Electrical Engineering

Power Systems

Comprehensive Theory

with Solved Examples and Practice Questions

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Power Systems

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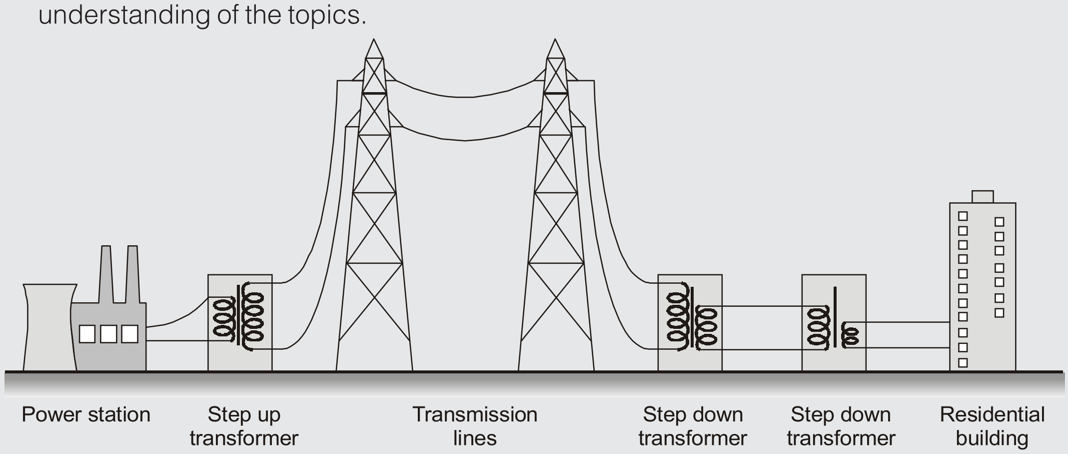
Introduction to Power Systems

An ***"Electric power system"*** is a network of electrical components used to supply, transmit and use electric power. An example of an electric power system is the network that supplies a region's home and industry with power for sizable regions, this power system is called ***"the grid"*** and can be broadly divided into the generators that supply the power, the transmission system that carries the power from the generating stations to the load centers and the distribution system that feeds the power to nearby homes and industries. Small power systems are also found in industry, hospitals, homes and commercial buildings. The majority of these systems relay upon ***"three-phase AC power"*** the standard for large scale power transmission and distribution across the modern world. Specialized power systems that do not rely upon the three-phase AC power are found in aircraft, electric rail systems, automobiles etc.

This course material embodies the principles and objectives of elements of power system. The aim of the course material on power system is to instill confidence and understanding of those concepts of power system that are likely to be encountered in the study and practice of electric power engineering. The presentation is tutorial with emphasis on a thorough understanding of fundamentals and underlying principles. This course material has been prepared in such a way to help the engineering students in understanding the basic concept of power system which will help them to excel in the competitive exams like GATE, IES, PSUs and other various competitive examinations. In each chapter, after every topic, wide number of solved examples have been discussed for the better understanding of the topics.



CHAPTER 1

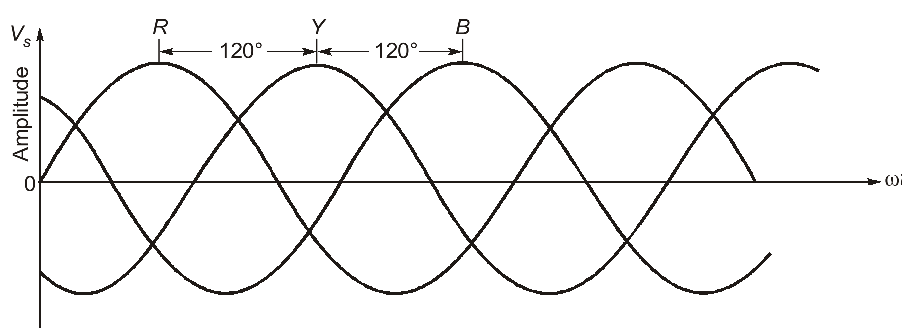
Performance of Transmission Lines, Line Parameters and Corona

1.1 Poly Phase AC Circuits

Poly phase circuits are important because all electric power is generated and distributed three-phase. A three-phase circuit has an ac voltage generator, also called an alternator, that produces three sinusoidal voltages that are identical except for a phase angle difference of 120° electrical. The electric energy is transmitted over either three or four wires, more often called lines. In them, three of the line currents are identical except for a phase angle difference of 120° electrical.

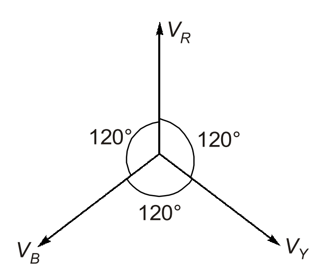
Generally, n phase systems are $\frac{360°}{n}$ apart in space.

1.2 Graphical Representation of 3-ϕ System



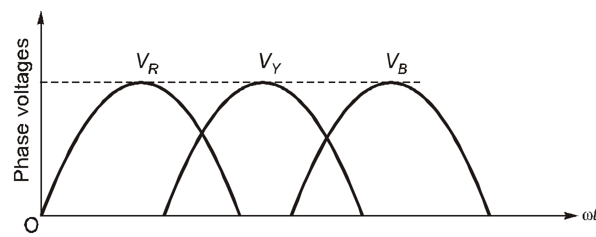
Here, phase sequence = RYB

and
$$V_R = V_m \sin\omega t \text{ volt} = V\angle 0° \text{ volt}$$
$$V_Y = V_m \sin(\omega t - 120°) \text{ volt} = V\angle -120° \text{ volt}$$
$$V_B = V_m \sin(\omega t - 240°) \text{ volt} = V\angle -240° \text{ volt}$$
$$= V\angle +120° \text{ volt}$$

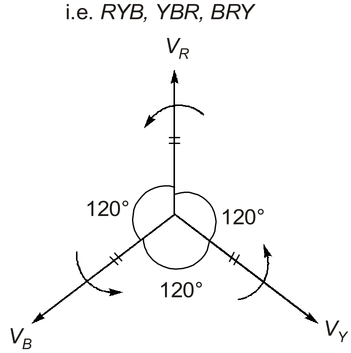
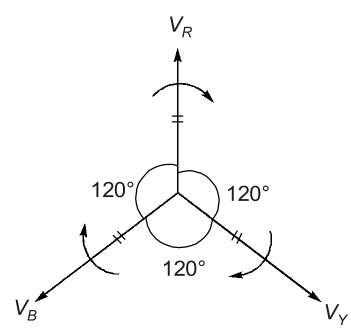
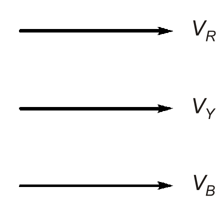


1.2.1 Phase Sequence

It is the order by which the phase voltages attain their peak value. The phase sequence may be positive, negative or zero (No particular sequence).



RYB is the universally adopted phase sequence.
For a 3-ϕ system phase sequence must be defined.

Positive Phase sequence	Negative Phase sequence	Zero Phase sequence
i.e. *RYB, YBR, BRY* 	i.e. *RBY* 	i.e. no particular order of phase sequence, means zero sequence 

Balanced and Unbalanced 3-ϕ System

For balanced 3-ϕ system: $I_R + I_Y + I_B = 0$
For unbalanced 3-ϕ system: $I_R + I_Y + I_B \neq 0$

1.2.2 Advantages of 3-ϕ System

The advantages of a 3-phase system over a single phase system are as under:

(*i*) the amount of conductor material needed to transfer same amount of power is lesser for three phase system thus it is more economical.
(*ii*) domestic power and industrial/commercial power can be provided from the same source,
(*iii*) voltage regulation of three phase is better.
(*iv*) the torque produced by a three phase motor is more.
(*v*) as three phase motors are self-starting while single phase motor are not, three phase system is certainly advantageous and versatile.
(*vi*) for a given size of the frame, three phase generator provides more output.
(*vii*) with the help of 3-ϕ system, interconnection is possible either in star or in delta.
(*viii*) a rotating magnetic field can be produced with the help of a balanced 3-phase winding (in space) when supplied with a balanced three phase current (in time).
(*ix*) three phase machines produce less vibration compared to a single phase machine.

Example - 1.1 What is the current flowing through the neutral in a balanced 3-phase star system?

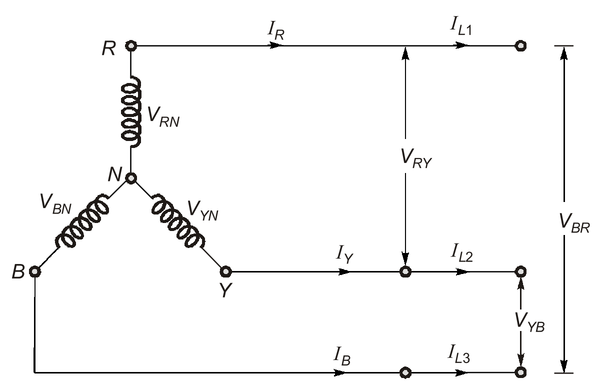
Solution:
Current flowing through the neutral is always zero as long as the system is working under balanced condition.
Under balanced condition: $I_R + I_Y + I_B = I_N = 0$ A

1.3 Type of 3-ϕ Connections

1. Star (Y) connection
2. Delta (Δ) connection

1.3.1 Star (Y) Connection

Figure shows a balanced three phase star connected system having phase sequence *RYB* (Positive phase sequence).



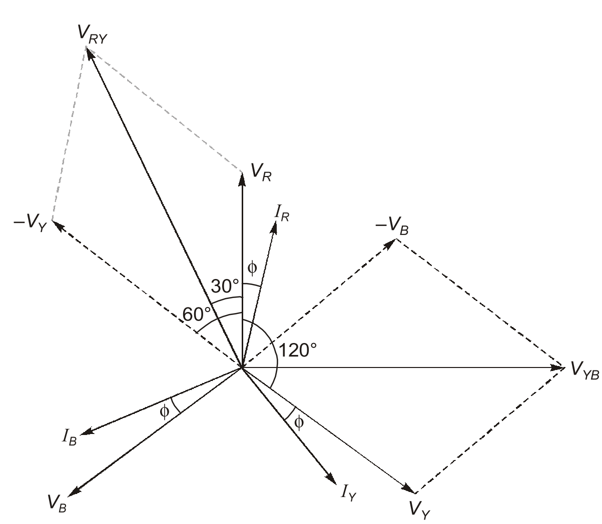
Here,

$\Rightarrow$ $|V_{RN}| = |V_{YN}| = |V_{BN}| = V_{Ph}$ are phase voltages (Voltage between a line and neutral)

$\Rightarrow$ $|V_{RY}| = |V_{YB}| = |V_{BR}| = V_L$ are line voltages (i.e. voltage between two phases)

$\Rightarrow$ $V_{RN} = (V_R - V_N)$

It's phasor diagram is shown below:



Conclusions

(*i*) Relation between line and phase current:

$I_R = I_Y = I_B = I_{Ph}$ = Phase current

$I_{L1} = I_{L2} = I_{L3} = I_L$ = Line current

Since the phase are connected in series. So, current remains constant.

(*ii*) Relation between line and phase voltage:

$$V_{RY} = V_{RN} - V_{YN}$$
$$V_{YB} = V_{YN} - V_{BN}$$

and
$$V_{BR} = V_{BN} - V_{RN}$$

Line voltage,
$$V_{RY} = \sqrt{|V_R|^2 + |V_Y|^2 + 2|V_R||V_Y|\cos 60^\circ} = \sqrt{V_{Ph}^2 + V_{Ph}^2 + 2V_{Ph}^2 \cdot \frac{1}{2}}$$

or
$$V_{RY} = V_L = \sqrt{3}\,V_{Ph}$$

(*iii*) Phase angle between V_L and I_L:

Type of load	Phase angle
RL load	30° + ϕ
R load	30°
RC load	30° – ϕ

(*iv*) w.r.t. reference V_{RY}:

Line voltages are

$$V_{RY} = V_L\angle 0^\circ$$
$$V_{YB} = V_L\angle -120^\circ$$
$$V_{BR} = V_L\angle -240^\circ = V_L\angle 120^\circ$$

(*v*) Phase voltages w.r.t. reference:

$$V_{RN} = V_L\angle -30^\circ$$
$$V_{YN} = V_L\angle -150^\circ$$
$$V_{BR} = V_L\angle -270^\circ = V_{Ph}\angle 90^\circ$$

Advantage of Star Connected System

With star system protection can be provided by connecting a protective device between neutral and earth for the detection of earth fault.

Analysis for Negative Phase Sequence

Let phase sequence = *RBY*

$$V_{RY} = (V_R - V_Y)$$

(*i*) Relation between line and phase voltage:

$$I_R = I_Y = I_B = I_{Ph}$$
$$I_{L1} = I_{L2} = I_{L3} = I_L$$
$$\boxed{I_L = I_{Ph}}$$

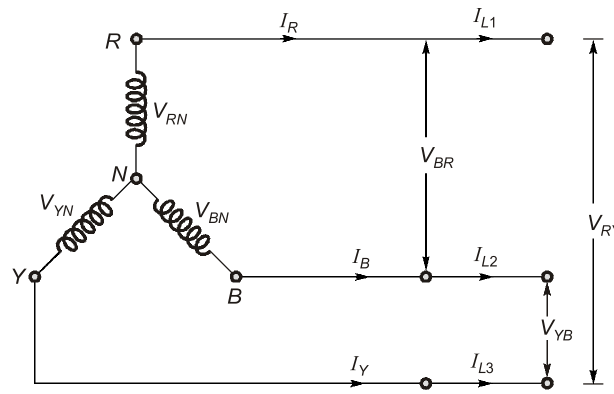


***Figure-1 :** Star connection for –ve phase sequence*

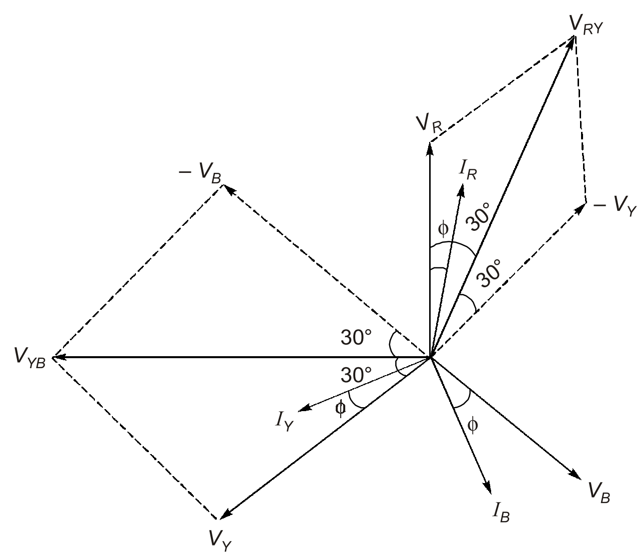


***Figure-2 :** Phasor diagram for negative phase sequence (RBY)*

(*ii*) Relation between line and phase voltage:

$$V_{BR} = V_{BN} - V_{RN}$$
$$V_{RY} = V_{RN} - V_{YN}$$
$$V_{YB} = V_{YN} - V_{BN}$$
$$Y_{RY} = \sqrt{|V_R|^2 + |V_Y|^2 + 2|V_R||V_Y|\cos 60^\circ} \quad \text{or} \quad V_{RY} = V_L = \sqrt{3}\, V_{Ph}$$

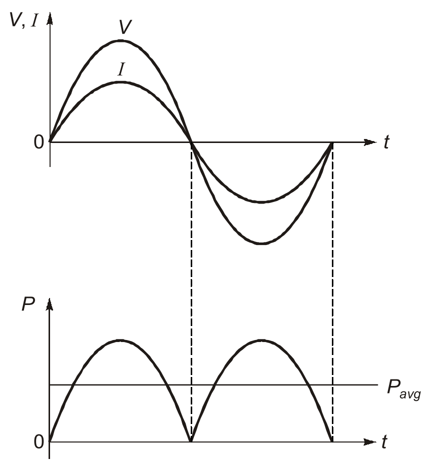
or,
$$V_{RB} = V_{RY} = V_{BY} = V_L = \sqrt{3}\, V_{Ph}$$

(*iii*) Phase angle between V_L and I_L:

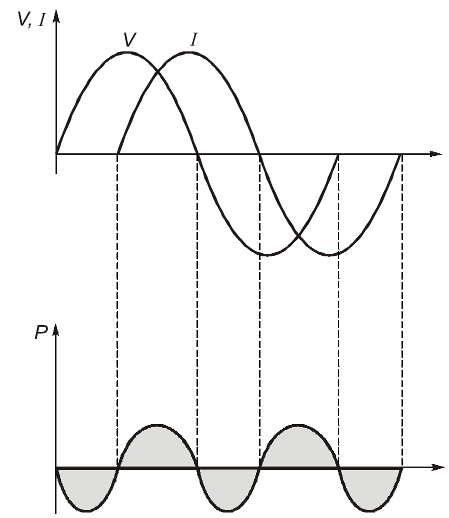
Type of load	Phase angle
RL	30 – ϕ)
R	30°
RC	(30 – ϕ)

(iv) To find average power (P_{avg}):

R-Load



Pure Inductive load



NOTE

P_{avg} = 0 for only inductive load (+ve half cycle equals to –ve half cycle)

- Line voltages w.r.t. reference (V_{RY}):

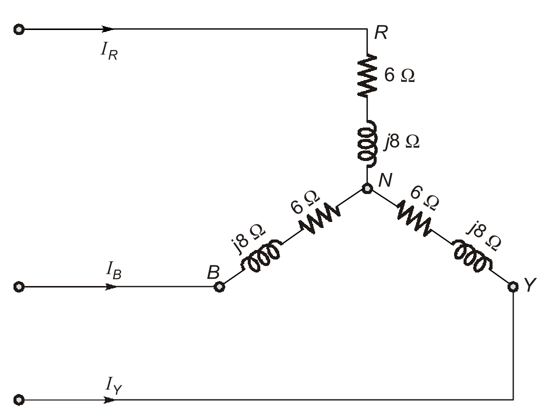
$$V_{RY} = V_L\angle 0$$
$$V_{YB} = V_L\angle -240°$$
$$V_{BR} = V_L\angle -120°$$

- Phase voltage w.r.t. reference (V_{RY}):

$$V_R = V_{Ph}\angle 30°$$
$$V_Y = V_{Ph}\angle 150°$$
$$V_B = V_{Ph}\angle 270°$$

Example - 1.2 For given figure, find the line currents provided the supply is balanced 100 V, 50 Hz three phase supply.

Solution:



$$I_{Ph}\text{ (Phase current)} = \frac{V_{Ph}}{Z_{Ph}}$$

Since in Y-connection, $V_{Ph} = \dfrac{V_L}{\sqrt{3}}$ and $I_{Ph} = I_L$

$\therefore$
$$I_{Ph(RN)} = \frac{100\angle 0^\circ}{\sqrt{3}(6+j8)} = \frac{100\angle 0^\circ}{10\sqrt{3}\angle 53.13^\circ}$$

$$= \frac{10}{\sqrt{3}}\angle -53.13^\circ \text{ A} = I_L = \text{Line current}$$

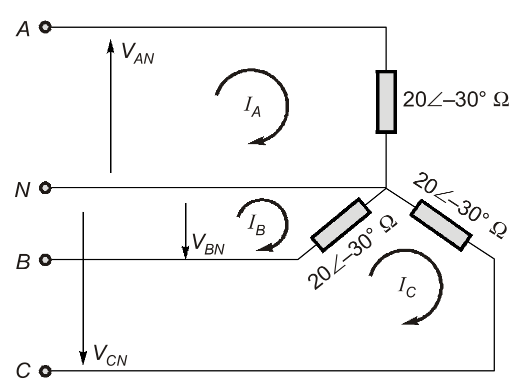
Similarly, $$I_{Ph(YN)} = \frac{100\angle -120^\circ}{10\sqrt{3}\angle 53.13^\circ} = \frac{10}{\sqrt{3}}\angle -173.13^\circ \text{ A} = I_L = \text{line current}$$

and $$I_{Ph(BN)} = \frac{100\angle 120^\circ}{10\sqrt{3}\angle 53.13^\circ} = \frac{10}{\sqrt{3}}\angle 66.87^\circ \text{ A} = I_L = \text{line current}$$

So, $$|I_{Ph}| = |I_L| = \frac{10}{\sqrt{3}} \text{ A} = 5.77 \text{ A} \qquad [I_R = I_Y = I_B]$$

Example - 1.3 A three-phase, 4 wire CBA system, with an effective line voltage of 169.7 V, has three impedances of 20∠–30° Ω in a Y-connection (figure). Determine the line currents and draw the voltage current phasor diagram.

Solution:



Line voltage = 169.7 V

So, $$|V_{CN}| = |V_{BN}| = |V_{AN}| = \frac{169.7}{\sqrt{3}} \approx 98 \text{ V}$$

Phase sequence is CBA. Let V_{CN} be the reference phasor.

So, $$V_{CN} = 98\angle 0^\circ \text{ V},\ V_{BN} = 98\angle -120^\circ \text{ V and } V_{AN} = 98\angle -240^\circ \text{ V}$$

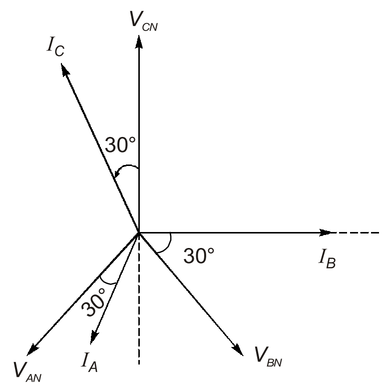
$$Z_A = Z_B = Z_C = 20\angle -30\ \Omega$$

Line current are: $$I_A = \frac{V_{AN}}{Z_A} = \frac{98\angle -240^\circ}{20\angle -30^\circ} = 4.9\angle -210^\circ \text{ A} = 4.9\angle 150^\circ \text{ A}$$

$$I_B = \frac{V_{BN}}{Z_B} = \frac{98\angle -120^\circ}{20\angle -30^\circ} = 4.9\angle -90^\circ \text{ A}$$

and $$I_C = \frac{V_{CN}}{Z_C} = \frac{98\angle 0^\circ}{20\angle -30^\circ} = 4.9\angle 30^\circ \text{ A}$$

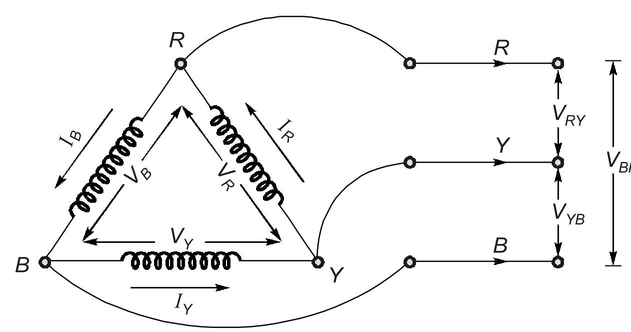
Voltage current phasor diagram is as shown below:



1.3.2 Delta (Δ) Connection

Phase sequence is *RYB*

$$I_R = I_B + I_{L1} \text{ or } I_{L1} = I_R - I_B$$
$$I_Y = I_R + I_{L2} \text{ or } I_{L2} = I_Y - I_R$$
$$I_B = I_Y + I_{L3} \text{ or } I_{L3} = I_B - I_Y$$



(*i*) Relation between Line and Phase voltage

$$V_R = V_Y = V_B = V_{Ph}$$
$$V_{RY} = V_{YB} = V_{BR} = V_L$$

∴ $\boxed{V_L = V_{Ph}}$

For parallel connection voltage remains same.

(*ii*) Relation between Line and Phase current

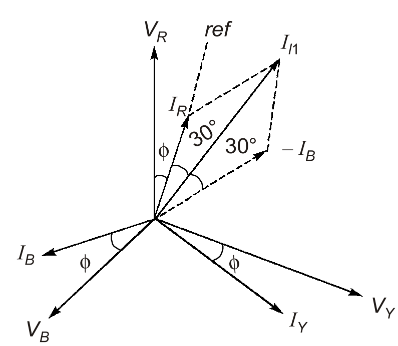
$$I_{L1} = I_R + (-I_B)$$
$$I_{L2} = I_Y + (-I_R)$$
$$I_{L3} = I_B + (-I_Y)$$

From phasor diagram,

$$I_{L1} = \sqrt{|I_R|^2 + |I_B|^2 + 2|I_R|\,|I_B|\cos 60°}$$

or, $I_L = \sqrt{3}\, I_{Ph}$

Therefore, $I_L = I_{L2} = I_{L3} = I_L = \sqrt{3}\, I_{Ph}$



Phasor diagram

(*iii*) Phasor angle between V_L and I_L

Type of Load	Phase angle
RL	30 + ϕ
R	30°
RC	30 – ϕ

(*iv*) Current w.r.t. reference phasor (I_R)

$$I_R = I_{Ph}\angle 0°$$
$$I_Y = I_{Ph}\angle -120°$$
$$I_B = I_{Ph}\angle -240° = I_{Ph}\angle +120°$$

(*v*) Line current w.r.t. reference phasor (I_R)

$$I_{L1} = I_L\angle{-30°}$$
$$I_{L2} = I_L\angle{-150°}$$
$$I_{L3} = I_L\angle{-270°} = I_L\angle{+90°}$$

1.4 Power Calculations

1. Single phase power, $P_{1\text{-}\phi} = V_{Ph}\, I_{Ph} \cos\phi$
2. Three phase power, $P_{3\text{-}\phi} = 3\, V_{Ph} I_{Ph} \cos\phi$
3. Three phase power in star connection,

$$P_{3\text{-}\phi(Y)} = 3\cdot\frac{V_L}{\sqrt{3}}\cdot I_L \cos\phi = \sqrt{3}\, V_L I_L \cos\phi$$

4. Three phase power in delta connection,

$$P_{3\text{-}\phi(\Delta)} = 3\cdot V_L\cdot\frac{I_L}{\sqrt{3}}\cos\phi = \sqrt{3}\, V_L I_L \cos\phi$$

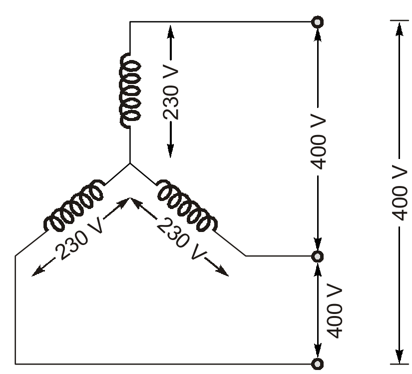
5. Three phase reactive power,

$$P_{(Y)} \text{ or } P(\Delta) = \sqrt{3}\, V_L I_L \sin\phi$$

6. Total apparent power, $s = \sqrt{3}\, V_L I_L$

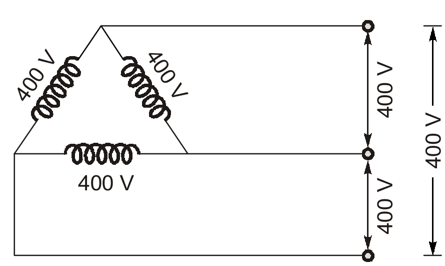
NOTE: Three phase power in star is equal to that in delta connection which is equal to $\sqrt{3} V_L I_L \cos\phi$.

Example:



***Y*-Connection**

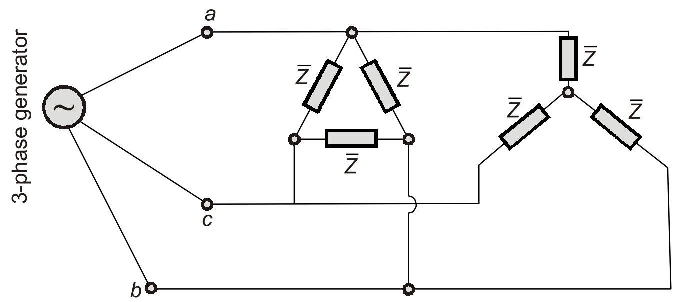
$$V_{Ph} = \frac{V_L}{\sqrt{3}} = \frac{400}{\sqrt{3}} \text{ V} = 230 \text{ V}$$



Δ-Connection

$$V_{Ph} = V_L = 400 \text{ V}$$

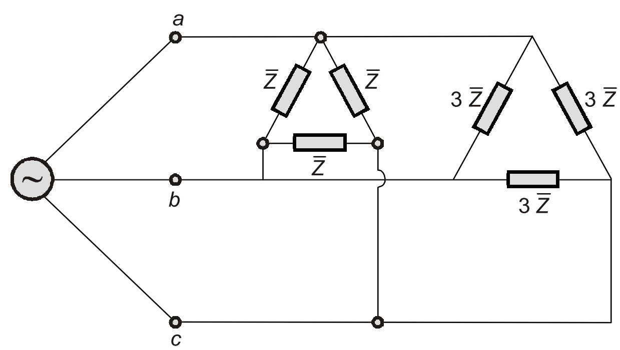
Example - 1.4 A 415 V, three phase generator supplies power to both a delta and a star connected load in the manner shown in figure. All the phase impedances are identical and specifically equal to (5 + *j*8.66) Ω. Compute the total generator current in each line.

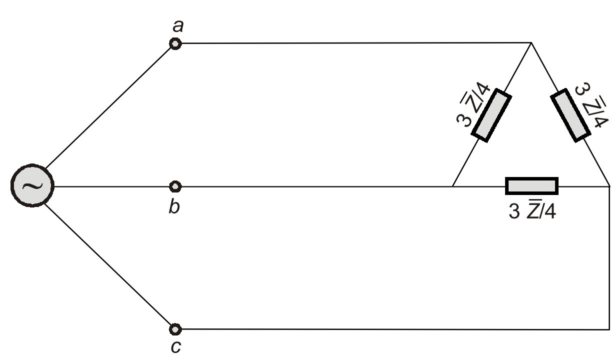


Solution:

Converting equivalent star load into delta,

$$Z_\Delta = 3Z_Y = 3\bar{Z}$$





Equivalent star connection is

$$\text{Line current} = \frac{(415/\sqrt{3})}{(Z/4)} = \frac{400\times 4}{\sqrt{3}\times(5+j8.66)} = 95.84\angle{-60°}\text{ A}$$

$\therefore$

$$I_a(L) = 95.84\angle{-60°}$$
$$I_b(L) = 95.84\angle{-180°}$$
$$I_c(L) = 95.84\angle{60°}$$

22. For a bundled conductor, $C_n = \dfrac{2\pi\varepsilon}{ln\left(\dfrac{D_{eq}}{D_{SC}^{b}}\right)}$ F/m

23. Corona:

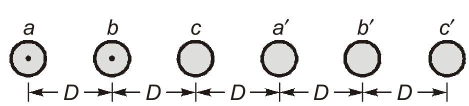
- Air density factor is, $\delta = \left(\dfrac{3.92h}{t+273}\right)$
- Breakdown strength of air at NTP = 30 kV/cm/peak = 21.1 kV/cm/rms = g_0
- At any temperature and pressure, critical disruptive voltage is given by $\left[V_{d_0} = g_0\delta m_0 r\, ln\left(\dfrac{d}{r}\right)\right]$

  or, $\left[V_{d_0} = 21.1\, r\delta m_0\, ln\left(\dfrac{d}{r}\right) \text{ kV/cm/rms per phase}\right]$

- Visual critical voltage is, $\left[V_V = g_0\,\delta\, r M_v\left(1+\dfrac{0.3}{\sqrt{\delta r}}\right) ln\left(\dfrac{d}{r}\right) \text{ kV (rms) to neutral}\right]$
- Corona power loss is given by $\left[P_C = \dfrac{244}{\delta}(f+25)\sqrt{\dfrac{r}{d}}\,(V_{ph}-V_{d0})^2\times 10^{-5} \text{ kW/km/phase}\right]$

Student's Assignments 1

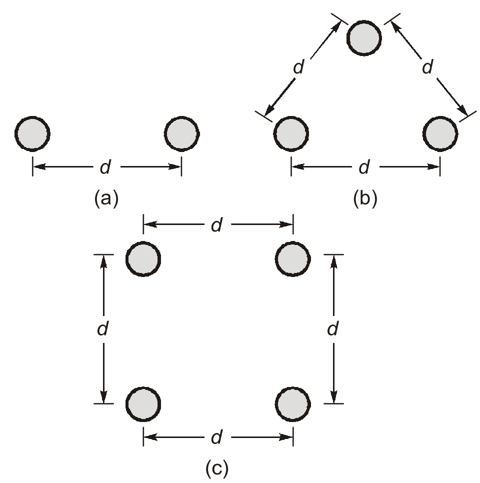
Q.1 Find the 50 Hz susceptance to neutral per kilometer of a double-circuit three-phase line with transposition as shown in figure below. Given $D = 7$ m and radius of each of the six conductors is 1.38 cm.



(Double circuit three-phase line with flat spacing)

Q.2 An overhead line 50 kms in length is to be constructed of conductors 2.56 cm in diameter, for single-phase transmission. The line reactance must not exceed 31.4 ohms. Find the maximum permissible spacing.

Q.3 Find the self GMD of three arrangements of bundled conductors shown in figure given below in terms of the total cross-sectional area A of conductors (same in each case) and the distance 'd' between them



Q.4 A 3-phase, 132 kV, 50 Hz overhead transmission line has steel cored aluminium conductors of equivalent copper area of 1.5 cm^2 and effective diameter of 39.8 mm spread equilaterally 8 m apart. Calculate the line constants. The resistivity of copper is 1.73 μΩ-cm.

Q.5 Determine the auxiliary constants of a 3-ϕ, 50 Hz, 150 km long transmission line having resistance, inductance and capacitance per phase per km of 0.2 Ω, 1.5 mH and 0.008 μF respectively. Neglect the conductance of the line.

Q.6 A 20 km, 20 kV, 50 Hz, 3-phase, 50 Hz transmission line is delivering 5 MW of power at a power factor of 0.8. The conductors have an effective diameter of 12 mm and a X-sectional area of 95 mm^2. These are arranged in an equilateral triangular formation, the distance between their centers being one meter. Find the:
(*i*) sending-end voltage
(*ii*) percentage voltage drop and
(*iii*) efficiency of transmission

Q.7 A 1000 km long, 3-phase, 50 Hz transmission line has resistance per phase per km= 0.1 Ω; reactance per phase per km = 0.5 Ω; susceptance per phase per km = 10×10^{-6} ℧. If the line supplies a load of 20 MW at 0.98 pf lagging at 65 kV at the receiving end, calculate by the nominal-π method the regulation and efficiency of the line. Neglect leakage

Q.8 A 3-phase, 220 kV, 50 Hz transmission line consists of 3.0 cm diameter conductors spaced 2 meters apart in equilateral triangle formation. If the temperature is 20°C and atmospheric pressure 75 cm, determine the corona loss per km of the line. Take irregularity factor as 0.80.

Q.9 A transmission line conductor across a hill is supported by two towers at a height 60 m and 90 m above ground level. The horizontal distance between them is 400 m. The horizontal distance between them is 400 m. The tension in the conductors is 3000 kg. Find the clearance between the ground and conductor at a point midway between the two towers if weight of conductor is 0.8 kg/m.

Q.10 A 3-ϕ transmission line has corona loss of 48 kW at 96 kV and 90 kW at 112 kV. Determine the disruptive voltage between lines.

Student's Assignments 1 Explanations

1. 5.53×10^{-6} mho/km

2. 1.48 m

3. (*i*) $0.557\, d^{1/2} A^{1/4}$
(*ii*) $0.633\, d^{2/3} A^{1/6}$
(*iii*) $0.746\, d^{3/4} A^{1/8}$

4. $R = 0.11533$ Ω/km/conductor
$L = 1.25$ mH/km/phase
$C = 0.00928$ μF/km/phase

5. $A = D = 0.987\angle 0.3°$; $B = 76\angle 67.1°$ Ω;
$C = 0.37 \times 10^{-3}\angle 90.1°$ s

6. (*i*) 22.2 kV (*ii*) 12% (*iii*) 93.3%

7. 15.15%; 94.56%

8. 0.425 kW/km

9. 69.66 m

10. Solution:

Power loss due to corona

$$P_c = \frac{244}{\delta}(f+25)\sqrt{\frac{r}{d}}(V_{ph}-V_{d0})^2 \times 10^{-5}$$

kW/km/phase

Taking δ, *r*, *d* and *f* as constant

$$P_c \propto (V_{ph} - V_{d0})^2$$

$$48 \propto \left(\frac{96}{\sqrt{3}} - V_{d0}\right)^2 \quad ...(1)$$

and

$$90 \propto \left(\frac{112}{\sqrt{3}} - V_{d0}\right)^2 \quad ...(2)$$

From equation (1) and (2) we get,

$$\frac{90}{48} = \frac{\left(\frac{112}{\sqrt{3}} - V_{d0}\right)^2}{\left(\frac{96}{\sqrt{3}} - V_{d0}\right)^2}$$

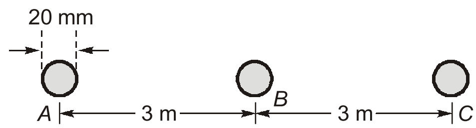
$$V_{d0} = 30.4 \text{ kV}$$

∴ Disruptive voltage between lines

$$= \sqrt{3} \times V_{d0} = 52.65 \text{ kV}$$

Student's Assignments 2

Q.1 The capacitance and charging current per unit length of the line for the following arrangement of conductors of diameter 20 mm shown in figure below will be respectively given by (Line voltage = 220 kV).



(a) 9.3737 μF, 1.261 mA
(b) 3.2323 pF, 1.261 mA
(c) 9.37.37 pF, 0.374 mA
(d) 3.2323 mF, 0.374 mA

Q.2 The highest transmission voltage in India through UHVAC is
(a) 400 kV (b) 132 kV
(c) 1200 kV (d) 765 kV

Q.3 In overhead lines, we generally use
(a) copper conductors
(b) all aluminium conductors
(c) ACSR conductors
(d) None of these

Q.4 In context of corona which statement is not true?
(a) corona is voltage effect
(b) corona takes place on short transmission lines
(c) corona is accompanied with power loss
(d) corona attenuates lightning surges

Q.5 In a transmission line the distributed constants are
(a) resistance and shunt conductance only
(b) resistance and inductance only
(c) resistance, inductance and capacitance only
(d) resistance, inductance, capacitance and shunt conductance

Q.6 Skin effect in a transmission line is due to
(a) supply frequency
(b) self inductance of conductor
(c) both (a) and (b)
(d) high sensitivity of material in the center

Q.7 When an alternating current flows through a conductor
(a) entire current passes through the core of the conductor.
(b) portion of conductor near the surface carries more current in comparison to the core.
(c) current remains uniformly distributed over the whole x-section of the conductor.
(d) portion of conductor near the surface carries less current in comparison to the core.

Q.8 The inductance of a single-phase two-wire line is given by (D is distance between conductors and 'r'' is the radius of conductor)

(a) $0.4 \log_e\left(\frac{D}{r'}\right)$ mH/km

(b) $0.55 \log_e\left(\frac{D}{r'}\right)$ mH/km

(c) $\frac{1}{2}\times 10^{-7}$ Wb-T/m

(d) $0.55 \log_e\left(\frac{r'}{D}\right)$ mH/km

Q.9 The self GMD of a conductor with three strands each of radius 'r' and touching each other is
(a) $r\,(0.7788 \times 2 \times 2)^{1/3}$
(b) $r\,(0.7788 \times 2 \times 2 \times 2)$
(c) $r\,(0.7788 \times 2\times 2 \times 2)^{3}$
(d) $r\,(0.7788 \times 2 \times 2)^{3}$

Q.10 Proximity effect
(a) is more pronounced for large conductors, high frequencies and close proximity.
(b) increases the resistance of the conductors and reduces the self reactance.
(c) is substantially eliminated with stranded conductors.
(d) all of the above

Q.11 For equilateral spacing of conductors of an untransposed 3-phase line, we have
(a) balanced receiving-end voltage and no communication interference.
(b) unbalance receiving-end voltage and no communication interference.
(c) balance receiving-end voltage and communication interference.
(d) unbalanced receiving-end voltage and communication interference.

Q.12 The regulation of a line at full load 0.8 pf lagging is 12%. The regulation at full load 0.8 pf leading can be

(a) 24% (b) 18%
(c) 12% (d) 4%

Q.13 In case the characteristic impedance of a transmission line is equal to the load impedance
(a) the system will reasonable badly.
(b) all the energy sent will be absorbed by the load.
(c) all the energy sent will pass to the earth.
(d) all the energy will be lost in transmission line as transmission losses.

Q.14 Highest transmission voltage in India through UHVDC is
(a) 800 kV (b) 500 kV
(c) 1200 kV (d) 400 kV

Q.15 The ratio of line to line capacitance and line to neutral capacitance is
(a) 2 (b) 1/4
(c) 1/2 (d) 4

Q.16 In a transmission line of negligible resistance and conductance, the surge impedance will be
(a) $\frac{1}{\sqrt{LC}}$ (b) $\sqrt{C/L}$
(c) $\sqrt{LC}$ (d) $\sqrt{L/C}$

Q.17 The propagation constant of a transmission line is given by
(a) $j\omega\sqrt{LC}$ (b) $j\sqrt{LC}$
(c) $j\sqrt{L/C}$ (d) $j\sqrt{C/L}$

Q.18 The SIL of a single-circuit 220 kV line is around
(a) 90 MW (b) 120 MW
(c) 220 MW (d) 400 MW

Q.19 Power dispatch through a line can be increased by
(a) installing series capacitors
(b) installing shunt capacitors
(c) installing series reactors
(d) installing shunt reactors

Q.20 For a medium length transmission line, *A* is
(a) equal to *B*
(b) equal to *C*
(c) equal to *D*
(d) not equal to any of the above

Q.21 The surge impedance of a 500 miles long line 400 Ω. For a 250 miles length it will be
(a) 400 Ω (b) 500 Ω
(c) 200 Ω (d) none of these

Q.22 Apart from the "skin effect" the non-uniformly of the current distribution is also called by
(a) Faraday's effect (b) Bundled conductor
(c) Proximity effect (d) Ferranti effect

Q.23 The internal flux linkage due to internal flux of a conductor is
(a) $I \times 10^{-7}$ Wb-T/m (b) $\frac{I}{4} \times 10^{-7}$ Wb-T/m
(c) $\frac{I}{2} \times 10^{-7}$ Wb-T/m (d) $\frac{1}{2} \times 10^{-7}$ Wb-T/m

Q.24 Corona is likely to occur maximum in case of
(a) distribution line (b) transmission line
(c) domestic wiring (d) service mains

Q.25 The dielectric strength of air is
(a) proportional to barometric pressure
(b) proportional to absolute temperature
(c) inversely proportional to barometric pressure
(d) none of the above

Q.26 The minimum clearance of high voltage lines from ground across streets is
(a) 3 m (b) 5 m
(c) 6 m (d) 8 m

Q.27 The minimum clearance between 132 kV transmission line and ground is about
(a) 6.4 m (b) 3.2 m
(c) 10.5 m (d) 7.5 m

Q.28 For a 400 kV line, the spacing between phase conductors is around
(a) 8 m (b) 11 m
(c) 14 m (d) 17 m

Direction for Questions (29 to 32):

Each of the following question consists of two statements, one labelled the **'Assertion (A)'** and the other labelled the **'Reason (R)'**. Examine the two statements carefully and decide if the Assertion (A) and Reason (R) are individually true and if so whether the Reason (R) is correct explanation of the Assertion (A). Select your answers to these questions using the codes given below:

Codes:

(a) Both A and R are true and R is the correct explanation of A.
(b) Both A and R are true but R is not a correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

Q.29 **Assertion (A):** EHV transmission lines make use of bundled conductors.
Reason (R): Bundled conductors reduce the line inductance per phase and increase the capacitance.

Q.30 **Assertion (A):** Transposition of conductors in a transmission line is necessary.
Reason (R): Corona losses are reduced by transposition of conductors.

Q.31 **Assertion (A):** Corona reduces the effects of transients produced by lightning and other causes.
Reason (R): Charges induced on the line by lightning or other causes are partially dissipated as a corona loss.

Q.32 **Assertion (A):** High and extra high voltages are adopted for transmission of bulk power over long distances.
Reason (R): The maximum true power transferred over a given line increased with the increase in V_S and V_R.

Q.33 Match **List-I** with **List-II** and select the correct answer using the code given below the lists:

List-I
A. Skin effect
B. Proximity effect
C. Ferranti effect
D. Surge impedance

List-II
1. Increase in resistance but decrease in self inductance.
2. Increase in ac resistance.
3. Owing to voltage drop across line inductance due to flow of a charging current.
4. Square root of ratio of line impedance and shunt admittance.

Codes:

	A	B	C	D
(a)	2	1	3	4
(b)	1	2	4	3
(c)	3	4	2	1
(d)	4	3	1	2

Q.34 Match **List-I (Methods)** with **List-II (Line constants)** and select the correct answer using the code given below the lists:

List-I
A. Simple series impedance method
B. End condenser method
C. Nominal T-method
D. Nominal π-method

List-II

1. $A = D = 1 + \frac{1}{2}YZ$

$B = Z$ and $C = Y\left(1 + \frac{1}{4}YZ\right)$

2. $A = D = 1 + \frac{1}{2}YZ$

$B = Z = \left(1 + \frac{1}{4}YZ\right)$

$C = Y$

3. $A = D = 1$; $B = Z$; $C = 0$

4. $A = 1 + ZY$; $B = Z$; $C = Y$; $D = 1$

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	3	4	2	1
(c)	2	3	4	1
(d)	4	1	3	2

Q.35 Match **List-I (Type of conductors)** with **List-II (Applications in the field of Transmission and Distribution)** and select the correct answer using the code given below the lists:

List-I
A. All Aluminium (AA)
B. ACSR
C. Copper
D. Galvanised steel

List-II
1. Restricted use
2. LV lines with short spans
3. Stay wires, earth wires, ground wires
4. LV and HV lines with large spans

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	2	4	1	3
(c)	3	1	4	2
(d)	4	3	2	1

Q.36 In a 132 kV transmission line, weight of conductor = 680 kg/km, length of span = 300 m, ultimate strength = 2700 kg, safety factor = 2. Calculate the height above the ground at which the conductor should be supported. The ground clearance required is 8 m.
(a) 12.33 m (b) 13.66 m
(c) 10.27 m (d) 14.11 m

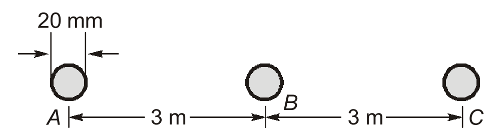
Q.37 A transmission line conductor having a diameter of 20 mm, weight of 0.67 kg/m. The span length is 260 m, the wind pressure is 45 kg/m^2 of the projected area with ice coating of 18 mm. The ultimate strength of the conductor is 4700 kg. Calculate maximum sag if safety factor is '2' and ice weighs 890 kg/m^3.
(a) 12 m (b) 15 m
(c) 13 m (d) None of these

Answer Key:

1. (c)	**2.** (d)	**3.** (c)	**4.** (b)	**5.** (d)
6. (c)	**7.** (b)	**8.** (a)	**9.** (a)	**10.** (d)
11. (c)	**12.** (d)	**13.** (b)	**14.** (b)	**15.** (c)
16. (d)	**17.** (a)	**18.** (b)	**19.** (a)	**20.** (c)
21. (a)	**22.** (c)	**23.** (c)	**24.** (b)	**25.** (a)
26. (c)	**27.** (a)	**28.** (b)	**29.** (b)	**30.** (c)
31. (a)	**32.** (a)	**33.** (a)	**34.** (b)	**35.** (b)
36. (b)	**37.** (c)			

Student's Assignments 2 Explanations

1. (c)



Radius, $r = \frac{20}{2} = 10 \text{ mm} = 0.01 \text{ m}$

spacing between conductors are

$d_1 = AB = 3$ m; $d_2 = BC = 3$ m; $d_3 = CA = 6$ m

Capacitance per phase per m length is

$$C_N = \frac{2\pi\varepsilon_0}{\log_e \frac{\sqrt[3]{d_1 d_2 d_3}}{r}}$$

$$= \frac{2\pi \times 8.854 \times 10^{-12}}{\log_e \frac{\sqrt[3]{3 \times 3 \times 6}}{0.01}} = 9.3737 \times 10^{-12} \text{ F}$$

$= 9.3737$ pF

Charging current per phase,

$$I_C = 2\pi f C_N V_{ph}$$

$$= 2\pi \times 50 \times 9.3737 \times 10^{-12} \times \frac{220 \times 10^3}{\sqrt{3}}$$

$= 0.374$ A

2. (d)
The highest transmission voltage in India through UHVAC is 765 kV operational between Seoni, POWER GRID (MP) and Sipat, NTPC.

3. (c)
Due to lower cost and lighter weight, ACSR (Aluminium conductor, steel reinforced) has replaced copper conductors for overhead lines and are being widely used.