ENERGY CONVERSION I ---------------------------------THREE PHASE TRANSFORMER SYSTEMS

I. GENERAL

A. The three phase transformer system may be composed of three single phase transformers properly connected or an integral three phase transformer having a common core with three legs.

B. The following connections are possible:

1. Y - Y with or without 4th wire
2. Y - Δ or Δ - Y.
3. Δ - Δ
4. Open ∠ (uses only two transformers)

C. Selection of a particular connection is based on the following considerations:

1. Are loads balanced or unbalanced?
2. Is there a path for third harmonic exciting current to flow? Not in YY
3. What voltage level(s) does the transformer system operate at? Y is nice for high voltage.
4. Are multiple sets of voltages needed? Y nice
5. Can the transformer windings be grounded at a suitable point?
6. Is reliability a factor? Δ Δ → ∠ ∠

D. Principle factors relating to selection of a particular Y or Δ connection:

1. The Y connection provides
   a) two sets of voltages,
   b) transformer voltages reduced from line to line voltages by $1/\sqrt{3}$, and
   c) a convenient point (neutral) to ground.
2. The Y connection has no path for third harmonic exciting current to flow.
3. The Δ connection provides a path for third harmonic current but does not provide a suitable point for grounding.

II. SPECIFIC CONNECTIONS (APPLICATIONS)

A. The Y - Y connection

1. will not satisfactorily support unbalanced loads,
2. requires a tertiary Δ for third harmonic current, and
3. is very suitable for operation between two high voltage levels where loads are balanced.

B. The Y - Δ or Δ - Y connection(s)

1. has neutral available on Y to provide a good grounding point,
2. provides a path for third harmonic current to follow in the Δ,
3. provides two sets of voltages on Y side, and
4. unbalanced loads are satisfactorily sustained,
5. transformer voltage rating on Y side is less than line-to-line voltage.

C. The Δ - Δ connection

1. has no suitable point for grounding unless a tertiary Y is used,
2. will sustain unbalanced loads,
3. gives satisfactory operation (if load is reduced) if one transformer fails (open) thus making reliability higher than other connections,
4. supports unbalanced loads satisfactorily, and
5. no third harmonic problems since there is a path for third harmonic current to flow in either Δ.

D. The Open Delta (∠ - ∠)

1. Provides an economic advantage if future growth is anticipated. One can buy two transformers and derate bank rating by 13.4% to satisfactorily transform three phase power. Later one can buy only one more transformer and increase load by 73.3% to utilize full capacity of the three transformers. This policy allows one to end up with 3 larger and more efficient transformers rather than 6 small and less efficient transformers.

2. Equations

$$\frac{\text{KVA load rating of } \angle - \angle}{\text{KVA bank rating of } \angle - \angle} = 0.866 \quad = \sqrt{3}$$

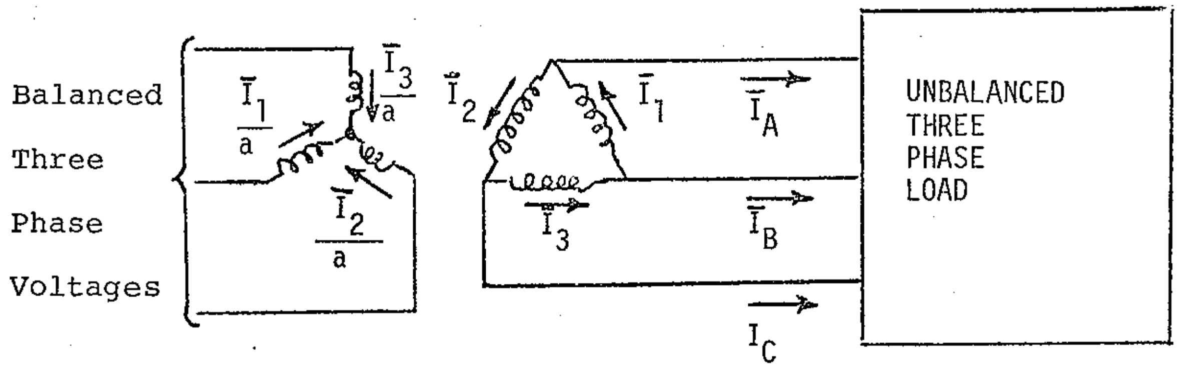
$$\frac{\text{KVA load rating of } \angle - \angle}{\text{KVA load rating of } \Delta - \Delta} = 0.578 \quad \frac{1}{\sqrt{3}}$$

3. The open delta connection tends to unbalance line to line voltages since each transformer must operate at a different power factor.

III. THREE PHASE TRANSFORMER SYSTEMS WITH UNBALANCED LOADS

A. Solving for currents in the Y-Δ system.

Consider a Y-Δ transformer system as shown in Figure 1 which is loaded with an unbalanced load giving unbalanced line currents. It is desired to determine the current flowing in each of the transformer windings.



a = Step-down Ratio

Figure 1. Y-Δ System with Unbalanced Line Currents

The currents can be found by solving a system of three Kirchoff current equations two of which are written for any two junctions of the Δ and one at the junction for the Y. These equations follow:

$$\bar{I}_1 - \bar{I}_2 = \bar{I}_A$$

$$-\bar{I}_1 + \bar{I}_3 = \bar{I}_B$$

$$\bar{I}_1 + \bar{I}_2 + \bar{I}_3 = 0$$

B.. Solution for Phase Currents in a $\Delta - \Delta$ System with Unbalanced Load.

Consider a $\Delta - \Delta$ transformer bank as shown in Figure 2. The unbalanced load draws line currents of known value, and it is desired to solve for the currents in each of the transformers.

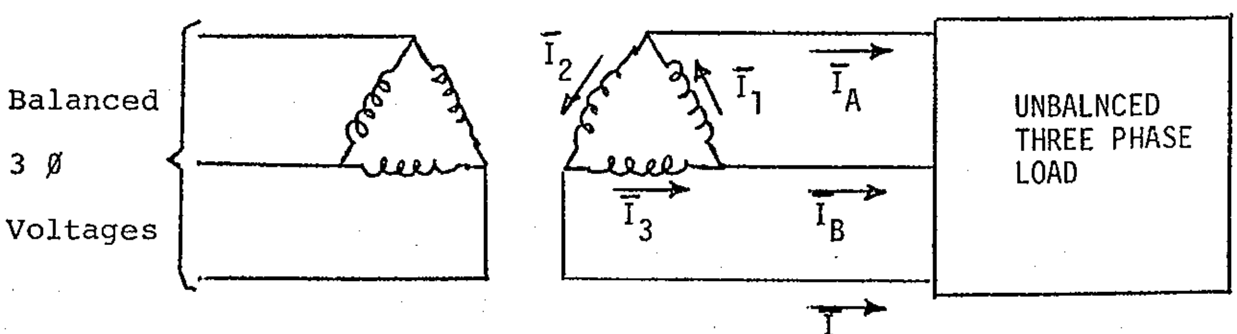


Figure 2. $\Delta - \Delta$ System with Unbalanced Line Currents.

Two of the equations for solving for the three unknowns may be Kirchoff current equations at any two of the three junctions in the Δ such as the following:

$$\bar{I}_1 - \bar{I}_2 = \bar{I}_A$$

$$-\bar{I}_1 + \bar{I}_3 = \bar{I}_B$$

The third equation must be a voltage equation around the loop formed by either Δ. In each transformer, an induced voltage is encountered as well as an impedance drop voltage IZ where Z is the impedance of the winding. Hence the equation is as follows:

$$\bar{I}_1 \bar{Z}_1 - \bar{E}_1 + \bar{I}_2 \bar{Z}_2 - \bar{E}_2 + \bar{I}_3 \bar{Z}_3 - \bar{E}_3 = 0$$

Now since this is a balanced three-phase voltage system, the induced voltages add to zero around the loop leaving an equation involving impedances and currents as follows:

$$\bar{I}_1 \bar{Z}_1 + \bar{I}_2 \bar{Z}_2 + \bar{I}_3 \bar{Z}_3 = 0$$

If the three transformers have identical impedances, the $\bar{Z}$ may be factored out leaving what appears to be a Kirchoff current equation but which is really a degenerate Kirchoff voltage equation. Solution of the three equations simultaneously will give each of the phase currents.