Experiment #3: Three Phase Transformer

Behind the board of your station are three single phase transformers. Any one of them can be used as a single phase transformer. The three can also be connected together into a three phase transformer. As discussed in the previous lecture, the simplified T-model of a single phase transformer is shown in figure 1 below. Three single phase transformers can be connected into one three phase transformer in one of several ways as discussed below.

The three transformers have a total of six windings with twelve terminals to be connected. There are four ways to do this: Y-Y, Δ-Y, Y-Δ, and Δ-Δ. In figure 2 we show a Δ-Y connected three phase transformer. The primary is delta and the secondary is Y. Note that the delta does not look like Δ! Instead, each leg of the delta is parallel to one leg of the Y. This is done purposely so we know which windings share the same iron. The T-model used for a single transformer can be used for each of the three transformers which make up the three phase transformer.

Note that there is both a phase shift and a gain involved with this connection. Assuming a turns ratio of \(a\), what is the output voltage as a function of the input voltage for this connection? Take for example the ratio of \(V_{ab}\) on the low and high voltage sides (or primary and secondary sides). What is the phase shift? What is the voltage gain?

Note in figure 2 the “sense” of the windings is indicated by dots. What do you think would happen if one of the windings were connected “backwards”? Note also that one side has three wires, while the Y side has four. If we use the neutral, we have a 4-wire Y, and if we do not, we have a 3-wire Y.
It is noteworthy that in practice a transformer usually has a Δ side. This is important in order to reduce third order harmonics in the voltage. This was explained in the lecture and is due to nonlinear iron magnetization curves.

It is possible to have a three phase transformer using only two single phase transformers. This is the so-called open delta operation. Thus if we have a Δ-Δ transformer, and we remove one leg of the delta, then we have a V-V transformer (also called an open delta transformer). This runs well as a three phase transformer but would have a power rating only \( \frac{1}{\sqrt{3}} \) of that of three transformers connected into one Δ-Δ three phase unit. In this case, even if the primary is a balanced three phase voltage, the secondary will be unbalanced. This is due not only to harmonics but also due to having two instead of three leakage impedance voltage drops. This imbalance is easier to tolerate compared to complete loss of power which can happen in other connections.

Experiment outline:

1. Make sure you know the “sense” of the windings. Connect the transformers into a Y-Δ with the Y as the primary using the low voltage windings (often referred to as the X windings) and the Δ as the secondary using the high voltage windings (often referred to as the H windings). Now excite the Y with balanced three phase and neutral up to 110 volts per phase. What is the line to line voltage on the primary? On the secondary? Connect a balanced Y load made up of 250 Ohm each leg to the secondary. Measure the power SUPPLIED AT THE PRIMARY using two wattmeters. Measure voltages line to line and per phase on each side. Compare with the theoretical value (using the model of the single phase units).

2. Repeat using a Y-Y connection. Is it safe for the load to be 250 Ohm each leg as before? If not, what should you choose? Discuss this with your lab group and consult your instructor before performing the experiment!

3. Now make a Δ-Δ transformer and apply 110 volt on the low voltage side (per phase). Repeat the above experiment for this case.

4. Modify to a V-V transformer and repeat. Again, decide on the load, but before you operate any equipment, check with the instructor.

5. For one of these cases, discuss and compute transformer efficiency.