Experiment — 4
Three-Phase Transformer Connections

Introduction

When it is necessary to raise or to lower the voltage of a three-phase power supply, by means of three transformers, any one of the four combinations of connections shown in Table 1 may be used:

<table>
<thead>
<tr>
<th>Low-tension side</th>
<th>High-tension side</th>
</tr>
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<tbody>
<tr>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Y</td>
<td>Δ</td>
</tr>
<tr>
<td>Δ</td>
<td>Y</td>
</tr>
<tr>
<td>Δ</td>
<td>Δ</td>
</tr>
</tbody>
</table>

Table 1

Theoretically, all four combinations may be made to give correct results; but in practice, in a given case, one particular combination usually has some advantages. When the transformer primaries are connected in Y and the secondaries are connected in Δ, or *vice versa*, the line voltages in the two circuits become displaced by 30 electrical degrees.

Objectives

The purpose of this experiment is to learn the principal characteristics of the four combinations of transformer winding connections presented in the introduction.

Prelab Assignments

Review the theory of 3-phase transformer connections. Prepare tables with suitable headings and captions to enter your results. Bring observed memory stick to capture waveforms from the instruments for your report. Draw circuit diagrams and determine how many multimeters are needed to perform the experiment.

Equipment

1- Three single-phase transformers
2- Multimeters
3- Variable Resistance Loads
4- Fluke Meter
Procedure

When connecting three-phase transformers, the Δ side should never be closed until a test is first made to determine that the voltage within the Δ is zero. If not, and the Δ is closed on itself, the resulting current will be of short-circuit magnitude, with resulting damage to the transformers. To determine the proper phase relationships in a Δ connected secondary, the voltage is measured across two windings. This voltage should be equal to the voltage across either winding. If not, one of the windings must be reversed. One side of the third winding is then connected and the voltage is measured across the three windings. This voltage must be very close to zero. If not, the third winding connection must be reversed.

Two of the key differences discussed in textbooks that you should explore are the ability to suppress third harmonics and the phase shift created by some of the configurations. Measuring harmonics can be done easily with the Fluke meters. Measuring voltage shifts is not as easy since one side of the probe is grounded by the oscilloscope as indicated in the last paragraph. One method you can consider is to place a resistor across the voltage to be viewed on the oscilloscope. Assuming that the current through the resistance is in phase with the voltage a current clamp probe or a current transformer will output a voltage proportional to the current which is floating and can have one side safely grounded by a scope probe. The Fluke meter itself can also be used since it can view one voltage and one current at the same time.

1. Label the three live wires of the three-phase supply a, b, and c. Measure the three line to neutral voltages and the three line to line voltages. Test if the neutral is grounded or not.
2. Connect the primaries of three single-phase transformers in Y, with the secondaries open. Arrange to observe the waveform of the primary phase currents with rated voltage and 110 per cent rated voltage applied. Note that the black terminal of the oscilloscope cable is connected to the chassis of the oscilloscope and to the ground of the system. This last point and its implications should be fully understood and extreme care should be taken to avoid grounding a live point. Study Fig. 1 carefully to understand the grounding system of the scope.
3. Connect three single-phase transformers in succession in the four possible ways listed in the introduction, and measure all the voltages and characteristics of the three-phase transformers that you create. Read the rest of this procedure before doing this step to save yourself some time.
4. With three single-phase transformers connected Y-Y and no load on the secondary side, check the line-to-neutral voltages on the secondary side. Explain any unbalance observed. Connect the neutral of the primary Y to the source of neutral and repeat the previous measurements. Is there any difference in your readings? If possible, repeat this test with one transformer in the bank different from the others.
5. With the Y-Y connection of part 4 and no neutral, connect an unbalanced load on the secondary side. Check the phase voltages under load with and without a neutral connection and record observations.

6. With the primaries Y-connected and the secondaries Δ-connected, open one corner of the Δ. Measure the voltage appearing across these open terminals and determine its frequency.

7. Connect the primary and the secondary windings of two single-phase transformers in open Δ. Check the phase angles of the line-to-line voltages on both primary and secondary sides with a 3-phase resistive load on the secondary side.
Discussion

1. Discuss the advantages and disadvantages of the connections used in the laboratory. Specifically point out those that you observed.

2. Discuss any other results that you think are interesting or confirm or disprove your expectations.

3. Where is the open $\Delta$ used and for what reason?

4. Explain the effect of the neutral on any voltage unbalance observed in parts 4 and 5 of the procedure.

5. What precautions must be observed when paralleling 3-phase transformer banks?
6. What is meant by transformer magnetizing inrush current? Did you see any signs of its presence while performing the experiment?

References

1- The A.I.E.E., Transactions, of 1914, Vol. 33, has several interesting papers and discussions about practical considerations of transformers connections.