a straightforward of Faraday's Law of Electromagnetism Induction. The basic transformer consists of two coils in proximity. Figure 2 shows a two coils (windings) ideal transformer. The transformer is ideal because its iron core is lossless and infinity permeable, its windings have no losses, and the leakage fluxes does not exist. [2]

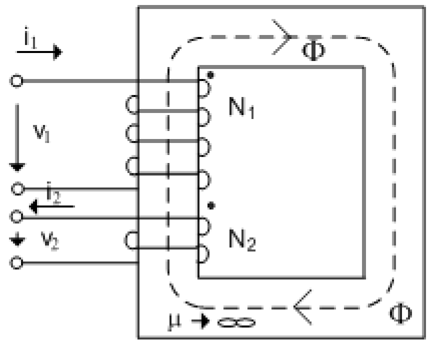


Figure 2 An ideal transformer.

One winding of N1 turns (primary) is excited with alternating current (i1) and establishes a flux Φ1 which alternates with the current. The other winding (secondary) is linked by this flux and thus has a mutually induced emf. This emf will drive a load current to any circuit connected to the terminals of secondary winding. The load current will produce a flux Φ2 which usually will oppose the flux Φ1 produced by the current i1 following through primary winding. The resulting flux thorough the core is Φ, and in the case of ideal transformer.

$$\phi = \phi_1 - \phi_2 \qquad (1)$$

According to Faraday's Law the emf's e1 and e2 induced in the two windings by the flux Φ are:

$$e_1 = -N_1 \frac{d\phi}{dt} \quad (2)$$

$$e_2 = -N_2 \frac{d\phi}{dt} \quad (3)$$

From (2) and (3),

$$\frac{e_1}{e_2} = \frac{N_1}{N_2} = \frac{E_1}{E_2} = k \quad (4)$$

Where E1, E2 are rms values of e1 and e2 and k is known as the turns ratio.

## 1.3 No ideal Transformer, Referring Secondary Quantities to the Primary.

A no ideal (actual) transformer has core and resistive losses and because its core has not an infinite permeability it requires a finite mmf for its core magnetization. Also, not all fluxes link with the primary and the secondary windings because of flux leakages which do not exist in an ideal transformer. In Figure 3 shows a no ideal transformer with all its parameters, $R_1$ and $R_2$ being the resistances of the primary and secondary windings. The primary and the secondary leakage fluxes are shown as $\Phi_{1\sigma}$ and $\Phi_{2\sigma}$, respectively. If $\Phi_{1m}$ and $\Phi_{2m}$ are respectively the primary and the secondary core fluxes (magnetizing fluxes) than for each winding the total flux $\Phi_1$, respectively $\Phi_2$ is a sum of fluxes,

$$\phi_1 = \phi_{1m} + \phi_{1\sigma} \text{ , } \phi_2 = \phi_{2m} + \phi_{2\sigma} \quad (5)$$

which leads to:

$$\phi = \phi_{1m} - \phi_{2m} + \phi_{1\sigma} - \phi_{2\sigma} \quad (6)$$

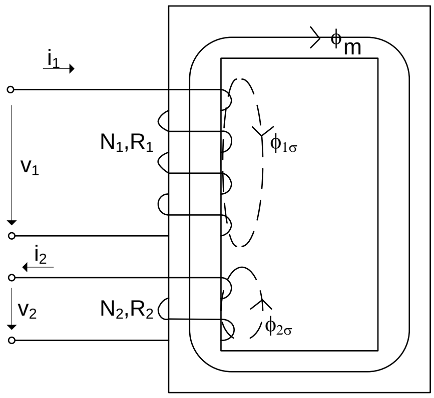


Figure 3. A non-ideal transformer

where the resulting core flux is:

$$\phi_m = \phi_{1m} - \phi_{2m} \quad (7)$$

The primary winding voltage equation is:

$$v_1 = R_1 i_1 + \frac{d\lambda_1}{dt}, \quad (8)$$

where the flux linkage Φ1 is given by:

$$\lambda_1 = N_1(\phi_m + \phi_{1\sigma}) \tag{9}$$

By substituting (7) in equation (8),

$$v_1 = R_1 i_1 + \frac{d}{dt}(N_1 \phi_{1\sigma}) + \frac{d}{dt}(N_1 \phi_m) \tag{10}$$

The secondary windings voltage equation is

$$v_2 + R_2 i_2 + \frac{d\lambda_2}{dt} = 0 \tag{11}$$

where $\lambda_2$ is the flux linkage

# 2 Equivalent Circuit from Test Data, Computing the Transformer's Characteristics.

The major use of the equivalent circuit of a transformer is in determining its characteristics. The transformer parameters, the resistances and the reactances, of the equivalent circuit may be obtained from no-load (open circuit) and short-circuit tests.

## 2.1 Open – Circuit Test. (No – Load Test)

In this test the secondary winding is open-circuit and the rated voltage at rated frequency is applied to the primary winding. The voltages, current and power at the terminals of this winding are measured. The open-circuit voltage of the secondary winding is also measured and a check on the turn's ratio can be obtained. If $P_{10}$, $V_{1N}$ and $I_{10}$ are the input power, voltage and current, respectively, are obtained:

$$\underline{V_1} = (\underline{Z_1} + \underline{Z_m})\underline{I_{10}} \tag{12}$$

$$P_{10} = p_{Fe} + I_{10}^2 R_1 \tag{13}$$

Where the impedances are:

$$\underline{Z_1} = R_1 + jX_1 \tag{14}$$

$$\underline{Z_m} = R_m + jX_m \tag{15}$$

primary winding impedance and magnetizing impedance.
With quite a good accuracy, from no-load test data are obtained:

$$R_m \cong R_0, \quad X_m \cong X_0 \tag{16}$$

The turns ratio is approximately,

$$k \cong \frac{V_{1n}}{V_{20}} \tag{17}$$

In figure 4 is presented the equivalent circuit for no-load test.

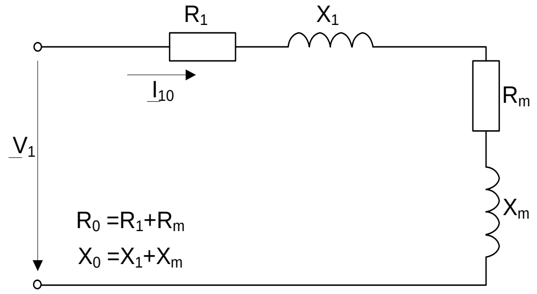


Figure 4 The equivalent circuit for no-load test

## 2.2 Short-Circuit Test.

In this test the secondary winding is short-circuited across its terminals and a reduced voltage is applied to the primary terminals. This reduced voltage was such a value as to cause a specific current – the rated one – to flow in the short circuited secondary. The reduced voltage which applied to primary produces the rated value of the current in the secondary winding is named short-circuit voltage, and is given usually by its referred to the primary rated voltage, vs,

$$v_{sc} = \frac{V_{sc}}{V_{1N}} \cdot 100 \tag{18}$$

Where $V_{sc}$ is the actual value of primary voltage and $V_{1N}$ is the rated one.
the equivalent circuits reduce to that of Figure 5.

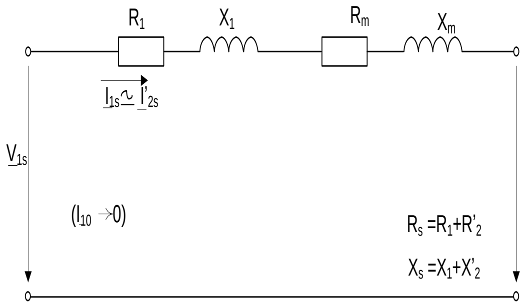


Figure 5 Short – Circuit

Thus, if $P_{1sc}$, $I_{1sc}$, and $V_{sc}$ are, respectively the input power, current, and voltage measured on the primary winding terminals under short-circuit test than, considering the simplified equations:[3]

$$\begin{gathered} \underline{V}_{sc} = \underline{Z}_1 \underline{I}_{1sc} + \underline{Z}'_2 \underline{I}'_{2sc} \\ \underline{I}_{1sc} \cong \underline{I}'_{2sc} \quad \left(\underline{I}_{10} \to 0\right) \end{gathered} \tag{19}$$

If $R_1$ is given the results of $R'_2$ and $R_2$ is given because k is known from no-load test. To separate $X_1$ and $X'_2$ is usually quite complicated, it requires another test, and therefore assuming that the leakage reactance is divided equally between the primary and secondary,

$$X_1 \cong X'_2 \cong \frac{1}{2} X_{sc} \tag{20}$$

The measured power represents, by neglecting the core losses which are very small, only the conductor type (Joule) losses, and it is the rated value, that is

$$P_{sc} = R_{sc} \cdot I_{1N}^2 \tag{21}$$

# 3 Modeling in Simscape.

Simscape Electrical provides component libraries for modelling and simulating electronic, mechatronic, and electrical power systems. It includes models of semiconductors, motors, and components for applications such as electromechanical actuation, smart grids, and renewable energy systems. You can use these components to evaluate analog circuit architectures, develop mechatronic systems with electric drives, and analyze the generation, conversion, transmission, and consumption of electrical power at the grid level. [4]
With Simscape, you build physical component models based on physical connections that directly integrate with block diagrams and other modeling paradigms.
Using the blocks provided by the Matlab platform it is possible to simulate the behaviour of a monophase transformer which are equivalent with practical experiments for open-test and short-circuit test.
Using these blocks which include the equations described above it is possible to make a comparison between practical results and simulations one.

## 3.1 Simulation for an open-circuit test.

In figure 6, is presented the model for open-circuit test done in Simscape.

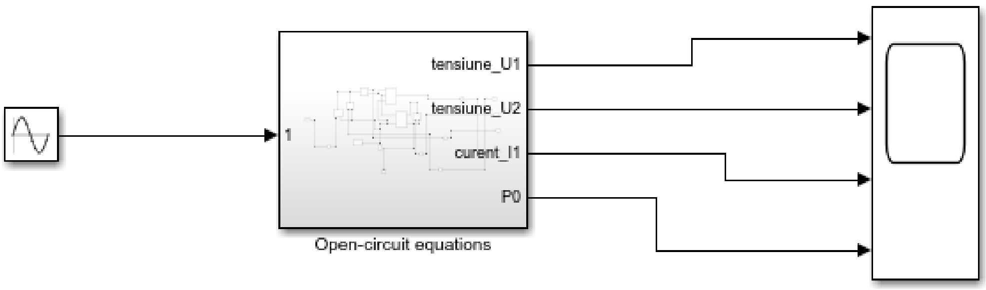


Figure 6 Model for open-circuit test.

The model contains a subsystem presented in figure 7.

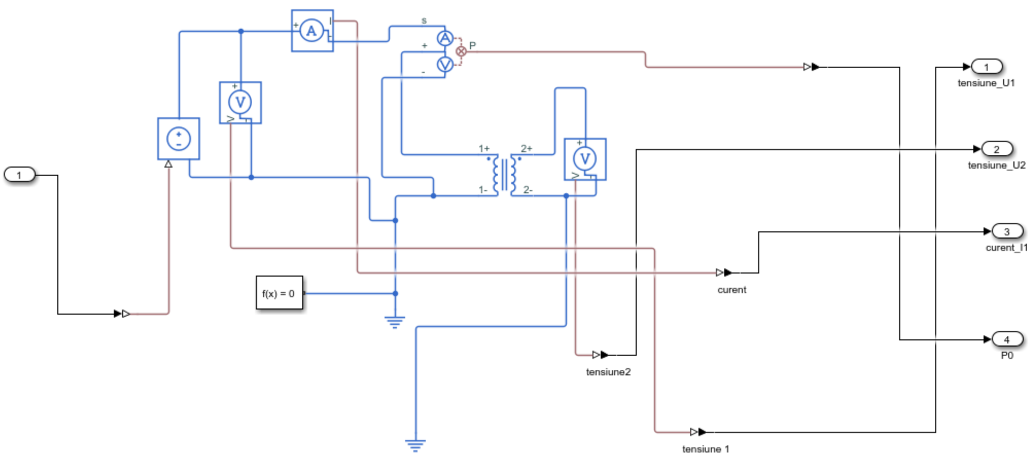


Figure 7 Open -circuit equations

### 3.2 Simulation for short-circuit test

In Figure 8 is presented the model created with Simscape help for an short-circuit test. The model contains a subsystem with all the sensors necessary for a practical application. (Figure 9)

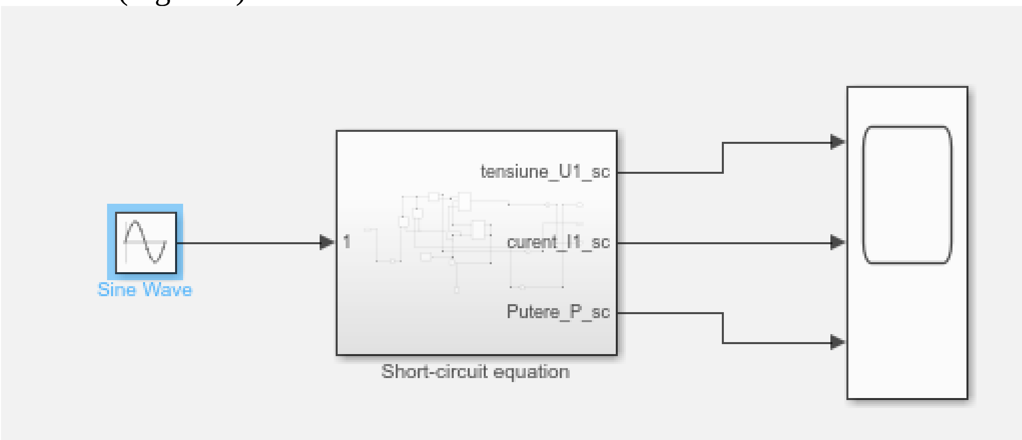


Figure 8 The model for short-circuit applications

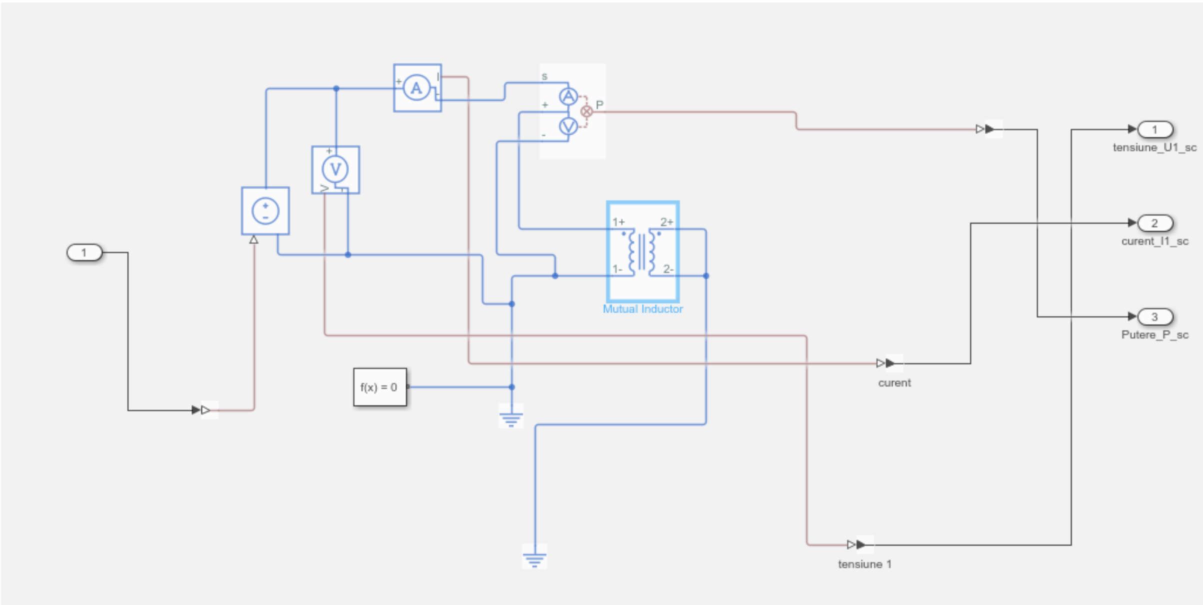


Figure 9 The equations for short-circuit tests.

## 4 Results

In Figures 10 and 11 are presented the results obtained for open and sort circuit tests. The electrical circuits are done into the laboratory applications. The results obtained respect the results obtained in laboratory.
The results are done using the Simulink Library resources for reding an interactive model. To do so, Simulink offers a series of buttons and visualization interfaces named “dashboard” able to create interactive models. [5]
It is thus possible to alter the buttons to modify the model configuration to notice what’s happened when you introduce another value. The “Real-Time Pacer” block of the Real-Time Pacer library makes possible these adjustments to be performed.

The Simscape functionalities and libraries are very good in build up usable models. This should be a first step in creating a digital model very useful in learning process. The results are pretty accurate and help the students to understand the phenomena happens inside more efficiently.

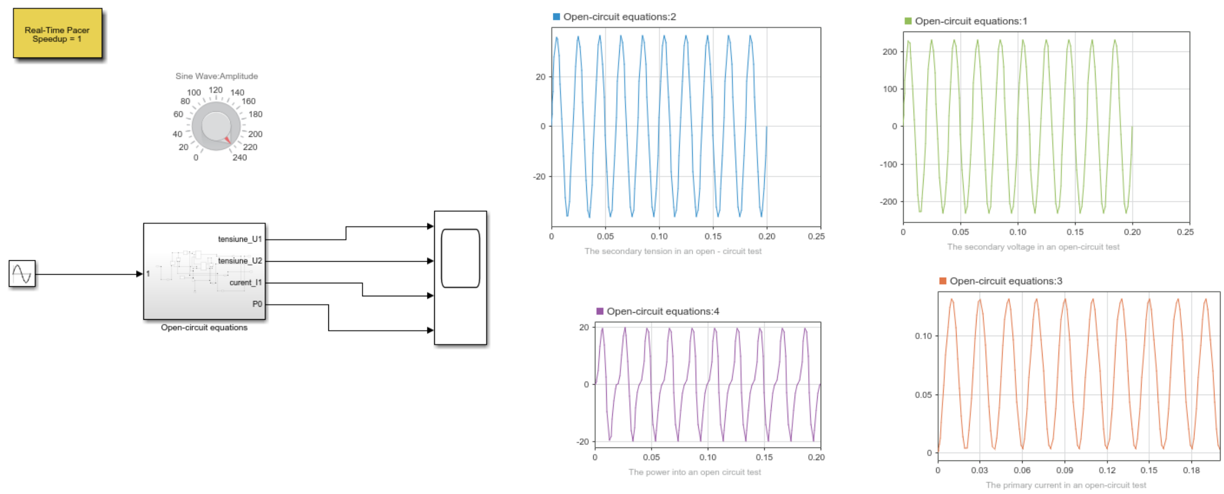


Figure 10. Results obtained for an open-circuit test (the primary voltage, the primary current, the secondary voltage and the power)

The results obtained are according to the practical results of testing done in laboratory.

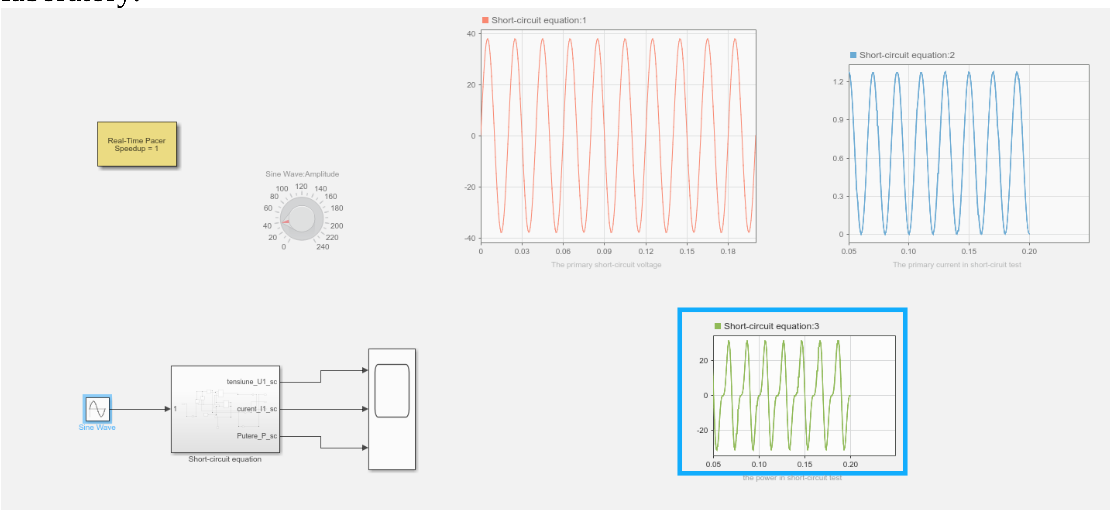


Figure 11 Results obtained for an open-circuit test (the primary voltage, the primary current, the secondary voltage and the power)

# 5 Conclusions

The paper does not present the proper heating loss associated with the hysteresis phenomenon, the nonlinear dependency of the voltage or the coil current. This thing could be done by a MATLAB program uses the principles for constructing a single piecewise linear hysteresis loop for an interactive input. The program can create the look-up table feature to generate the corresponding array of flux as the hysteresis loop when is traversed over a cycle of current. The flux array is then time differentiated to form the coil-induced voltage in accordance with Faraday's law. The normalized current, flux, and voltage could be plotted for inspection which will be the future development of applications of equivalent circuit for a monophase-transformer.[6]

## References

[1] Simion, A., *Electrical machines. Vol.1,2,3, (Maşini electrice, Transformatoare electrice)*, Editura Gh. Asachi, Iaşi, vol.1, 2000 – 2006.
[2] Boldea, I., Nasar, S.A., *Vector control of AC drives, CRC Press*, New York, 1992.
[3] Viorel Alina Cristina, Viorel I.A. *Electrical Machines*, LucianBlaga University of Sibiu, 2016.
[4] www.mathworks.com
[5] Liebgott,I., *Modeling and Simulation of Multi-Physics Systems with MATLAB_Simulink for students and Engineers, second edition, Introduction to Model-Based- Design*, University of Nice, 2016.
[6] Cathey J.J., *Electric Machines: Analysis and Design, Applying MATLAB*, McGraw Series in Electrical and Computer Engineering, ISBN 0-07-242370-6, 2001.