Three-phase Transformer Connections, phase conversion and harmonics

Acknowledgement: *The materials presented in this lecture has been taken from open source, reference books etc. This can be used only for student welfare and academic purpose.*

Recap

- Needs of three phase transformer and its types with application
- Magnetic core over view
- Classification
- Merits and demerits

Lecture-9 Objectives

- Connections of three phase transformer and its application
- Necessary and desirable conditions of the transformer
- Scott-T connections and phase conversions
- Phase conversion
- Harmonics

Three Phase Transformer Connections

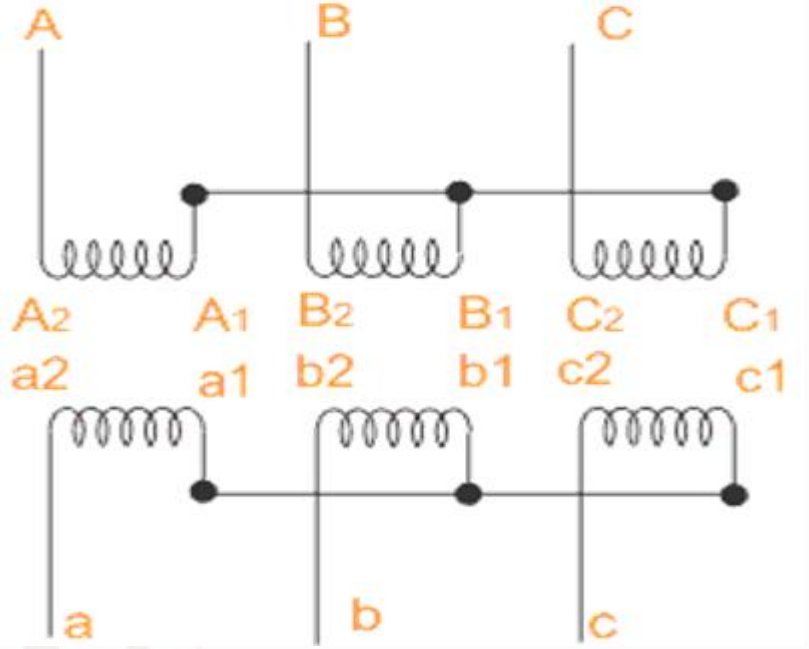
- Star / Star (Y – Y)
- Delta / Delta (Δ – Δ)
- Star / Delta(Y – Δ)
- Delta / Star (V – Y)

Star / Star (Y/Y) Connection

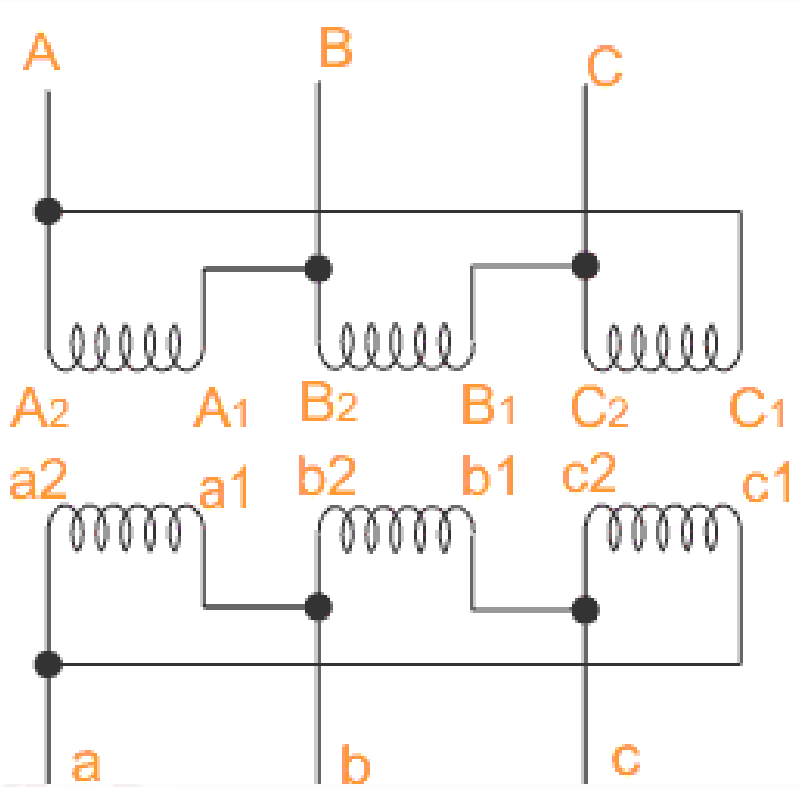
- It is also called zero degree connection.

$$V_{ph} = \frac{V_L}{\sqrt{3}} \quad and \quad I_L = I_{ph}$$

- Hence number of turns / phase and the amount of insulation required is minimum.
- This connection is economical for small rating high voltage transformers.
- It works well for balanced load.



Delta / Delta (Δ/Δ) Connection



- It is also called zero degree connection.

$$V_L = V_{ph} \quad \text{and} \quad I_{ph} = \frac{I_L}{\sqrt{3}}$$

- Hence number of turns / phase required is more.
- This connection is economical for large rating low voltage transformers.
- This connection is satisfactory for both balanced and unbalanced loads.
- But neutral unavailable.

Star / Delta (Y/Δ) Connection

- On primary side,

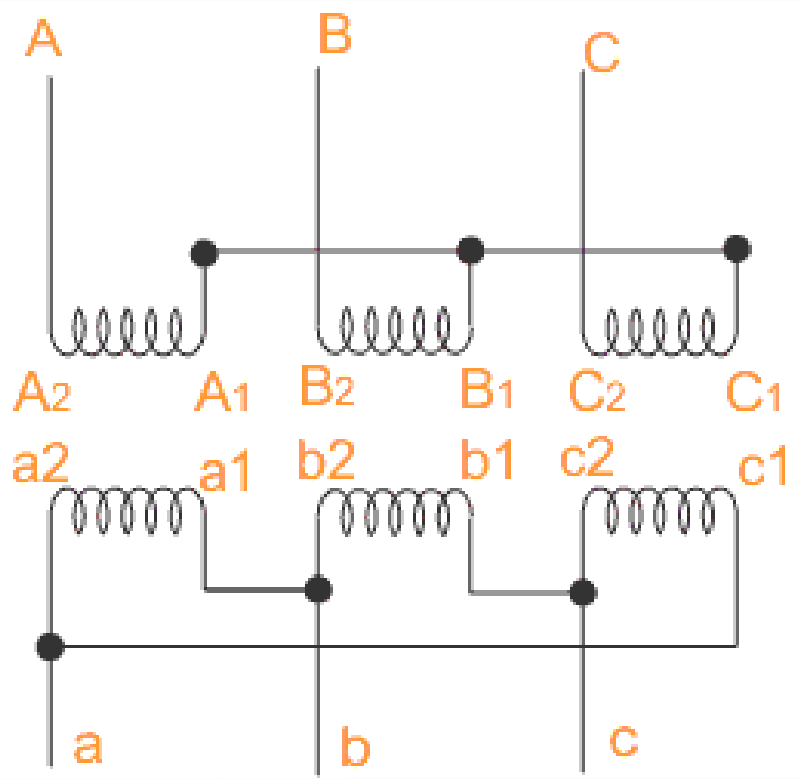
$$V_{ph} = \frac{V_L}{\sqrt{3}} \quad and \quad I_L = I_{ph}$$

- On secondary side,

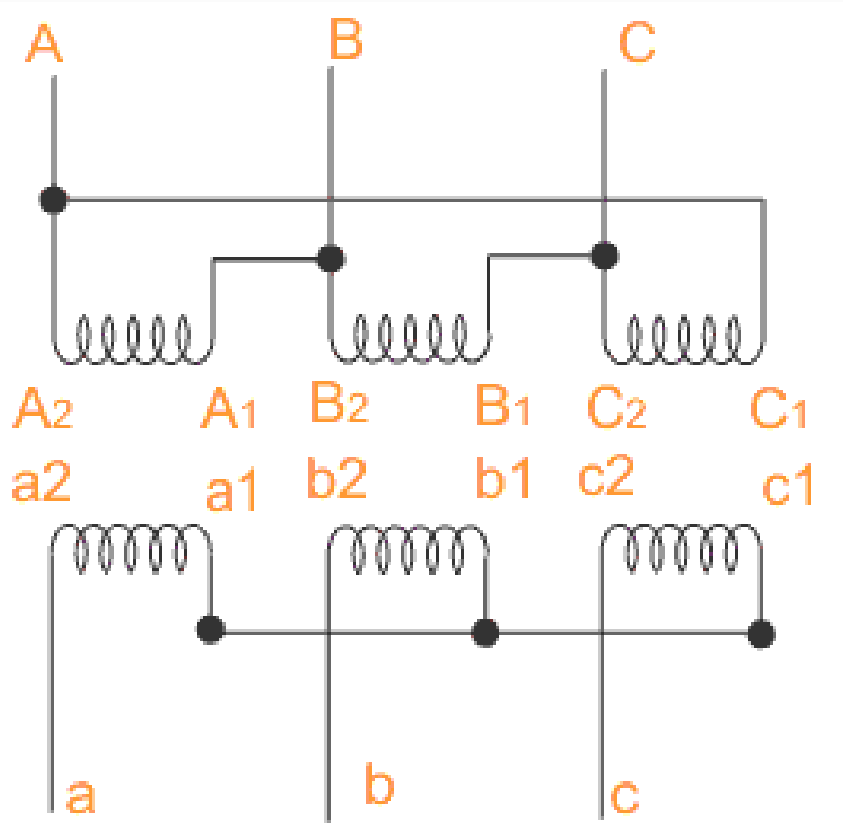
$$V_L = V_{ph} \quad \text{and} \quad I_{ph} = \frac{I_L}{\sqrt{3}}$$

$$\frac{V_{PS}}{V_{PP}} = \frac{V_{LS}}{V_{LP}/\sqrt{3}} = K$$

$$\frac{V_{LS}}{V_{LP}} = \frac{1}{\sqrt{3}} K$$



Delta / Star (Δ /Y) Connection



- On primary side,

$$V_L = V_{ph} \quad \text{and} \quad I_{ph} = \frac{I_L}{\sqrt{3}}$$

- On secondary side,

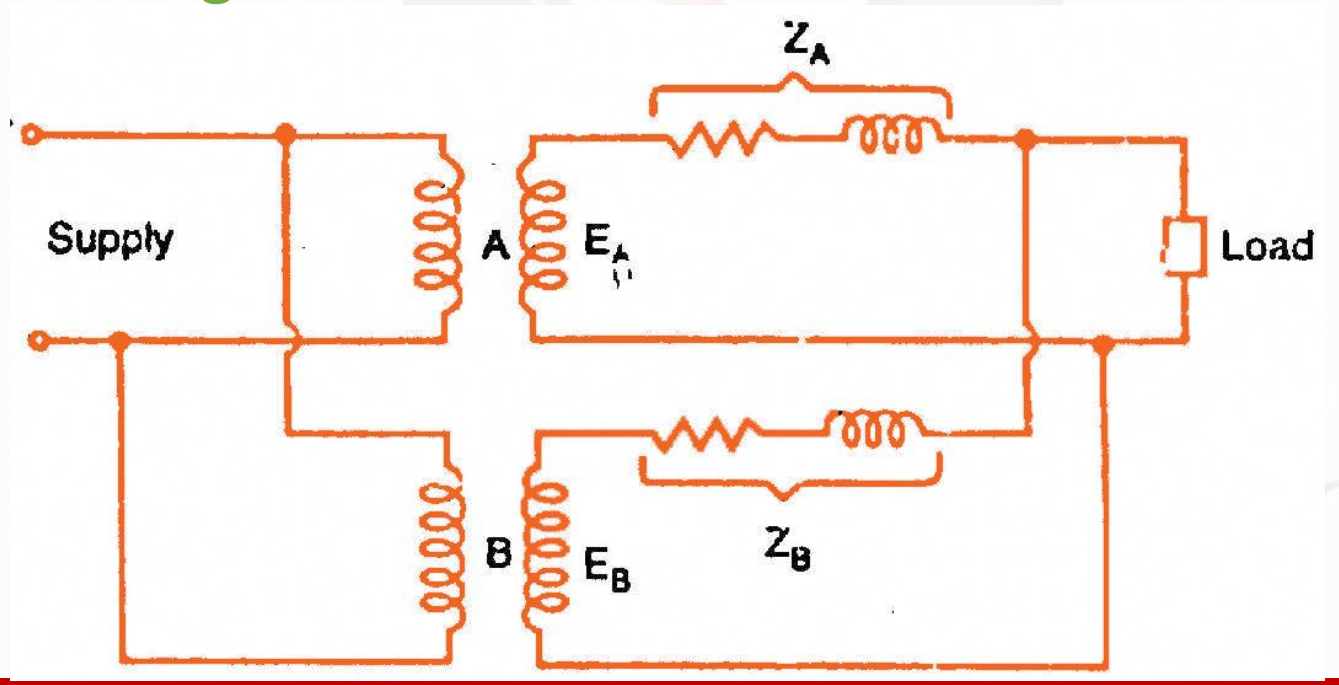
$$V_{ph} = \frac{V_L}{\sqrt{3}} \quad and \quad I_L = I_{ph}$$

$$\frac{V_{PS}}{V_{PP}} = \frac{V_{LS}/\sqrt{3}}{V_{LP}} = K$$

$$\frac{V_{LS}}{V_{LP}} = \sqrt{3}\,K$$

Parallel Operation of Transformers

- Two transformers are said to be connected in parallel when their primary windings are connected to a common supply bus bar and secondary windings are connected to a common load.

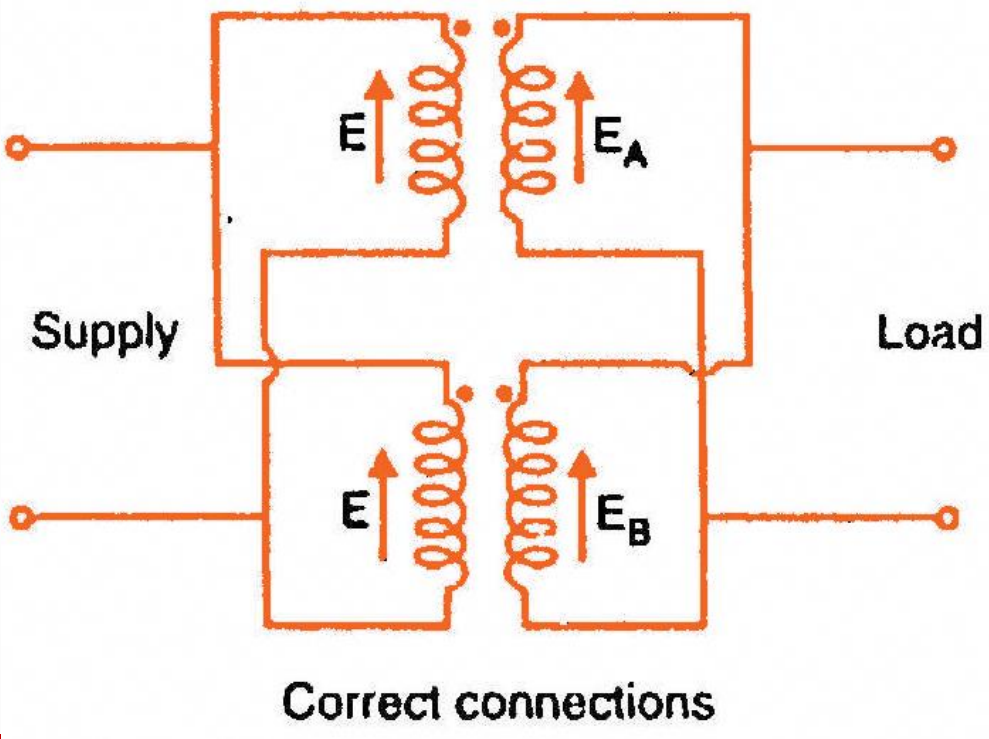


Necessary for Parallel Operation of Transformers

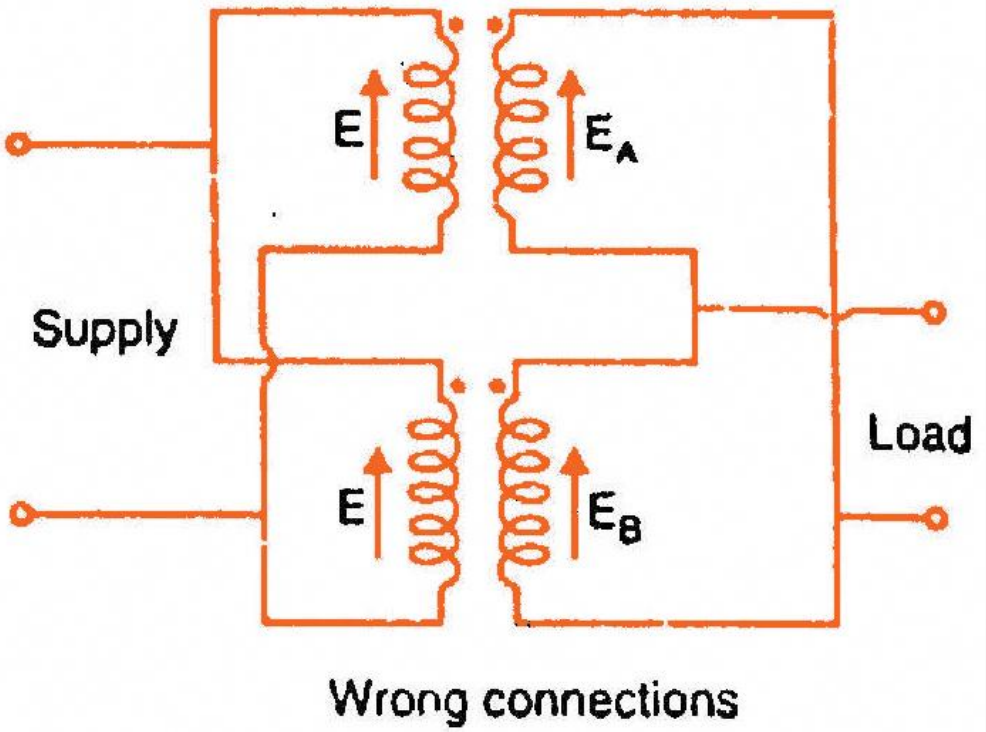
- For supplying a large load, it is uneconomical to have a single large transformer.
- There is a scope for future expansion of a substation to supply a load beyond the capacity of the transformer installed.
- Uninterruptible supply is possible even if one of the transformer fails or if it is taken out for maintenance.

Conditions for satisfactory Parallel Operation

- Transformers should be properly connected with regard to their polarities.



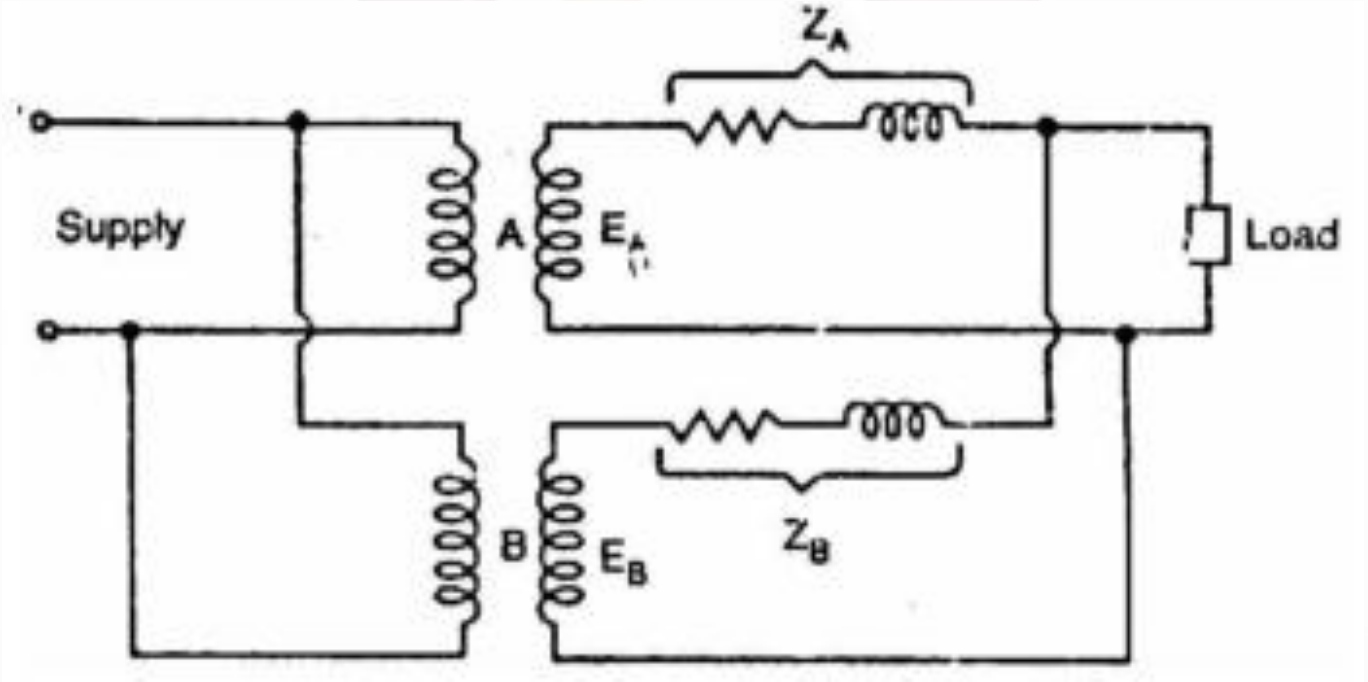
Correct connections



Wrong connections

Conditions for satisfactory Parallel Operation

- The voltage ratings and voltage ratios of the transformers should be identical.



Conditions for satisfactory Parallel Operation

- Same phase sequence.
- The impedances of the transformers should be equal.
- If this condition is not met, the transformers will not share the load according to their kVA ratings.
- It can be corrected by inserting proper amount of resistance

Conditions for satisfactory Parallel Operation

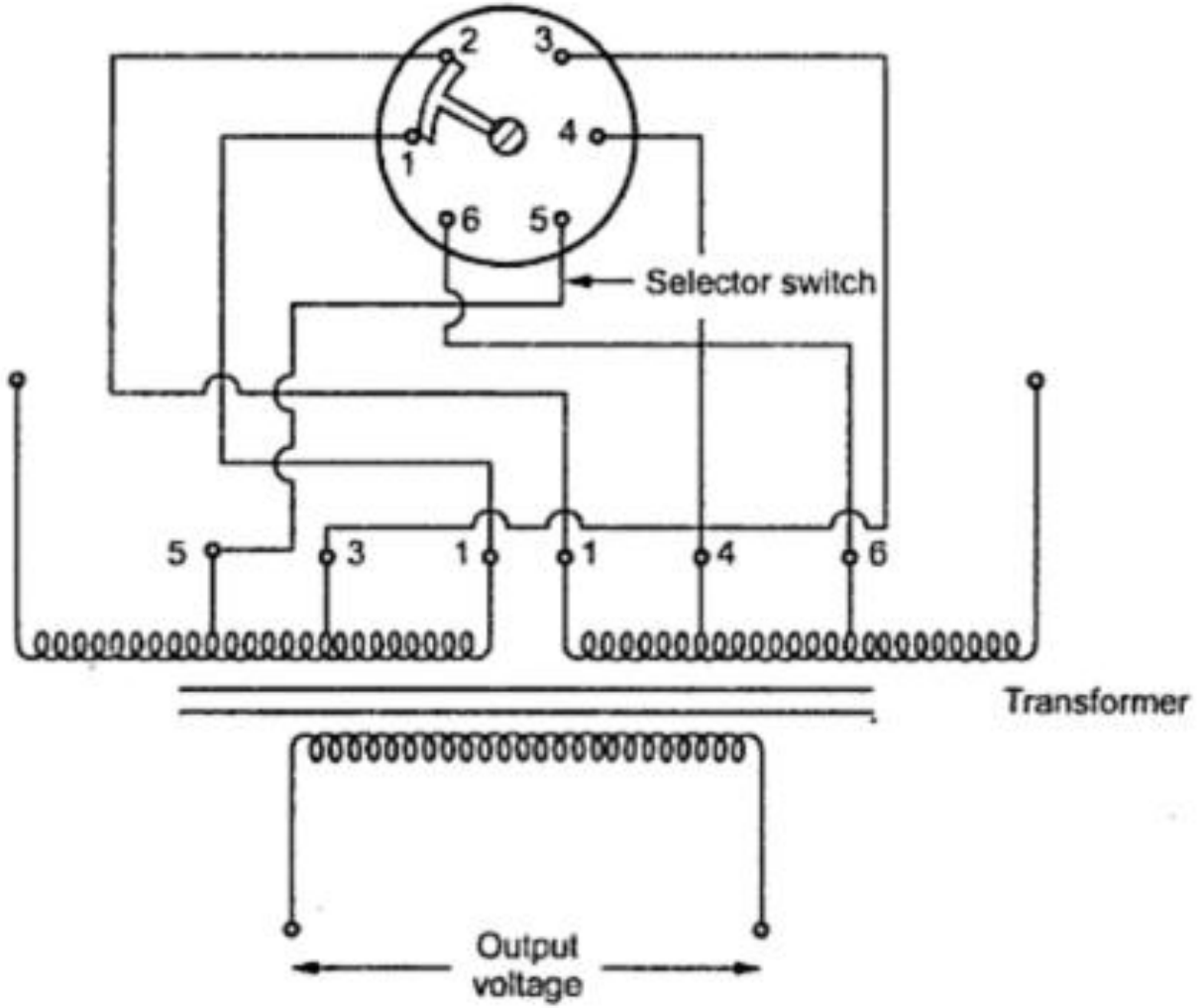
- The reactance/resistance ratios of the transformers should be the same in order to avoid circulating currents.
- The power factor of the load supplied by the transformers will not be equal.
- One transformer will be operating with a higher and the other with a lower power factor than that of the load.

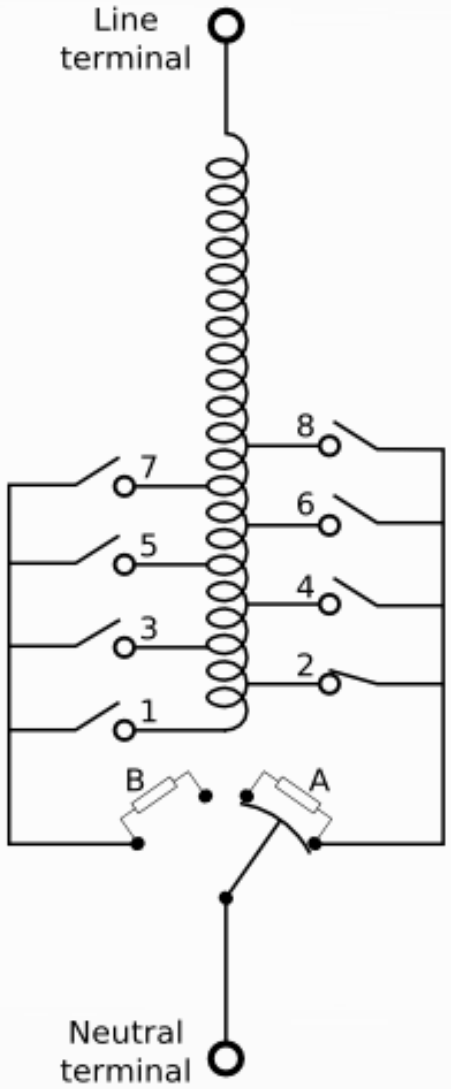
Tap Changing Transformers

- Voltage variation in power system is a normal phenomenon due to rapid growth of industries and distribution network.
- Therefore system voltage control is essential for:
  - ✓ Adjustment of consumer's terminal voltage within prescribed limits.
  - ✓ Control of real and reactive power flow in the network.
- Turns ratio of the transformer is varied for achieving tap changing.

Off Load Tap Changing

- It is required to de-energise the transformer before changing the tap.

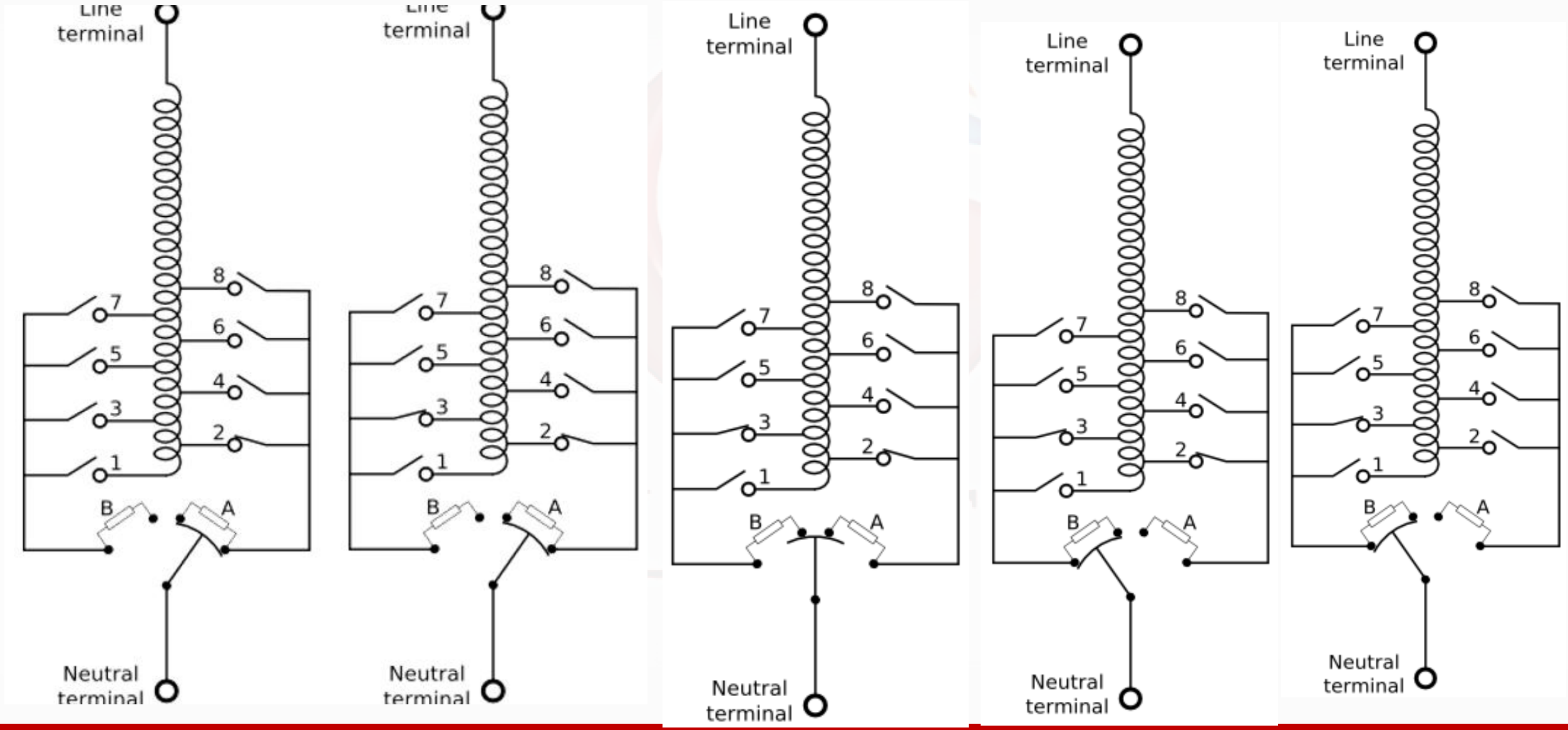




On Load Tap Changing

- Tap changing is done while transformer is delivering load.
- The operating efficiency of electrical system is improved.
- It is fitted with almost all power transformers.

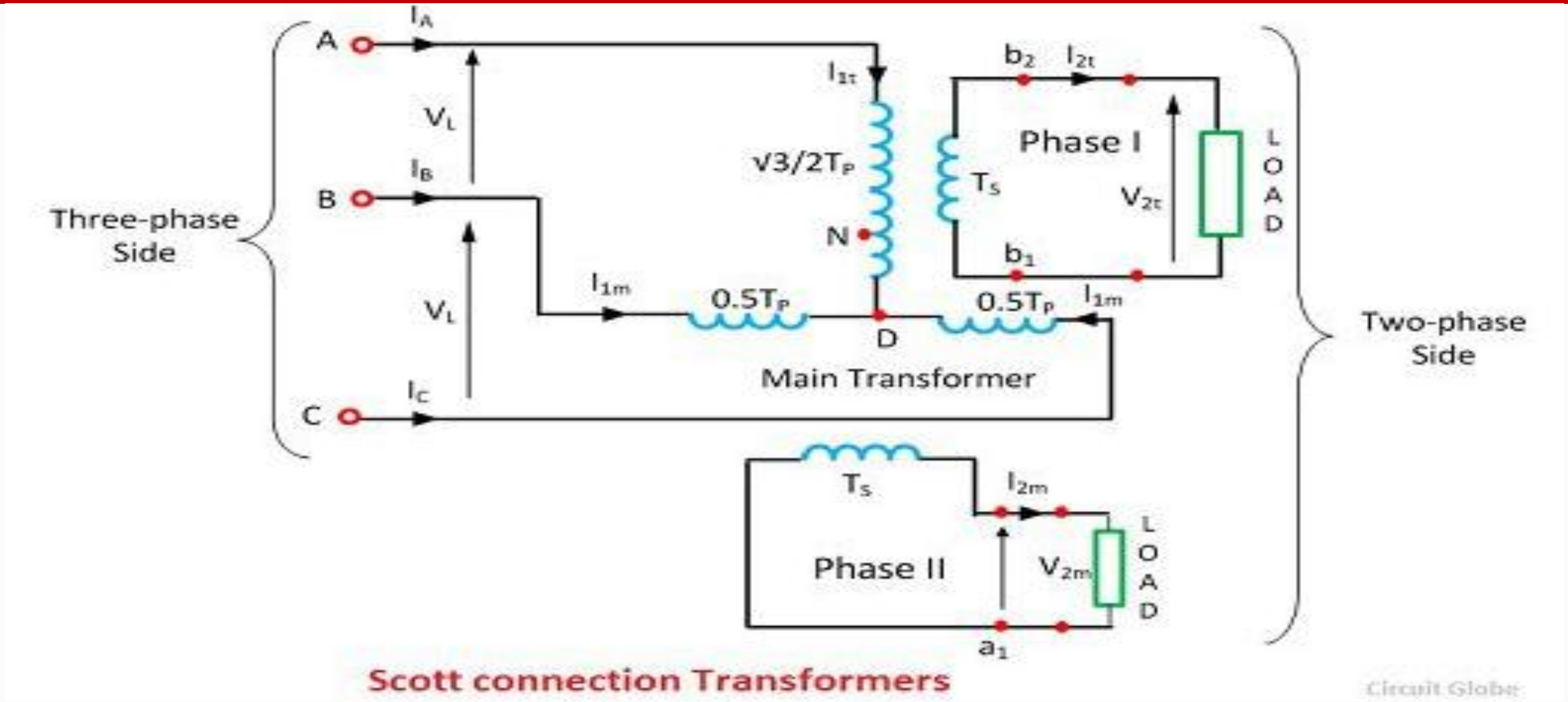
Three-phase Transformer Connections, phase conversion and harmonics



Scott-T Transformer Connection

- The Scott-T Connection is the method of connecting two single phase transformer to perform the 3-phase to 2-phase conversion and vice-versa.
- The two transformers are connected electrically but not magnetically.
- One of the transformers is called the main transformer, and the other is called the auxiliary or teaser transformer.
- The identical, interchangeable transformers are used for Scott-T connection in which each transformer has a primary winding of Tp turns and is provided with tapping at 0.289Tp , 0.5Tpand 0.866 Tp.

Three-phase Transformer Connections, phase conversion and harmonics

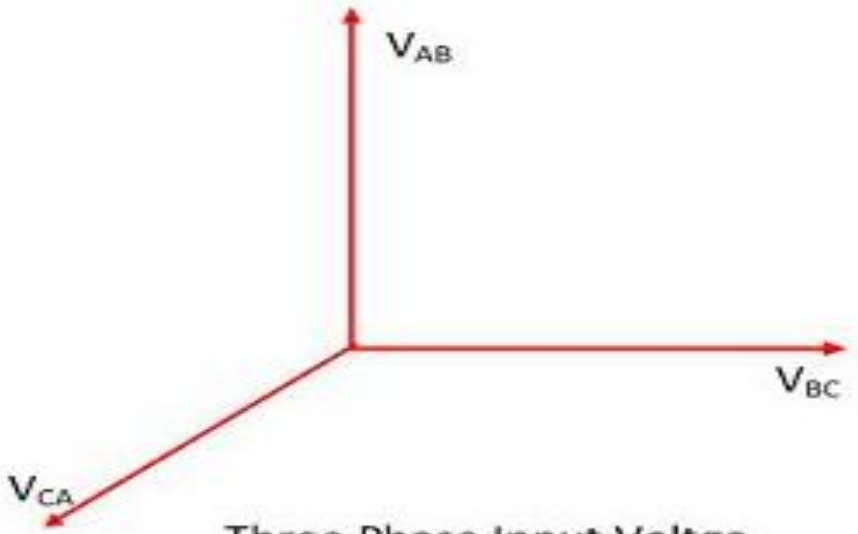


Three-phase Transformer Connections, phase conversion and harmonics

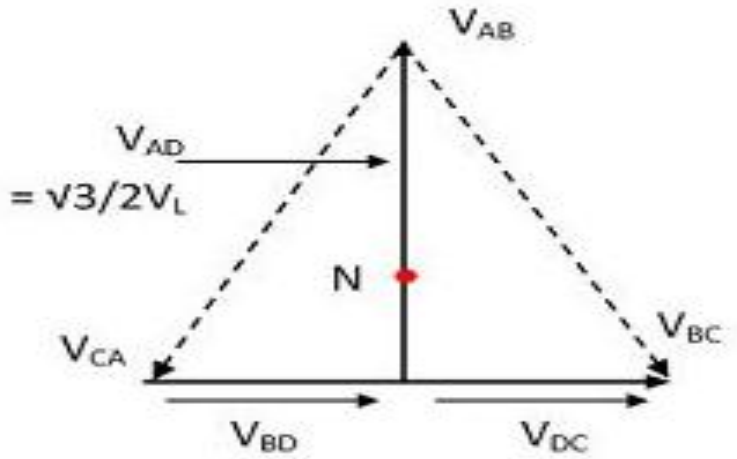
- The main transformer is centre tapped at D and is connected to the line B and C of the 3-phase side. It has primary BC and secondary a_1a_2. The teaser transformer is connected to the line terminal A and the centre tapping D. It has primary AD and the secondary b_1b_2.

- The line voltages of the 3-phase system V_{AB}, V_{BC}, and V_{CA} which are balanced are shown in the figure below. The same voltage is shown as a closed equilateral triangle. The figure below shows the primary windings of the main and the teaser transformer.

$$|V_{AB}| = |V_{BC}| = |V_{CA}| = |V_L|$$



Three Phase Input Voltge



Voltage on transformer Primary Winding

The D divides the primary BC of the main transformers into two halves and hence the number of turns in portion BD = the number of turns in portion DC = $T_p/2$.The voltage V_{BD} and V_{DC} are equal, and they are in phase with V_{BC}.

$$V_{BD} = V_{DC} = \frac{1}{2}V_{BC} = \frac{1}{2}V_L < 0°$$

$$V_{BD} = V_{DC} = \frac{1}{2}V_{BC} = \frac{1}{2}V_L < 0°$$

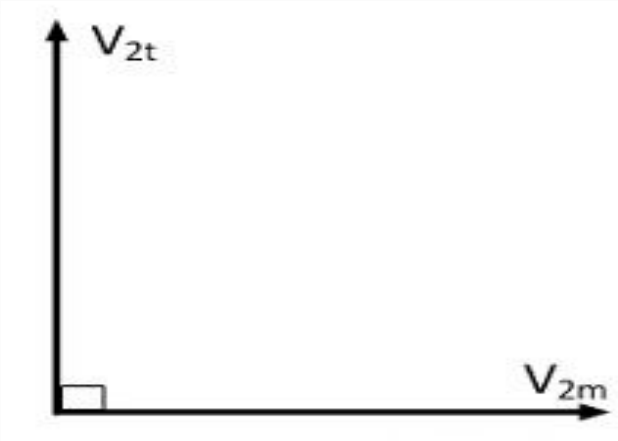
The voltage between A and D is

$$V_{AD} = V_{AB} + V_{BD}$$

$$V_{AD} = V_L\left(-\frac{1}{2} + j\frac{\sqrt{3}}{2}\right) + \frac{1}{2}V_L$$

$$V_{AD} = V_L\left(j\frac{\sqrt{3}}{2}\right) = 0.866V_L < 90°$$

- The teaser transformer has the primary voltage rating that is √3/2 or 0.866 of the voltage ratings of the main transformer.
- Voltage V_{AD} is applied to the primary of the teaser transformer and therefore the secondary of the voltage V_{2t} of the teaser transformer will lead the secondary terminal voltage V_{2m} of the main transformer by 90º as shown in the figure below.



Then,

$$\frac{V_{S_1}}{V_{AD}} = \frac{T_S}{T_{AD}}$$

$$V_{2t} = \frac{T_S}{T_{AD}} V_{AD} = \frac{T_S}{\frac{\sqrt{3}}{2} T_P} \times \frac{\sqrt{3} V_t}{2}$$

$$\frac{T_S}{T_P} V_L = v_{2m}$$

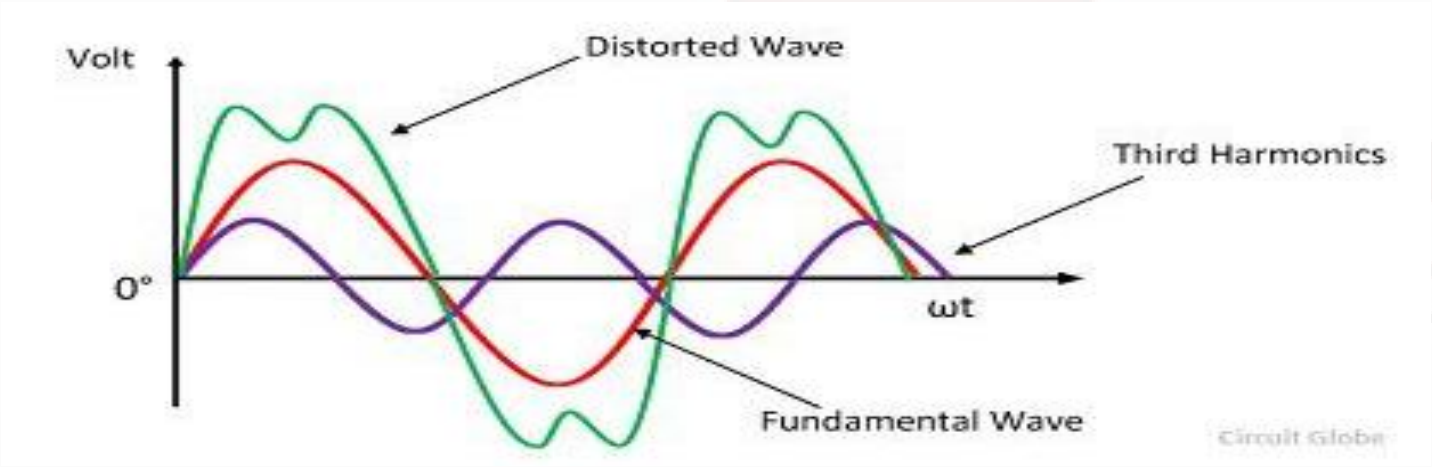
- For keeping the voltage per turn same in the primary of the main transformer and the primary of the teaser transformer, the number of turns in the primary of the teaser transformer should be equal to $\sqrt{3}/2T_p$. Find out the position of neutral N.

Harmonics in Three Phase Transformers

- The harmonic is the distortion in the waveform of the voltage and current.
- It is the integral multiple of some reference waves.
- The harmonic wave increases the core and copper loss of the transformer and hence reduces their efficiency.
- It also increases the dielectric stress on the insulation of the transformer.

Three-phase Transformer Connections, phase conversion and harmonics

- In a three-phase transformer, the non-sinusoidal nature of magnetising current produces sinusoidal flux which gives rise to the undesirable phenomenon.
- The phase magnetising currents in transformer should contain third harmonics and higher harmonics necessary to produce a sinusoidal flux.



Summary

- Connections of three phase transformer and its application
- Necessary and desirable conditions of the transformer
- Scott-T connections and phase conversions
- Phase conversion
- Harmonics