Basic Electronics (EE-101)

Dr. Samarendra Dandapat

Department of Electronics & Electrical Engineering

IIT Guwahati

Email: samaren@iitg.ernet.in

Lecture Plan

Polyphase Systems / Circuits

- ★ Balanced Three-phase Systems (Star (Y) & Delta (Δ))
- ★ Three-phase Power Measurement

Magnetic Circuits

- ★ Electro-magnetism
- ★ Mutual Inductance and Coupling

Frequency Response

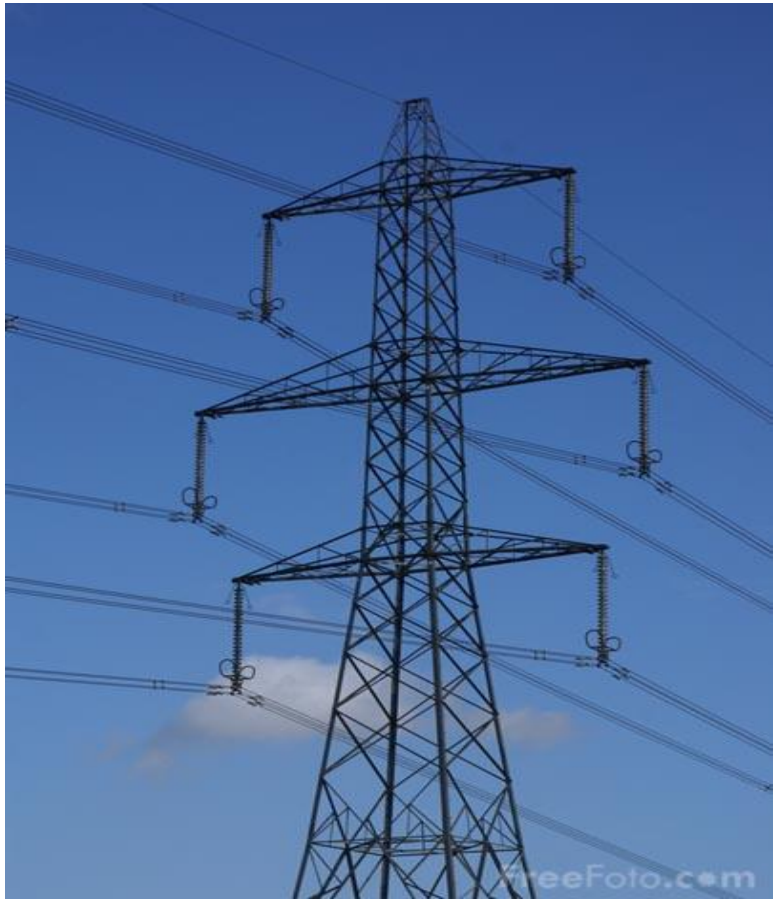
- ★ Resonance
- ★ Filters

Text Book: Engineering Circuit Analysis *by Hayt, Kemmerly and Durbin, McGraw Hill, 7th Ed.*

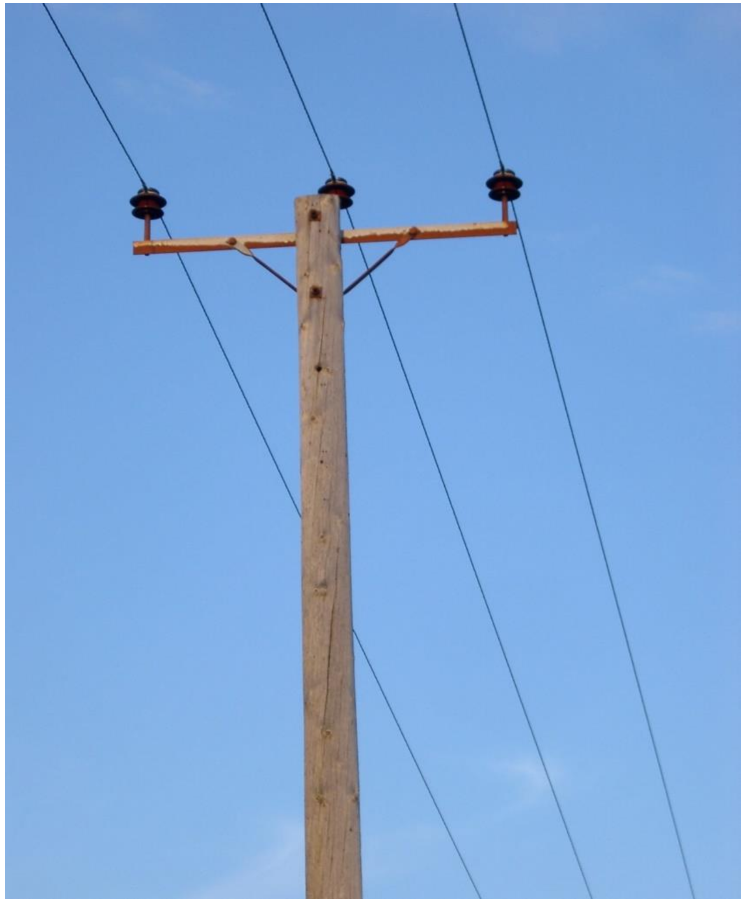
Polyphase Systems / Circuits

- Why Polyphase System?
- What is a Polyphase Source?
- Balanced Three-phase System.
- Wye (Y) and Delta (Δ) Connected Source and Load.
- Analysis of a balanced Three-phase System
- Power Measurement in a Three-phase System

Three-phase Transmission Lines over IIT Guwahati Campus



3-phase Transmission line



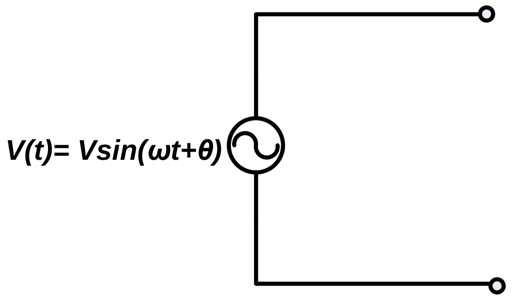
3-phase distribution line

Polyphase Systems

- A C systems came into existence in the late 1880s because of the generation , transmission and consumption limitation of DC power .
- During the first use of AC, one basic problem remained: single phase motors are not able to start by themselves. This led to the invention of poly phase system in the early 1890s .
- Consequently some advantages of 3-phase system over 1-phase system came out to be:
  - 3-phase generators, motors and transformers are simpler, cheaper and more efficient
  - 3-phase transmission lines deliver more power for a given cost or for a given weight of conductor
  - Voltage regulation of a 3-phase system is inherently better

Single-phase Source

A single-phase source is denoted by $v(t) = V\sin(\omega t + \theta)$ as a function of time or as $\boldsymbol{v} = V\angle\theta$ in phasor form. The amplitude can be maximum or rms value. For a sinusoid function the maximum and the rms quantities are related through a multiplying factor of $\sqrt{2}$. A single-phase source is shown as

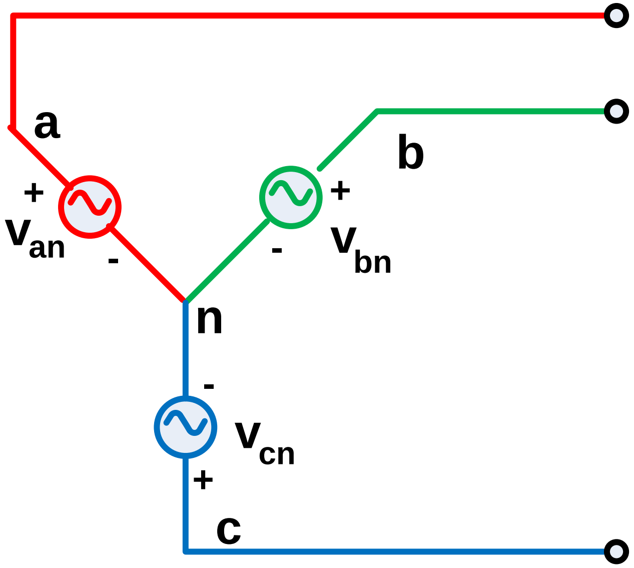


A single-phase source is characterized by three features:

- Amplitude, V (it can be a rms or peak value)
- Frequency, ω
- Phase, θ

Balanced Three-Phase Source

A Star (Y) connected balanced three-phase source consists of three single-phase sources



Various features of this three-phase source are:

- n is the neutral which is the common node for the three source voltages
- Quantities of three phases (of a 3-phase system) are represented by using subscripts '*a*', '*b*' and '*c*' or 'R', 'Y', 'B'. They are called phase-*a*, phase-*b* and phase-*c* *or* phase-*R*, phase-*Y* and phase-*B*
- v_{an}, v_{bn} and v_{cn} are the three-phase voltages

Balanced Three-Phase Source

For a balanced three-phase source

- The three phase voltages have equal magnitude
- All the sources operate at the same frequency
- Sum of the three phase voltages is equal to zero
- The three phase voltages differ from each other by a phase angle of 120^0

Mathematically the three phase voltages can be represented as

$|v_{an}| = |v_{bn}| = |v_{cn}|$

$v_{an} = V_P \sin \omega t$ with an equivalent phasor $V_P \angle 0^0$

$v_{bn} = V_P \sin(\omega t - 120^0)$, with an equivalent phasor $V_P \angle -120^0$

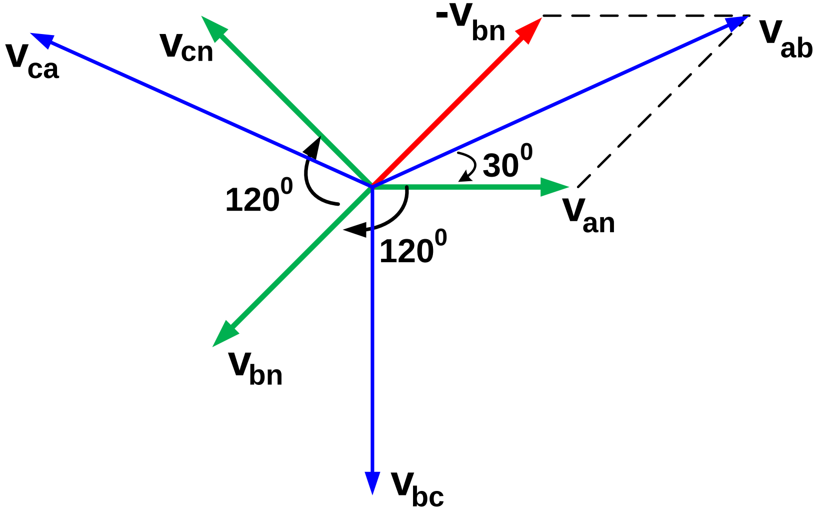
$v_{cn} = V_P \sin(\omega t - 240^0)$, with an equivalent phasor $V_P \angle -240^0$

This is called positive phase sequence. In this course, we will follow this phase sequence.

$v_{an} + v_{bn} + v_{cn} = 0$

Balanced Three-Phase Source

Graphically the three-phase voltages (phasors) can be seen as



v_{ab}, v_{bc} and v_{ca} are called line voltages which are the voltage difference between two corresponding phase voltages.

$$v_{ab} = v_{an} - v_{bn} = V_P\angle 0^0 - V_P\angle -120^0$$

$$= V_P \sin\omega t - V_P \sin\ (\omega t - 120^0)$$

$$= V_P[\sin\omega t\ - (\sin\omega t\ \cos 120^0 - \cos\omega t \sin 120^0)]$$

$$= V_P\left[\sin\omega t\ - (\sin\omega t\ (-\frac{1}{2}) - \cos\omega t \frac{\sqrt{3}}{2})\right]$$

$$= \sqrt{3}\ V_P\left[\frac{\sqrt{3}}{2}\sin\omega t + \frac{1}{2}\cos\omega t)\right]$$

$$= \sqrt{3}\ V_P\ [\cos 30^0 \sin\omega t + sin30^0 \cos\omega t)]$$

$$= \sqrt{3}\ V_P \sin(\omega t +\ 30^0)$$

Balanced Three-Phase Source

Line voltage $v_{ab} = \sqrt{3}\, V_P \sin(\omega t + \ 30^0)$ leads the phase voltage v_{an} by an angle of 30^0 and its magnitude is $\sqrt{3}$ times the magnitude of the phase voltage V_P. The three line voltages are

$$v_{ab} = \ \sqrt{3}\, V_P \sin(\omega t + 30^0),\ \Leftrightarrow V_L \angle 30^0$$

$$v_{bc} = \sqrt{3}\, V_P \sin\ (\omega t - \ 90^0), \Leftrightarrow V_L \angle -90^0$$

$$v_{ca} = \sqrt{3}\, V_P \sin\ (\omega t - \ 210^0), \Leftrightarrow V_L \angle -210^0$$

$$|v_{ab}| = |v_{bc}| = |v_{ca}|$$

$$v_{ab} + v_{bc} + v_{ca} \ = 0$$

Balanced Three-Phase Load

Three-phase loads can be either star (Y) connected or delta (Δ) connected. In delta connection, the impedances are connected back-to-back as shown in Fig. 1 (a). There is no neutral point in delta connection. Fig. 1(b) shows a star connected load.

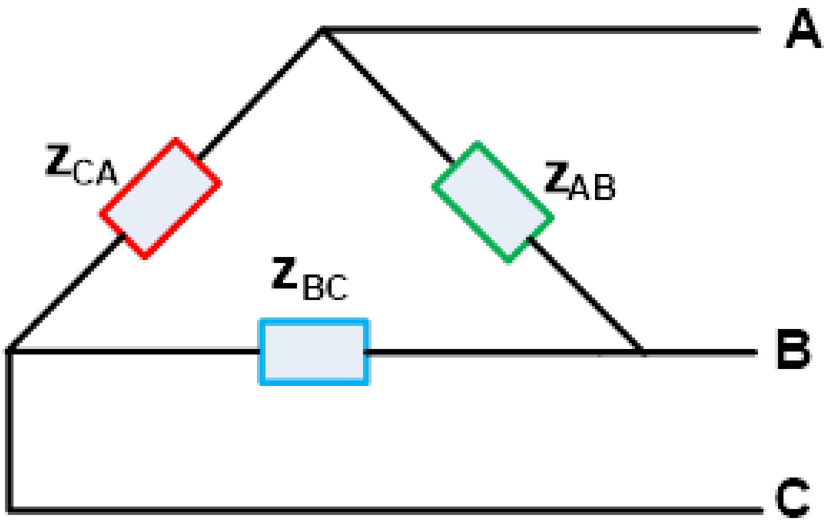


Fig. 1(a)

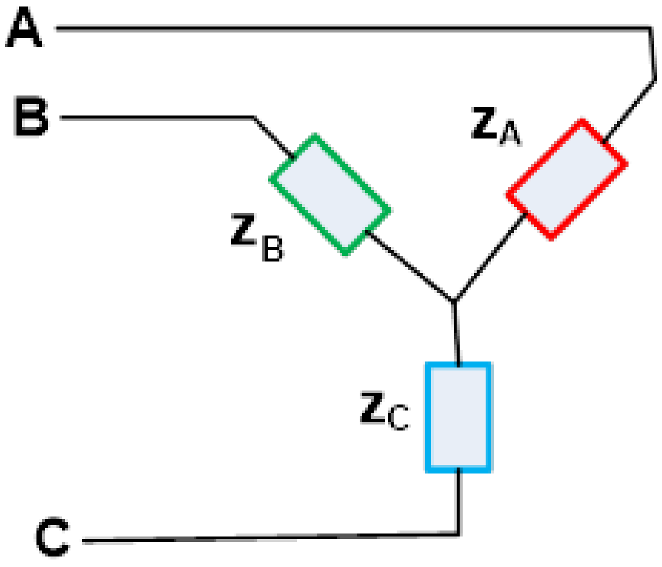


Fig. 1(b)

Balanced Three-Phase Load

For circuit analysis, the star connected loads can be represented using the delta connected loads and vice-versa.

The impedance seen between the lines A and B in the star connected load is $\mathbf{Z_A + Z_B}$ (series combination of $\mathbf{Z_A}$ and $\mathbf{Z_B}$). In the delta connected load, the impedance seen between A and B is $\mathbf{Z_{AB}}$ in parallel with the series combination of $\mathbf{Z_{CA}}$ and $\mathbf{Z_{BC}}$.

$$Z_A + Z_B = Z_{AB} \,||\, (Z_{BC} + Z_{CA})$$
$$= \frac{Z_{AB}(Z_{BC} + Z_{CA})}{Z_{AB} + Z_{BC} + Z_{CA}}$$

Similarly,

$$Z_B + Z_c = \frac{Z_{BC}(Z_{AB} + Z_{CA})}{Z_{AB} + Z_{BC} + Z_{CA}}$$
$$Z_c + Z_A = \frac{Z_{CA}(Z_{AB} + Z_{BC})}{Z_{AB} + Z_{BC} + Z_{CA}}$$

Balanced Three-Phase Load

Solving these three equations, the star connected impedances can be represented with equivalent delta connected impedances as

$$Z_A = \frac{Z_{AB}Z_{CA}}{Z_{AB} + Z_{BC} + Z_{CA}}$$

$$Z_B = \frac{Z_{AB}Z_{BC}}{Z_{AB} + Z_{BC} + Z_{CA}}$$

$$Z_c = \frac{Z_{BC}Z_{CA}}{Z_{AB} + Z_{BC} + Z_{CA}}$$

Similarly, delta connected loads (**Z_{AB}, Z_{BC}** and **Z_{CA}**) can be derived in terms of star connected loads (**Z_A, Z_B** and **Z_C**). Students can attempt this as an exercise.