5-3 Transformers in Three-Phase Circuits

Three single-phase transformers can be connected to form a *three-phase transformer bank* in any of the four ways shown in Fig. 1. In all four parts of this figure, the windings at the left are the primaries, those at the right are the secondaries, and any primary winding in one transformer corresponds to the secondary winding drawn parallel to it. Also shown are the voltages and currents resulting from balanced impressed primary line-to-line voltages V and line currents I when the ratio of primary-to-secondary turns N1/N2 = ***a*** and ideal transformers are assumed. 4 Note that the rated voltages and currents at the primary and secondary of the three-phase transformer bank depends upon the connection used but that the rated kVA of the three-phase bank is three times that of the individual single-phase transformers, regardless of the connection.

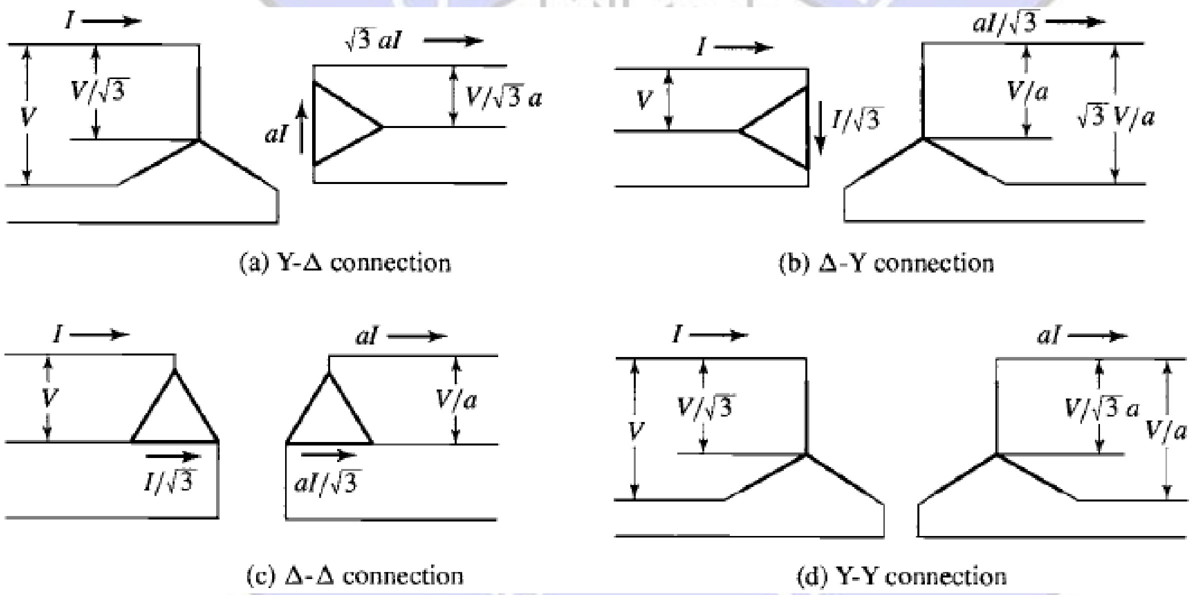

Figure 1 Common three-phase transformer connections; the transformer windings are indicated by the heavy lines

The Y- Δ connection is commonly used in stepping down from a high voltage to a medium or low voltage. One reason is that a neutral is thereby provided for grounding on the high-voltage side, a procedure which can be shown to be desirable in many cases. Conversely, the Δ-Y connection is commonly used for stepping up to a high voltage. The Δ - Δ connection has the advantage that one transformer can be removed for repair or maintenance while the remaining two continue to function as a three-phase bank with the rating reduced to 58 percent of that of the original bank; this is known as the *open-delta,* or V, connection. The Y-Y connection is seldom used because of difficulties with exciting-current phenomena.

Instead of three single-phase transformers, a three-phase bank may consist of one *three-phase transformer* having all six windings on a common multi-legged core and contained in a single tank. Advantages of three-phase transformers over connections of three single-phase transformers are that they cost less, weigh less, require less floor space, and have somewhat higher efficiency. A photograph of the internal parts of a large three-phase transformer is shown in Fig. 2.

Circuit computations involving three-phase transformer banks under balanced conditions can be made by dealing with only one of the transformers or phases and recognizing that conditions are the same in the other two phases except for the phase displacements associated with a three-phase system. It is usually convenient to carry out the computations on a single-phase (per-phase-Y, line-to-neutral) basis, since transformer impedances can then be added directly in series with transmission line
impedances. The impedances of transmission lines can be referred from one side of the transformer bank to the other by use of the square of the ideal line-to-line voltage

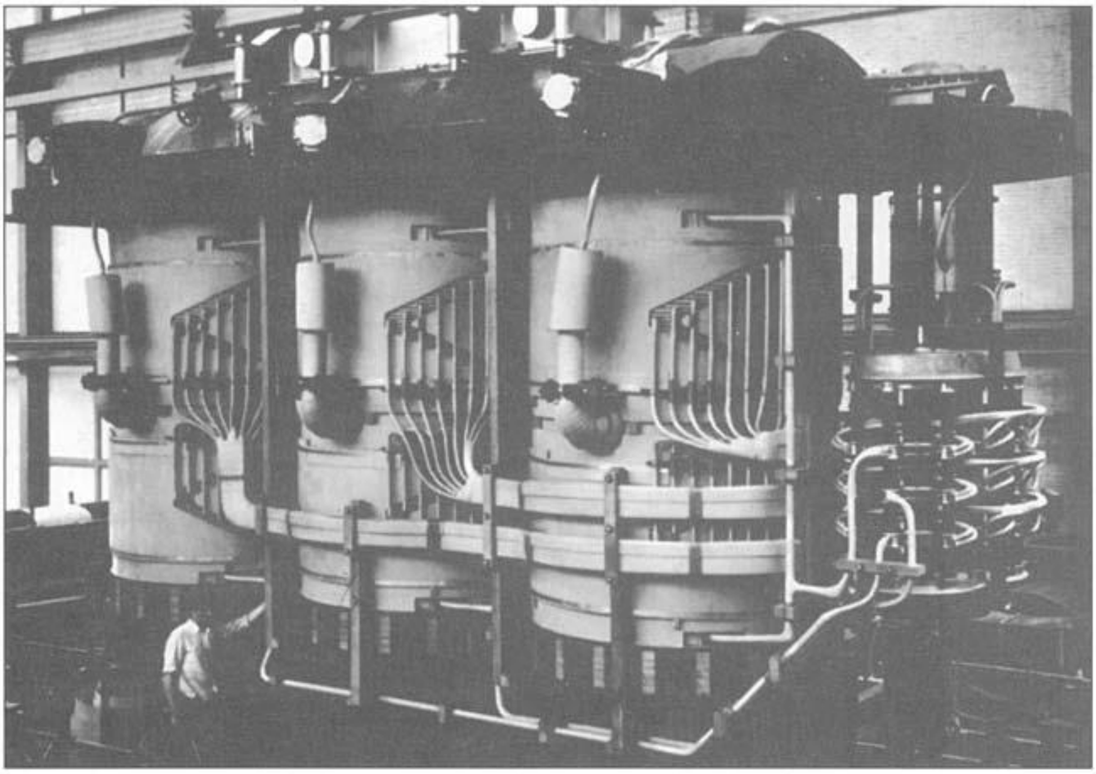

Figure 2 A 200-MVA, three-phase, 50-Hz, three-winding, 210/80/10.2-kV transformer removed from its tank. The 210-kV winding has an on-load tap changer for adjustment of the voltage.

ratio of the bank. In dealing with Y-Δor A-Y banks, all quantities can be referred to the Y-connected side. In dealing with A-A banks in series with transmission lines, it is
convenient to replace the Δ-connected impedances of the transformers by equivalent Y-connected impedances. It can be shown that a balanced A-connected circuit of ZΔ Ω/phase is equivalent to a balanced Y-connected circuit of Zy Ω/phase if

$$Z_Y = \frac{1}{3} Z_\Delta$$