# Lab Exercise 10: Simulation of Zero-sequence Currents in Three-Phase Transformers

| Students | ID | | | |
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| | | | **Group** | |
| | | | **Date** | |
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## I.    Introduction:

Transformer plays an important role in the power transmission and distribution system, for transferring energy between different voltage levels. Transmission systems normally transfer large amount of energy, hence the use of three-phase transformers.

*Definition:* **Three-phase transformer** is a static electrical machine, used for transferring energy from one three-phase voltage/current system to another three-phase voltage/current system, due to electromagnetic induction phenomenon.

Transformers are constructed from magnetic cores and windings.

The lab exercise is constructed to help students build mathematical models of three-phase transformer in the simulation environment of MATLAB/Simulink, used for investigating zero-sequence currents in Δ-Y connected three-phase transformers. Magnetic saturation will be considered in the transformers' model.

## II.    Model of saturated three-phase transformers

1. Model of a two-winding transformer (Fig. 1-1)



Fig. 1-1
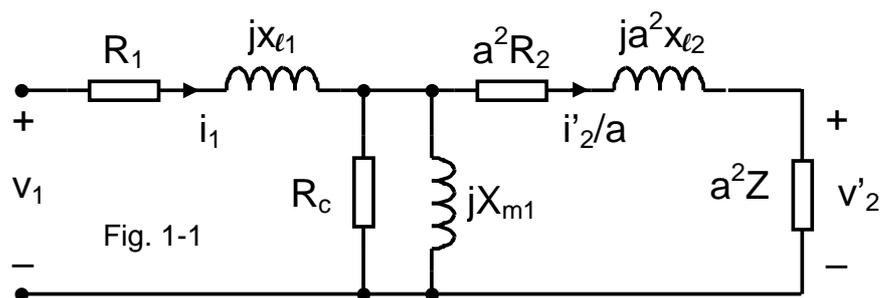
$$i_1 = \frac{\psi_1 - \psi_m^{sat}}{x_{l1}} \qquad\qquad i_2' = \frac{\psi_2' - \psi_m^{sat}}{x_{l2}'}$$

$$\psi_1 = \int \left\{ \omega_b v_1 - \omega_b r_1 \left( \frac{\psi_1 - \psi_m^{sat}}{x_{l1}} \right) \right\} dt \qquad \psi_2' = \int \left\{ \omega_b v_2' - \omega_b r_2' \left( \frac{\psi_2' - \psi_m^{sat}}{x_{l2}'} \right) \right\} dt$$

$$\psi_m^{sat} = x_M \left( \frac{\psi_1}{x_{l1}} + \frac{\psi_2'}{x_{l2}'} - \frac{\Delta\psi}{x_{m1}^{unsat}} \right) \qquad\qquad \frac{1}{x_M} = \frac{1}{x_{m1}^{unsat}} + \frac{1}{x_{l1}} + \frac{1}{x_{l2}'}$$

$$\psi_1 = \omega_b \lambda_1 \qquad \psi_2' = \omega_b \lambda_2' \qquad\qquad \omega_b \text{ is the base frequency for inductance calculation}$$

A look-up table can be used to implement the saturation characteristic of the magnetic core, where flux linkage is calculated at any time step from the unsaturated value and the difference between it and the saturated value. The difference between to unsaturated and saturated flux linkages can be determined from the open-circuit test.

For three-phase transformers, depending on the magnetic core structure and three-phase connections, one can use the single-phase equivalent circuit above, or the full three-phase equivalent circuits.

Consider a Y-Y connection for a three-phase transformer (Fig. 1-2), a single-phase equivalent circuit can be developed, as shown in Fig. 1-3.
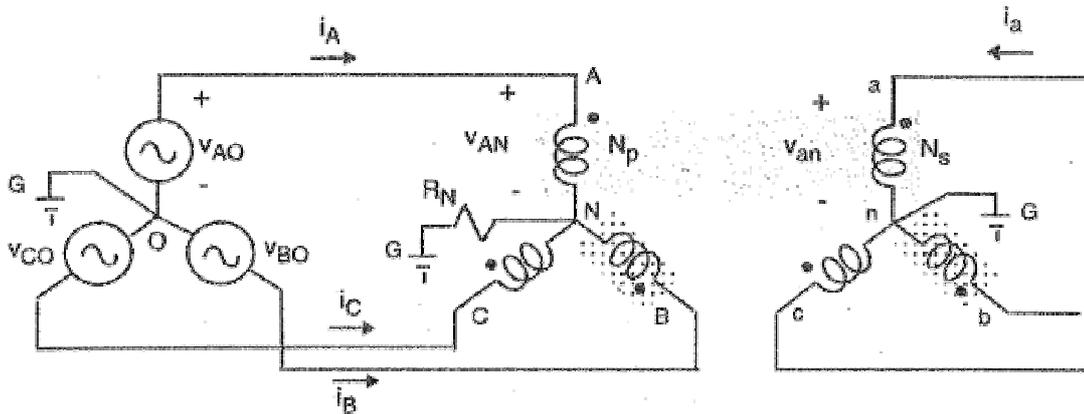


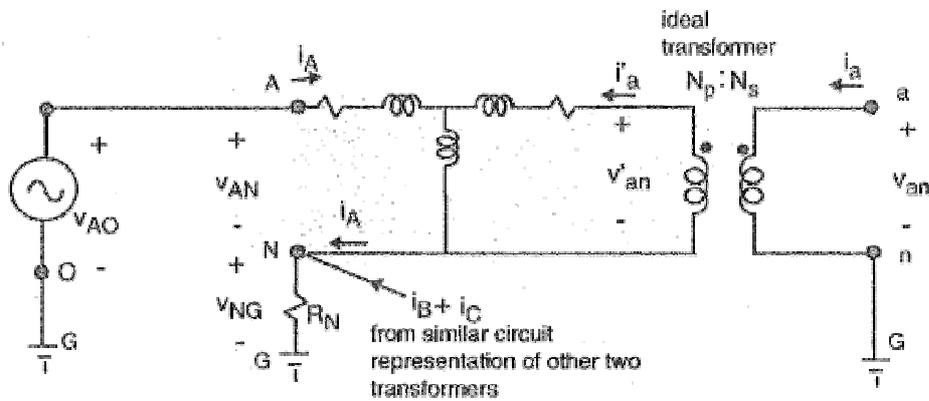Fig. 1-2 A three-phase transformer with Y-Y connection



Fig. 1-3 Single-phase equivalent circuit of a Y-Y three-phase transformer

Three single-phase equivalent circuits can be put together for a full equivalent circuits, for investigating inrush currents in all three phases, or unbalanced operating conditions. Consider now a three-phase transformer with $\Delta$-Y connection, the full model of the machine can be seen in Fig. 1-4. Note the way three single-phase equivalent circuits are linked to form a full equivalent circuits.

Zero-sequence current for the windings is defined as $(i_{AB} + i_{BC} + i_{CA})/3$, whilst zero-sequence current for the line currents is defined as $(i_a + i_b + i_c)/3$.
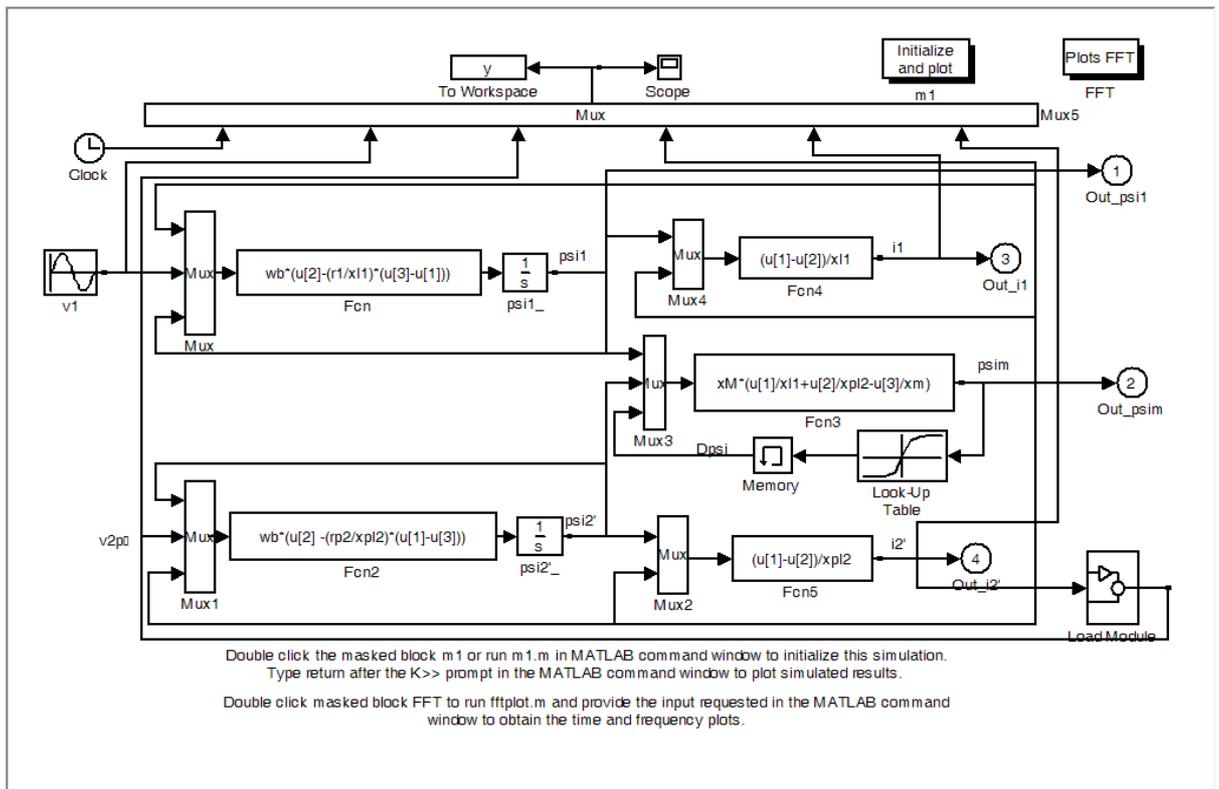
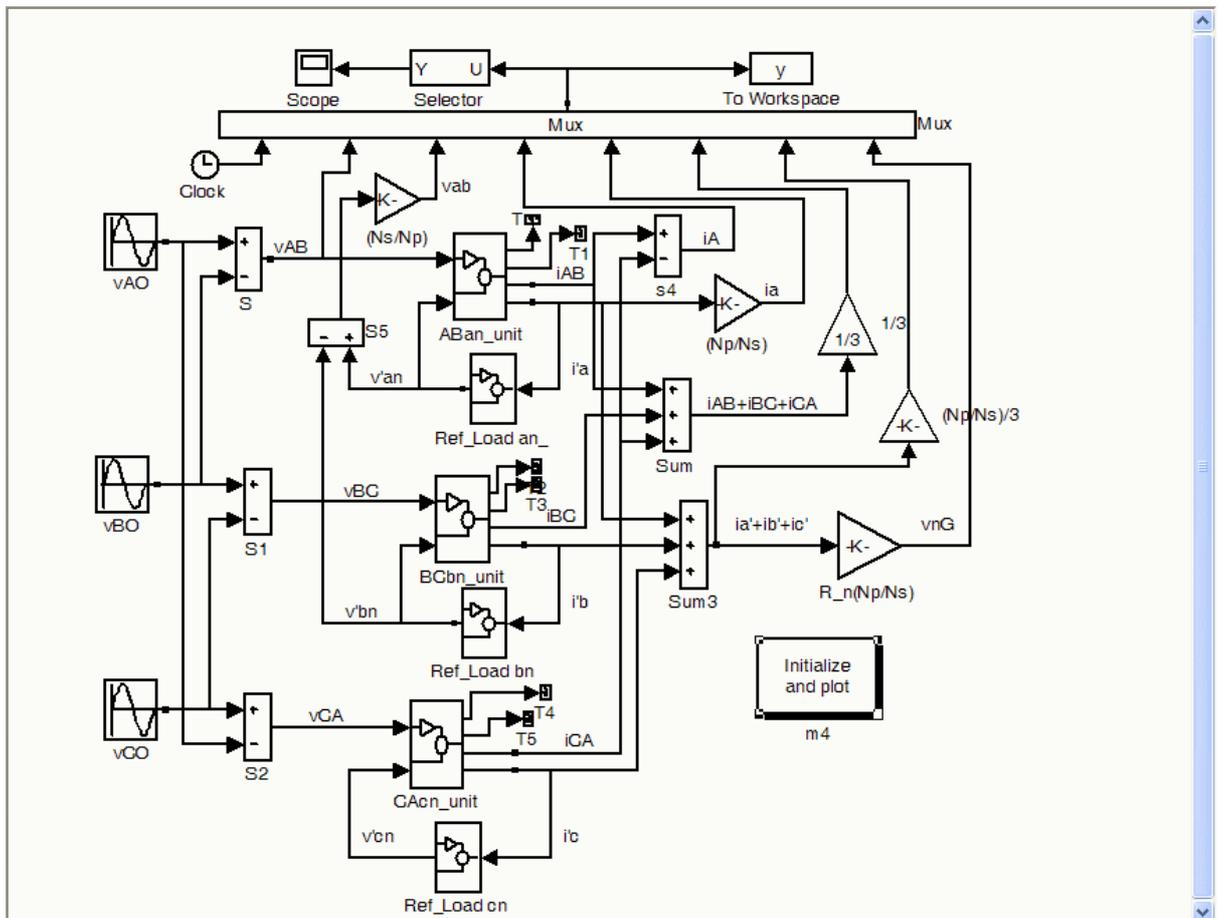Fig. 1-3 Single-phase equivalent circuit of a Y-Y three-phase transformer



Fig. 1-4 Full model of a Δ-Y three-phase transformer

A Look-Up Table was used to simulate magnetic saturation (Fig. 1-5), and the load circuit can be used to link secondary current to the secondary voltage (Fig. 1-6). Dpsi table will be set in the initialization script.
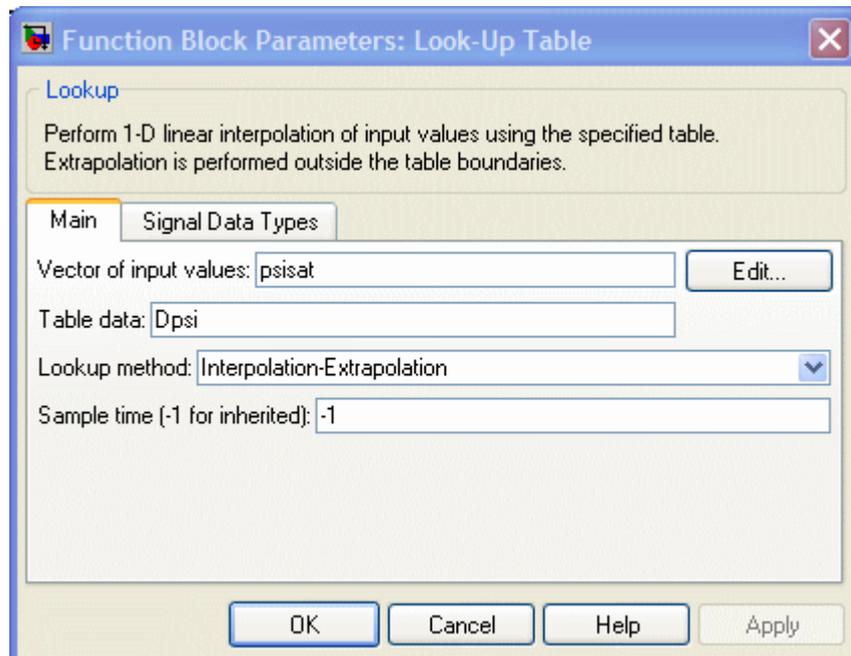


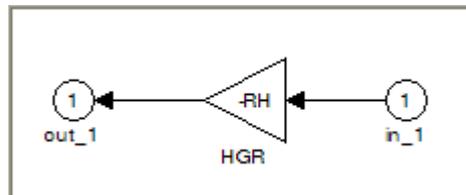Fig. 1-5 Look-Up Table for magnetic saturation simulation



Fig. 1-6 Load circuit

**III.     References:**
1. *A.E. Fitzgerald, Charles Kingsley, Stephen D.Umans*, Electric Machinery, *McGraw Hill*.
2. *Chee-Mun Ong*, Dynamic Simulation of Electric Machinery: Using MATLAB/ SIMULINK, *Prentice Hall*.

**IV.     Lab exercise goals:**
1. Build a three-phase transformer model in MATLAB/Simulink.
2. Study parameters of the model, and an approach to incorporate magnetic saturation into the model.
3. Simulate zero-sequence currents in a Δ-Y connected three-phase transformer.

**V.     Lab equipment:**
- PC with MATLAB/Simulink installed, pen, and ruler.

**VI.     Simulation of inrush currents in three-phase transformers:**

- Build a single-phase model for a two-winding transformer, with magnetic saturation and load circuit.
- Build a three-phase transformer's model.
- Connect three-phase voltage sources to input terminals, note that the phase displacement for all three-phase voltages are 120°.
- Modify the "param.m" file to reflect the machine's parameters as given to the group by the instructor.
- Run the initialization procedure and then the simulation.
- Comment on zero-sequence currents for windings and line currents under balanced condition.
- Unbalance the secondary by removing the inductor from load phase a, repeat the simulation and examine zero-sequence currents for windings and line currents.
- Increase the neutral resistance to a large value (e.g., 100 times of the base impedance), with the secondary loading still unbalanced, repeat the simulation and examine zero-sequence currents for windings and line currents, explain the results.

## VII.    **Lab report:**
- Hand in the report no later 1 week after all the lab exercice finish.
- Note clearly student's names, ID numbers, group number, date of exercise.
- Lab results should be clear, concise, and complete as required.
- Plagiarism might result in zero mark being given to all partners.