Determination of equivalent circuit parameters of Three-phase three winding Transformer

INTRODUCTION

In this experiment we determine the equivalent circuit parameters of a 3-phase, 3-winding transformer. In this experiment, the 3-phase, 3-winding transformer is realized by using a bank of three numbers of single phase 3-winding transformers. The primary windings of the three single phase transformers are connected in star or delta as per the required voltage to be supported. The connection of the three secondary windings and the three tertiary windings are also decided on the basis of the same criterion – the voltage to be supported.

Some of the usages of a three winding transformer in power system are listed below:

1. In case an unbalanced three-phase load is connected in the secondary, the tertiary winding may be used to reduce the unbalance in primary.
2. If the primary and secondary windings are star-connected, a delta connected tertiary provides a path for the third harmonic and thus helps to reduce the third harmonic in the primary.
3. The tertiary winding provides option for reactive power injection into the system (used for voltage control)
4. A delta-connected tertiary winding provides reduced impedance to 'zero' sequence currents thereby allowing a larger earth fault current to flow for proper operation of the protective equipment.
5. Sometimes, a low voltage tertiary winding is used for supplying the lighting load of the substation.

For elaborate understanding of the utilities and advantages of a Tertiary winding please refer to any standard Text Book on machine theory.

The basic steps in extracting the relevant circuit parameters of a 3-phase, 3-winding transformer are similar to that for a basic single-phase 2-winding transformer, i.e., by conducting open circuit and short circuit tests. Only in this case, we need to conduct the short-circuit test three times, for the three possible pairs of windings.

THEORY

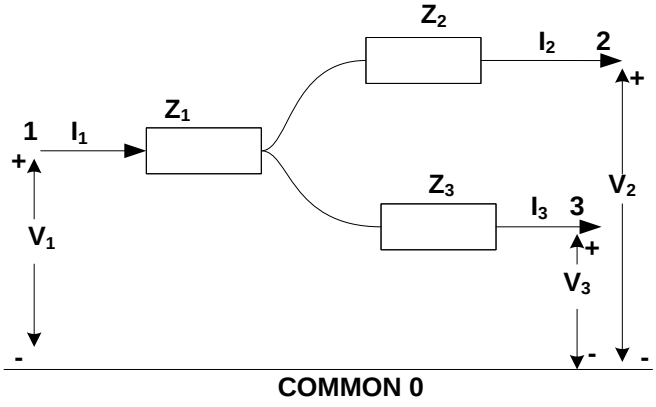

Figure 1:: Per phase Equivalent circuit Diagram of a 3 winding Transformer (Neglecting the shunt connected magnetizing and core loss branches)

The Subscripts 1 2 & 3 indicate primary secondary and Tertiary respectively. The individual impedances can be obtained by conducting 3 short circuit tests, one on each pair of windings. It may be recalled from the short circuit test of single phase Transformers that

$$Z = V_{sc} / I_{sc} \quad \textbf{(1);} \qquad R = P_{sc} / I_{sc}^2 \quad \textbf{(2);} \qquad X = \sqrt{Z^2 - R^2} \quad \textbf{(3);}$$

Where V_{sc}= short circuit voltage, I_{sc}= Short circuit current, P_{sc}= Power input, Z= lumped impedance & R= lumped resistance and X=lumped reactance. Also Z=R + jX.

From the three short circuit tests we obtain 3 lumped impedances namely Z_{12}, Z_{23} & Z_{13}

Where $\mathbf{Z_{ij}=Z_i+Z_j}$

From the above we get $Z_1 = \frac{1}{2}(Z_{12} + Z_{13} - Z_{23})$, similarly we can find Z_2 and Z_3.

For the open circuit test we have

$$Y = I_0 / V_1 \quad \textbf{(4);} \qquad V_1^2 G_i = P_0 \quad \textbf{(5);} \qquad B_m = \sqrt{Y^2 - G^2} \quad \textbf{(6);}$$

Where $Y_0 = G_i - jB_m$ is the equivalent admittance of the shunt branch of the equivalent circuit.

Based on the above equations one can obtain the values of the equivalent circuit parameters of the 3-phase, 3-winding transformer.

PROCEDURE

You will be provided with a SIMULINK page consisting of (a) three single-phase, three-winding transformer modules, (b) All the equipment modules available in SIMULINK that will be required for carrying out this virtual experiment. You have to make the connections and perform the experiment.

Open Circuit Test

1. The rating of each of the three identical single-phase, 3-winding transformer is

    1-phase, 50Hz, 2 kVA, 133V/66V/115V

Connect these to obtain a three-phase, three-winding transformer of the following rating

    3-phase, 50Hz, 6 kVA, 230V/115V/115V

Find the line current rating of the transformer bank.

2. Set the output voltage of the 3-phase variable voltage source at zero and then connect it to the primary winding of the transformer bank. Keep the secondary and the tertiary windings open. Connect the voltmeter, ammeter and wattmeter at suitable places for taking the necessary measurements.

3. Slowly increase the output of the variable voltage source and keep checking the voltmeter reading in the scope. Continue increasing the voltage till the voltmeter reads the rated primary voltage of the transformer bank. **Please note that due to small time steps of simulation, considerable time has to be allowed for the changes in voltage and current to settle down.**

4. Once the rated voltage is reached and readings of meters have settled down, note down the readings of the voltmeter, wattmeter and ammeter. Readings of line-to-line voltage and line-current should be taken for all three windings. **It should be checked if any of these readings is crossing the rated value. If so then there is some mistake in the circuit – correct it.**

5. Slowly decrease the voltage of the variable voltage source to zero. Check if all voltage and current readings have become zero.

B) Short-circuit test

6. The short circuit test is to be carried out thrice for the following winding pairs:
   SC Test #1: Short circuit secondary, keep tertiary open, supply primary
   SC Test #2: Short circuit tertiary, keep secondary open, supply primary
   SC Test #1: Short circuit tertiary, keep primary open, supply secondary
The supply is to be provided by connecting the three-phase variable voltage source. While connecting the voltage source and starting each short circuit test, **make sure that the output voltage of the source is zero**.

7. For each short circuit test, connect the voltmeter, ammeter and wattmeter at suitable places for taking the necessary measurements.

8. For each short circuit test, increase the supply voltage very slowly (from zero) till the line current in any of the two windings reach the rated value. Under this condition (once the readings of meters have settled down), take the reading of supply voltage, the active power supplied and line current of both the windings.

Calculations:

(i) Use the readings of the open circuit test to calculate the shunt parameters, R_i (=1/G_i, core loss component) and X_m (=1/B_m, magnetizing component).

(ii) Use the readings of the three shprt circuit test to calculate the impedances Z_{12}, Z_{13} and Z_{23}.

(iii) Compute the leakage impedances (Z_1, Z_2 and Z_3.) of the three windings using Z_{12}, Z_{13} and Z_{23}.

**** Results of both the tests are to be shown to the TAs (on the SIMULINK scopes)**

**** The results and calculations are to be submitted to the TA (as *.pdf document)**