

13 Poly Phase connections and Poly phase Transformers

The individual transformers are connected in a variety of ways in a power system. Due to the advantages of polyphase power during generation, transmission and utilization polyphase power handling is very important. As an engineering application is driven by techno-economic considerations, no single connection or setup is satisfactory for all applications. Thus transformers are deployed in many forms and connections. Star and mesh connections are very commonly used. Apart from these, vee or open delta connections, zig zag connections, T connections, auto transformer connections, multi winding transformers etc. are a few of the many possibilities. A few of the common connections and the technical and economic considerations that govern their usage are discussed here. Literature abounds in the description of many other. Apart from the characteristics and advantages of these, one must also know their limitations and problems, to facilitate proper selection of a configuration for an application. Many polyphase connections can be formed using single phase transformers. In some cases it may be preferable to design, develop and deploy a polyphase transformer itself. In a balanced two phase system we encounter two voltages that are equal in magnitude differing in phase by 90° . Similarly, in a three phase system there are three equal voltages differing in phase 120 electrical degrees. Further there is an order in which they reach a particular voltage magnitude. This is called the phase sequence. In some applications like a.c. to d.c. conversion, six phases or more may be encountered. Transformers used in all these applications must be connected properly for proper functioning. The basic relationship between the primary and secondary voltages (brought about by a common mutual flux and the number of turns), the polarity of the induced emf (decided by polarity test and used with dot convention) and some understanding of the magnetic

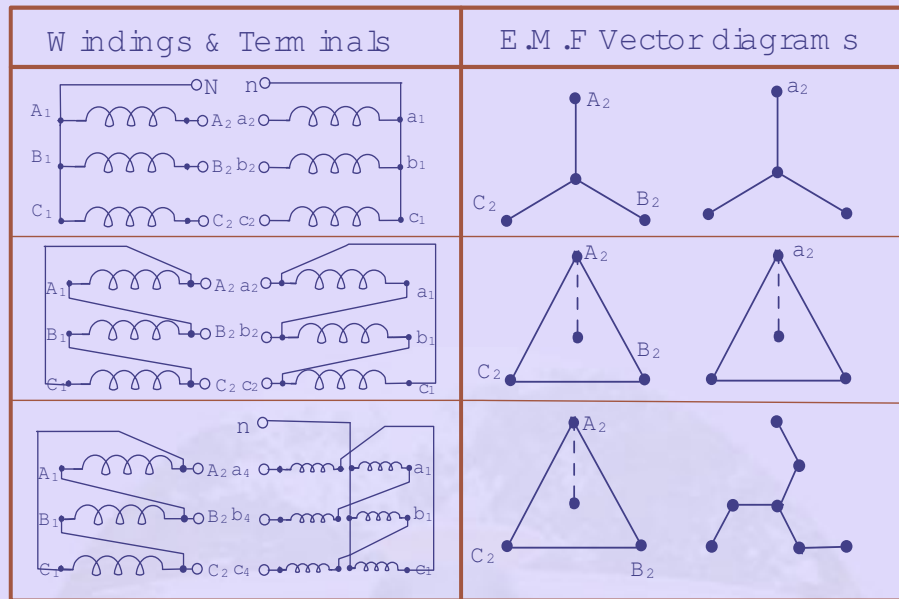
circuit are all necessary for the same. To facilitate the manufacturer and users, international standards are also available. Each winding has two ends designated as 1 and 2. The HV winding is indicated by capital letters and the LV winding by small letters. If more terminals are brought out from a winding by way of taps there are numbered in the increasing numbers in accordance to their distance from 1 (eg $A_1, A_2, A_3\dots$). If the induced emf at an instant is from A_1 to A_2 on the HV winding it will rise from a_1 to a_2 on the LV winding.

Out of the different polyphase connections three phase connections are mostly encountered due to the wide spread use of three phase systems for generation, transmission and utilization. Three balanced 3-phase voltages can be connected in star or mesh fashion to yield a balanced 3-phase 3-wire system. The transformers that work on the 3-phase supply have star, mesh or zig-zag connected windings on either primary secondary or both. In addition to giving different voltage ratios, they introduce phase shifts between input and output sides. These connections are broadly classified into 4 popular vector groups.

1. Group I: zero phase displacement between the primary and the secondary.
2. Group II: 180° phase displacement.
3. Group III: 30° lag phase displacement of the secondary with respect to the primary.
4. Group IV: 30° lead phase displacement of the secondary with respect to the primary.

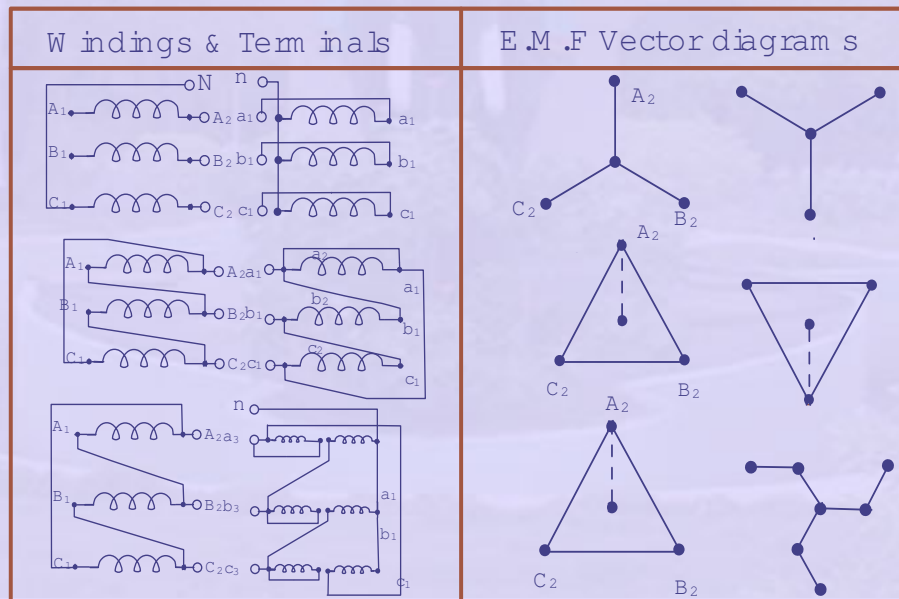
A few examples of the physical connections and phasor diagrams are shown in Fig. 35 and Fig. 36 corresponding to each group. The capital letters indicates primary and the small letters the secondary. D/d stand for mesh, Y/y - for star, Z/z for zig-zag. The angular displacement of secondary with respect to the primary are shown as clock position, 0°

Group1 0° Phase shift



(a)

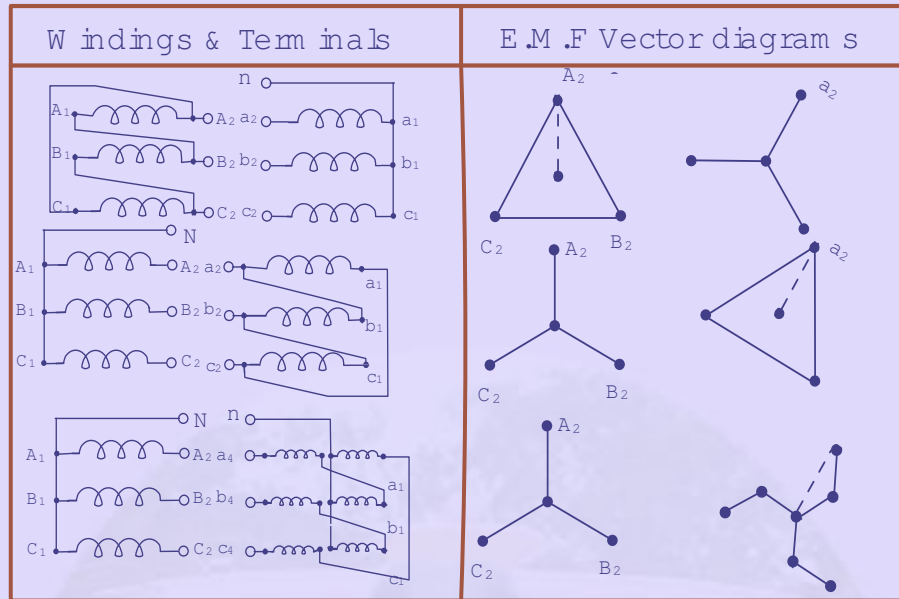
Group2 180° Phase shift



(b)

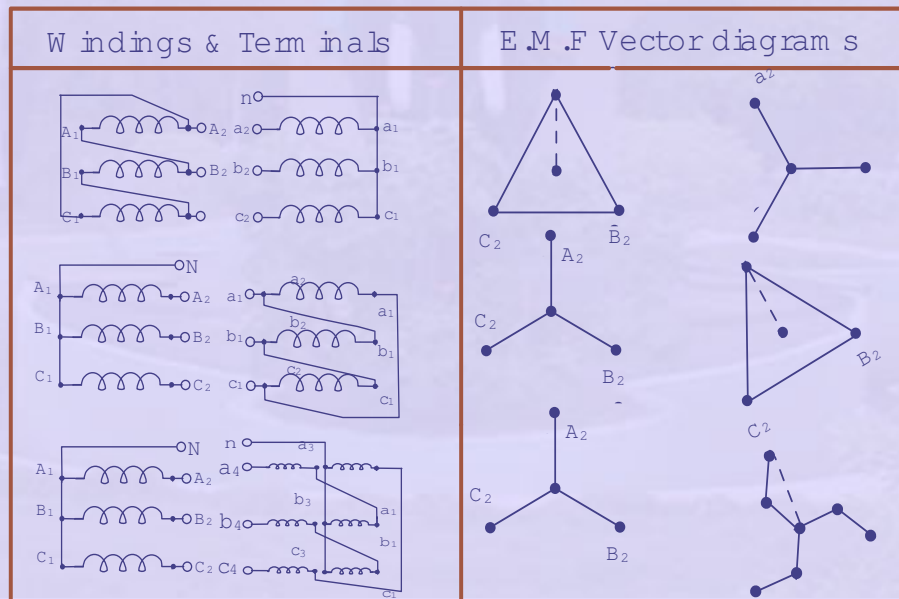
Figure 35: Vector Groups for 3-phase Transformer Connections
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Group 3 30° Phase shift



(a)

Group 4 $+30^\circ$ Phase shift



(b)

Figure 36: Vector Groups for 3-phase Transformer Connections
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referring to 12 o'clock position. These vector groups are especially important when two or more transformers are to be connected in parallel.

Star connection is normally cheaper as there are fewer turns and lesser cost of insulation. The advantage becomes more with increase in voltage above 11kV. In a star connected winding with earthed-neutral the maximum voltage to the earth is $(\frac{1}{\sqrt{3}})$ of the line voltage. Also star connection permits mixed loading due to the presence of the neutral. Mesh connections are advantageous in low voltage transformers as insulation costs are insignificant and the conductor size becomes $(\frac{1}{\sqrt{3}})$ of that of star connection and permits ease of winding. The common polyphase connections are briefly discussed now.

Star/star (Yy0, Yy6) connection This is the most economical one for small high voltage transformers. Insulation cost is highly reduced. Neutral wire can permit mixed loading. Triplen harmonics are absent in the lines. These triplen harmonic currents cannot flow, unless there is a neutral wire. This connection produces oscillating neutral. Three phase shell type units have large triplen harmonic phase voltage. However three phase core type transformers work satisfactorily. A tertiary mesh connected winding may be required to stabilize the oscillating neutral due to third harmonics in three phase banks.

Mesh/mesh (Dd0, Dd6) This is an economical configuration for large low voltage transformers. Large amount of unbalanced load can be met with ease. Mesh permits a circulating path for triplen harmonics thus attenuates the same. It is possible to operate with one transformer removed in open delta or Vee connection meeting 58 percent of the balanced load. Three phase units cannot have this facility. Mixed single phase loading is not possible due to the absence of neutral.

Star/mesh(Dy or Yd) This arrangement is very common for power supply transformers. The delta winding permits triplen harmonic currents to circulate in the closed path and attenuates them.

Zig zag/ star (ZY1 or Zy11) Zigzag connection is obtained by inter connection of phases. 4-wire system is possible on both sides. Unbalanced loading is also possible. Oscillating neutral problem is absent in this connection. This connection requires 15% more turns for the same voltage on the zigzag side and hence costs more.

Generally speaking a bank of three single phase transformers cost about 15% more than their 3-phase counter part. Also, they occupy more space. But the spare capacity cost will be less and single phase units are easier to transport.

Mesh connected three phase transformers resemble 3- single phase units but kept in a common tank. In view of this single tank, the space occupied is less. Other than that there is no big difference. The 3-phase core type transformer on the other hand has a simple core arrangement. The three limbs are equal in cross section. Primary and secondary of each phase are housed on the same limb. The flux setup in any limb will return through the other two limbs as the mmf of those limbs are in the proper directions so as to aid the same. Even though magnetically this is not a symmetrical arrangement, as the reluctance to the flux setup by side limbs is different from that of the central limb, it does not adversely affect the performance. This is due to the fact that the magnetizing current itself forms a small fraction of the total phase current drawn on load. The added advantage of 3-phase core is that it can tolerate substantially

large value of 3rd harmonic mmf without affecting the performance. The 3rd harmonic mmf of the three phases will be in phase and hence rise in all the limbs together. The 3rd harmonic flux must therefore find its path through the air. Due to the high reluctance of the air path even a substantially large value of third harmonic mmf produces negligible value of third harmonic flux. Similarly unbalanced operation of the transformer with large zero sequence fundamental mmf content also does not affect its performance. Even with Yy type of poly phase connection without neutral connection the oscillating neutral does not occur with these cores. Finally, three phase cores themselves cost less than three single phase units due to compactness.

