

ELECTRICAL ENGINEERING

POWER SYSTEMS



Comprehensive Theory
with Solved Examples and Practice Questions





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Power Systems

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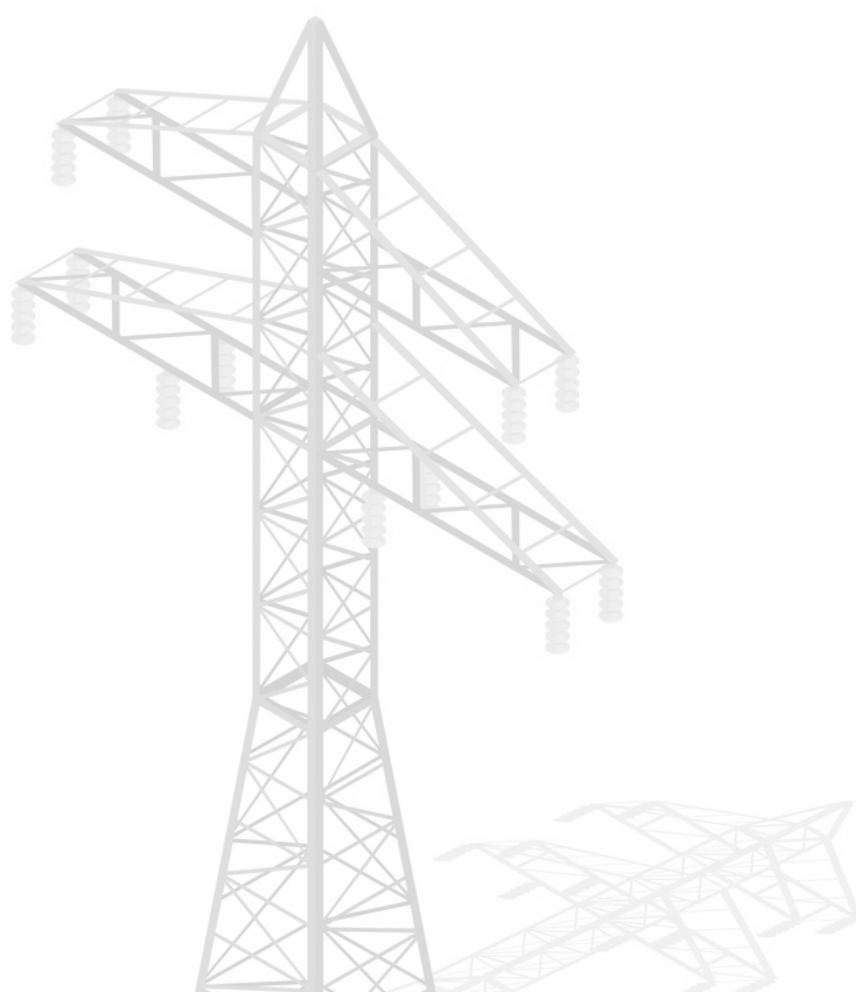
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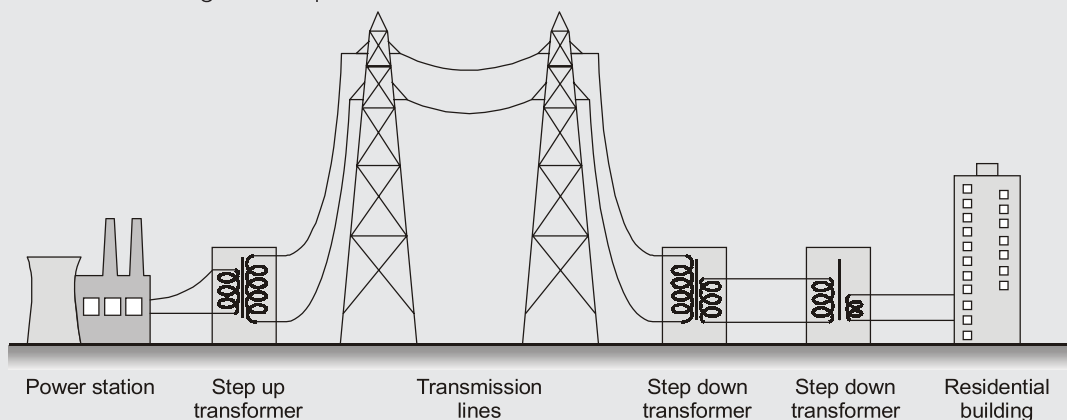


Power Systems

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 to understand the basic concept of power system which will help them to excel in the competitive exams like GATE, IES, PSUs and various other competitive examinations. In each chapter, after every topic, wide number of solved examples have been discussed for the better understanding of the topics.



Performance of Transmission Lines, Line Parameters and Corona

1.1 POLY PHASE AC CIRCUITS

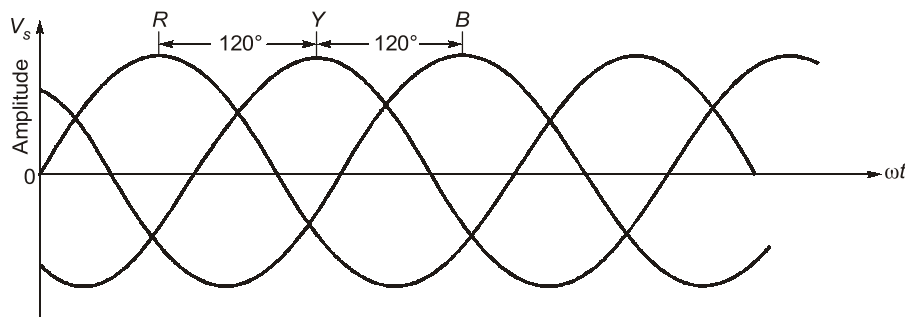
A polyphase system is a means of distributing alternating-current (AC) electrical power where the power transfer is constant during each electrical cycle. Polyphase systems have three or more energized electrical conductors carrying alternating currents with a defined phase between the voltage waves in each conductor.

For three-phase voltage, the phase angle is 120° or $\frac{2\pi}{3}$ radians. 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 $\frac{360^\circ}{n}$ apart in space. (if $n \neq 2$)

For $n = 2$, phase system are 90° apart in space.

1.2 GRAPHICAL REPRESENTATION OF 3- ϕ SYSTEM

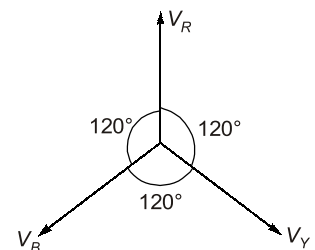


Here, phase sequence = RYB

and $V_R = V_m \sin \omega t$ volt = $V \angle 0^\circ$ volt

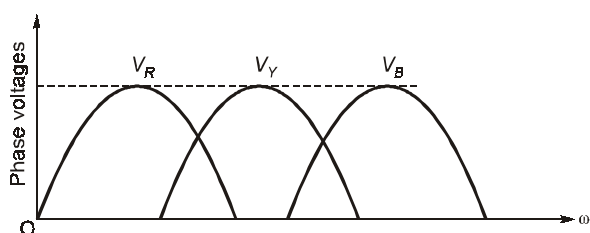
$V_Y = V_m \sin(\omega t - 120^\circ)$ volt = $V \angle -120^\circ$ volt

$V_B = V_m \sin(\omega t - 240^\circ)$ volt = $V \angle -240^\circ$ volt = $V \angle +120^\circ$ volt



1.2.1 Phase Sequence

Phase sequence is the order in which voltage waveforms of a polyphase AC source reach their respective peaks. For a three-phase system, there are only two possible phase sequences : RYB and RBY, corresponding to the two possible directions of alternator.



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

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

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

NOTE



- The phase sequence can be theoretically reversed by reversing the rotation of the rotor but practically it is not possible.
- The phase sequence can be practically reversed by interchanging the any two terminal of the machine.
- The phase sequence of all sources in practical power system will always be same.

1.2.2 Advantages of 3- ϕ System

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

- The amount of conductor material needed to transfer same amount of power is lesser for three phase system thus it is more economical.
- Domestic power and industrial/commercial power can be provided from the same source.
- Voltage regulation of three phase is better.
- The torque produced by a three phase motor is more. Also having better power factor.
- As three phase motors are self-starting while single phase motor are not, three phase system is certainly advantageous and versatile.
- For a given size of the frame, three phase generator provides more output.
- With the help of 3- ϕ system, interconnection is possible either in star or in delta.
- 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).
- Three phase machines produce less vibration compared to a single phase machines.
- For a while in use a three-phase system, converting systems like rectifiers the DC voltage waveform becomes smoother with the increase in the number of phases of the system.

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. $I_R + I_Y + I_B = I_N = 0 \text{ A}$

1.3 TYPE OF 3- ϕ CONNECTIONS

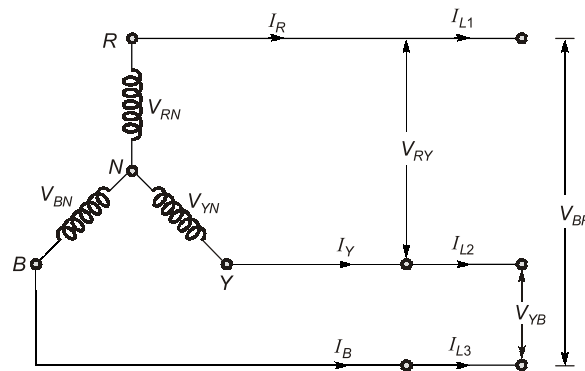
1. Star (γ) connection

2. Delta (Δ) connection

1.3.1 Star (Y) Connection

In star connection, three similar ends (star or finish) of the three windings are joined together at a common point. This point is known as star point or neutral point. Star connection is also known as Y or Wye connection.

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



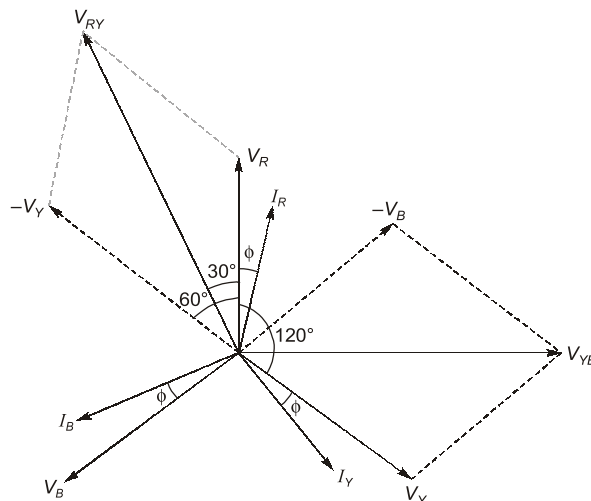
Here,

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

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

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

Its phasor diagram is shown below :



Conclusions

(i) Relation between line and phase current:

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

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

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

(ii) Relation between line and phase voltage:

$$V_{RY} = V_{RN} - V_{YN}; \quad V_{YB} = V_{YN} - V_{BN}; \quad \text{and} \quad V_{BR} = V_{BN} - V_{RN}$$

$$\text{Line voltage, } V_L = V_{RY} = \sqrt{|V_R|^2 + |V_Y|^2 + 2|V_R||V_Y|\cos 60^\circ} = \sqrt{V_{Ph}^2 + V_{Ph}^2 + 2V_{Ph}^2 \cdot \frac{1}{2}} = \sqrt{3} V_{Ph}$$

(iii) Phase angle between V_L and I_L :

Type of load	Phase angle
RL load	$30^\circ + \phi$
R load	30°
RC load	$30^\circ - \phi$

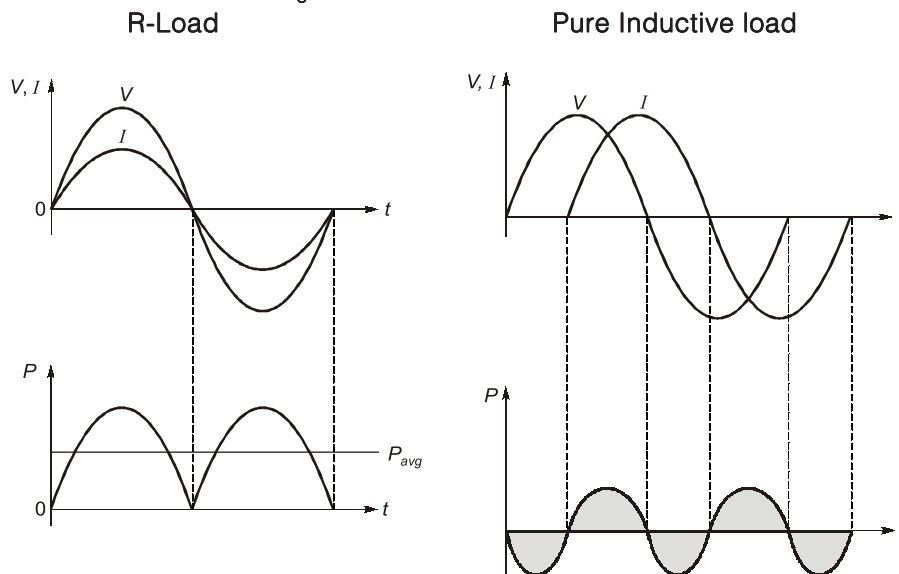
(iv) With respect to reference V_{RY} :

$$\text{Line voltages are : } V_{RY} = V_L \angle 0^\circ; \quad V_{YB} = V_L \angle -120^\circ; \quad V_{BR} = V_L \angle -240^\circ = V_L \angle 120^\circ$$

(v) Phase voltages with respect to reference (V_{RY}):

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

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



Advantage of Star Connected System

- 3-phase generators are usually star-connected. It is so because only $\frac{1}{\sqrt{3}}$ of the line voltage will appear on every phase winding of the alternator. It means in star connected generator, the number of coil turns required per phase is less than for a delta-connected generator.
- Star connection provides two voltages, i.e., phase voltage and line voltage. Hence, lighting loads are connected across the single phase whereas power loads like three-phase motors are connected across lines.

- (iii) Another advantage of the star connection is that the neutral of the generator can be earthed. In that case, the potential difference between each line and earth is equal to phase voltage, i.e., $\frac{V_L}{\sqrt{3}}$.

Disadvantage of Star Connected System

- (i) Less torque in motor.
- (ii) Construction cost is more expensive.



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

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

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

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

$$V_R = V_{Ph} \angle 30^\circ; \quad V_Y = V_{Ph} \angle 150^\circ; \quad V_B = V_{Ph} \angle 270^\circ$$

EXAMPLE : 1.2

A single phase ac system comprising of two overhead conductors is to be converted into a 3-phase, 3-wire system by providing an additional conductor of same size. If the operating line voltage and percentage line losses, power factor of load remains same in both systems. Find the percentage of additional load that can be transmitted by the three phase system?

Solution :

Let the operating voltage and power factor in both the systems be V volts and $\cos \phi$ respectively. If I_1 is single phase current, I_2 is the three phase current and R is the resistance of each conductor, then

Single phase system : $P_1 = VI_1 \cos \phi$ Watts

$$\text{Losses} = 2I_1^2 R \text{ Watts}$$

$$\text{Percentage line losses} = \frac{W_1}{P_1} \times 100 = \frac{2I_1^2 R}{VI_1 \cos \phi} \times 100$$

3- ϕ system : $P_2 = \sqrt{3}VI_2 \cos \phi$

$$\text{Line losses} = 3I_2^2 R$$

$$\text{Percentage line losses} = \frac{3I_2^2 R}{\sqrt{3}VI_2 \cos \phi} \times 100$$

For the same percentage line losses in both the cases, we have

$$\frac{2I_1^2 R}{VI_1 \cos \phi} \times 100 = \frac{3I_2^2 R}{\sqrt{3}VI_2 \cos \phi} \times 100$$

$$2I_1 = \sqrt{3}I_2; \quad I_2 = \frac{2}{\sqrt{3}}I_1$$

$$\therefore \text{Power transmitted in 3-}\phi \text{ system, } P_2 = \sqrt{3}V \times \frac{2}{\sqrt{3}}I_1 \cos \phi = 2VI_1 \cos \phi = 2P_1$$

$$\therefore \text{Percentage of additional load} = \frac{P_2 - P_1}{P_1} \times 100 = \frac{P_1}{P_1} \times 100 = 100\%$$

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

$$V_R = V_Y = V_B = V_{Ph}$$

$$V_{RY} = V_{YB} = V_{BR} = V_L$$

\therefore

$$V_L = V_{Ph}$$

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,

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

or,

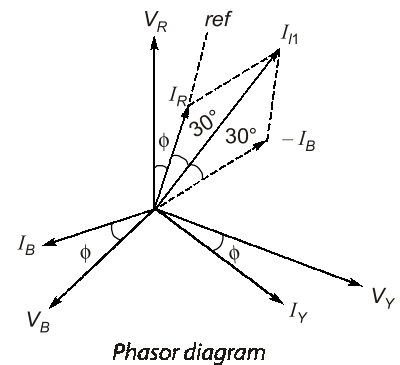
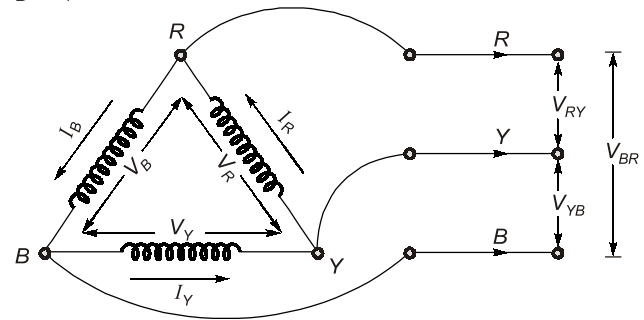
$$I_L = \sqrt{3} I_{Ph}$$

Therefore,

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

(iii) Phasor angle between V_L and I_L

Type of Load	Phase angle
RL	$30 + \phi$
R	30°
RC	$30 - \phi$



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

$$I_R = I_{Ph} \angle 0^\circ; \quad I_Y = I_{Ph} \angle -120^\circ; \quad I_B = I_{Ph} \angle -240^\circ = I_{Ph} \angle +120^\circ$$

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

$$I_{L1} = I_L \angle -30^\circ; \quad I_{L2} = I_L \angle -150^\circ; \quad I_{L3} = I_L \angle -270^\circ = I_L \angle +90^\circ$$

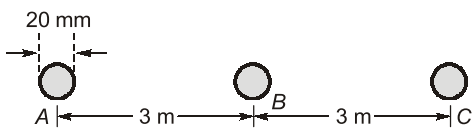
Advantage of Delta Connection

- More torque in motor.
- Protection is simple and less costly.
- While use delta connection, less current per winding for the same power output.
- Construction cost is low.

Disadvantage of Delta Connection

- No common neutral point.
- Detecting earth faults is difficult.
- Low voltage connection.

**OBJECTIVE
BRAIN TEASERS**

- Q1** A 3- ϕ transmission line has corona loss of 48 kW at 96 kV and 90 kW at 112 kV. The disruptive voltage between lines is ____.
- Q2** 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 μ F, 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
- Q3** 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
- Q4** 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 cross-section of the conductor.
(d) portion of conductor near the surface carries less current in comparison to the core.
- Q5** 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.
- Q6** 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%
- Q7** 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
- Q8** 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
- Q9** 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

Direction for Questions (10 to 13):

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.10 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.11 Assertion (A): Transposition of conductors in a transmission line is necessary.

Reason (R): Corona losses are reduced by transposition of conductors.

Q.12 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.13 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.14 For a 500 Hz frequency excitation, a 40 km power line will be modeled as

- (a) Short line (b) Medium line
(c) Long line (d) Data insufficient.

Q.15 The $ABCD$ parameters of 3-phase overhead transmission line are $A = D = 0.9\angle 0^\circ$; $B = 160\angle 90^\circ \Omega$ and $C = 0.92 \times 10^{-4} \angle 90^\circ \text{ S}$. At no load condition a shunt inductive reactor is connected at the receiving end of the line to limit the receiving end voltage and to be equal to the sending end voltage. The ohmic value of the reactor is

- (a) $\infty \Omega$ (b) 2000Ω
(c) 1600Ω (d) 1052.6Ω

Q.16 A travelling wave due to lightning with an incident voltage V travels through the overhead line of surge impedance 400Ω and enters a cable of surge impedance of 35Ω . The voltage entering the cable at the junction is

- (a) 0.12 V (b) 0.16 V
(c) 2.1 V (d) 2.7 V

Q.17 A single core cable 5 km long has an insulation resistance of $0.4 \text{ M}\Omega$. The core diameter is 20 mm and the diameter of the cable over the insulation is 50 mm. The resistivity of the insulating material is

- (a) $13.71 \text{ G}\Omega\text{-m}$ (b) $15.24 \text{ G}\Omega\text{-m}$
(c) $12.12 \text{ M}\Omega\text{-m}$ (d) $14.12 \text{ M}\Omega\text{-m}$

Q.18 Two conductors of a single phase line, each of 1 cm diameter, are arranged in a vertical plane with one conductor mounted 1 m above the other. A second identical line is mounted at the same height as the first and spaced horizontally

0.25 m apart from it. The two upper and the two lower conductors are connected in parallel. The inductance per km of the resulting double circuit line is

- (a) 0.84 mH (b) 0.92 mH
(c) $0.84 \mu\text{H}$ (d) $0.92 \mu\text{H}$

Q.19 At no load condition, a 3-phase, 50 Hz, lossless power transmission line has sending end and receiving end voltages of 420 kV and 440 kV respectively. Assume the velocity of travelling wave to be $3 \times 10^5 \text{ km/s}$, then the length of the line is _____ km.

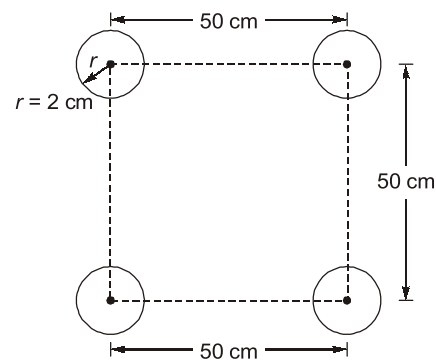
Q.20 A transmission line has the following parameters.

$$A = D = 0.96\angle 10^\circ, \quad B = 100\angle 80^\circ$$

For a load of 50 MW at 0.8 p.f. lag, 110 kV. Sending end voltage is 120 kV. The maximum power that can be transmitted is

- (a) 117.40 MW (b) 92.27 MW
(c) 121.74 MW (d) 98.43 MW

Q.21 A composite conductor consists of 4 conductors of radius 2 cm each. The conductors are arranged as shown below. The geometric mean radius GMR (in cm) for the given arrangement is _____.



Q.22 A 220 kV transmission line has the following line constants :

$$A = 0.85\angle 5^\circ, \quad B = 200\angle 75^\circ$$

If the voltage at each end is to be maintained at 220 kV. The power angle (in degrees) at unity power factor is _____

Q.23 A 500 km long transmission line has series impedance of $(0 + j0.5) \Omega/\text{km}$ and the shunt admittance of $(0 + j5) \mu\text{mho}/\text{km}$. The magnitude

of the characteristic impedance in ohm of the equivalent π -circuit of the transmission line will be

- (a) 141.72 Ω (b) 158.11 Ω
(c) 283.44 Ω (d) 316.22 Ω

Q.24 A surge of 15 kV magnitude travels along a cable towards its junction with an overhead line. The inductance and capacitance of the cable and overhead line are respectively 0.3 mH, 0.4 μ F and 1.5 mH, 0.012 μ F per km. The voltage rise at the junction due to the surge is ____ kV.

Q.25 A 500 kV, 2 μ sec rectangular surge on a line having a surge impedance of 350 ohms approaches a station at which the connected earth capacitance is 3000 pF. The maximum value of the transmitted wave is ____ kV.

Q.26 A three phase overhead line has resistance and reactance of 5 Ω and 20 Ω respectively. The load at the receiving end is 30 MW, 0.85 power factor lagging at 33 kV. The voltage at sending end is ____.

- (a) 37 kV (b) 51.16 kV
(c) 48.12 kV (d) 66.38 kV

Q.27 A short 3-phase transmission line connected to a 33 kV, 50 Hz generating station at the sending end is required to supply a load of 10 MW at 0.8 lagging power factor at 30 kV at the receiving end. If the minimum transmission efficiency is to be limited to 96%, the per phase value of resistance is ____ ohms.

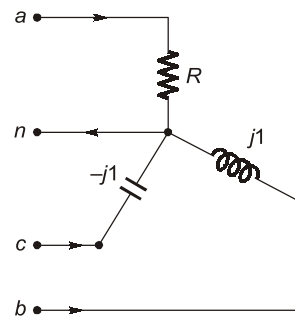
Q.28 The total susceptance and total reactance of a lossless overhead EHV line, operating at 50 Hz are given by 1.4 p.u. and 0.025 p.u. respectively. The approximate length of the line is (The velocity of wave propagation is 3×10^5 km/s)

- (a) 146.4 km (b) 178.6 km
(c) 162.6 km (d) 152.1 km

Q.29 A 132 kV transmission line having per phase line inductance of 10 mH/m and per phase line capacitance of 100 μ F/m. If length of the line is 80 km, its surge impedance loading is ____ MW.

Q.30 A three phase load is connected to a three phase balanced supply as shown in the figure. If

$$V_{an} = 10\angle 0^\circ \text{ V}, V_{bn} = 10\angle -120^\circ \text{ V and } V_{cn} = 10\angle 120^\circ \text{ V}$$



The value of R for $I_n = 0$ A is ____ Ω .

Q.31 In a power network, 380 kV is recorded at a 400 kV bus. A 60 MVAR, 400 kV shunt reactor is connected to the bus. The reactive power absorbed by the shunt reactor is ____ MVAR.

Q.32 The parameters of overhead transmission line are given as :

$$Z_s = 36 \Omega, \text{ and } Z_m = 11 \Omega$$

The positive sequence impedance, negative sequence impedance and zero sequence impedance are

- (a) 25 Ω , 25 Ω , 58 Ω (b) 25 Ω , 58 Ω , 25 Ω
(c) 48 Ω , 25 Ω , 25 Ω (d) 25 Ω , 0 Ω , 58 Ω

Q.33 An extra high voltage transmission line of length 200 km can be approximated by a lossless line having propagation constant $\beta = 0.0018$ rad/km. The percentage ratio of line length to wavelength is ____ %.

Q.34 A 400 km long transmission line operating at $V_s = 1$ p.u. at 50 Hz. The value of V_R at no load is ____ p.u. (Answer upto three decimals)

ANSWER KEY

- | | | | | |
|--------------|---------------|-------------|-------------|---------|
| 1. (52.65) | 2. (c) | 3. (b) | 4. (b) | 5. (c) |
| 6. (d) | 7. (a) | 8. (a) | 9. (a) | 10. (b) |
| 11. (c) | 12. (a) | 13. (a) | 14. (c) | 15. (c) |
| 16. (b) | 17. (a) | 18. (a) | 19. (288) | 20. (b) |
| 21. (22.9) | 22. (22) | 23. (d) | 24. (27.84) | |
| 25. (850.43) | 26. (b) | 27. (2.40) | 28. (b) | |
| 29. (0.57) | 30. (1742.40) | 31. (54.15) | 32. (a) | |
| 33. (5.73) | 34. (1.175) | | | |

HINTS & EXPLANATIONS

1. (52.65)

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

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

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

and

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

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

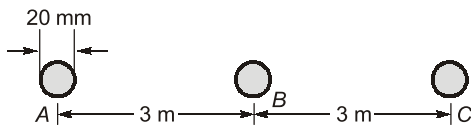
$$\frac{90}{48} = \frac{\left(\frac{112}{\sqrt{3}} - V_{d0} \right)^2}{\left(\frac{96}{\sqrt{3}} - V_{d0} \right)^2}$$

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

\therefore Disruptive voltage between lines

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

2. (c)



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

spacing between conductors are

$$d_1 = AB = 3 \text{ m}; d_2 = BC = 3 \text{ m}; d_3 = CA = 6 \text{ m}$$

Capacitance per phase per m length is

$$C_N = \frac{2\pi\epsilon_0}{\log_e \frac{\sqrt[3]{d_1 d_2 d_3}}{r}}$$

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

$$= 9.3737 \text{ pF}$$

Charging current per phase, $I_C = 2\pi f C_N V_{ph}$

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

$$= 0.374 \text{ mA}$$

3. (b)

- Corona on an overhead line occurs due to high electric field intensity at the surface of the conductor (resulting in ionization of air particles). For occurrence of corona, the potential gradient of the conductor must be greater than the dielectric strength of air. Hence it is a voltage effect phenomenon.
- Corona results into power loss called "corona loss".
- Corona acts as safety valve for the conductor surface and decreases the impact of lightning surges on the surface of the conductor. Hence, it attenuates lightning surges.
- Corona does not occur in short transmission lines (because of low voltage). Hence, option (b) is not true.

4. (b)

When an AC current flows through a conductor, the inductive reactance of the inner strands increases while that for the outer strand decreases so that outer strand conducts more current than the inner strand. Due to this reason, portion of conductor near the surface carries more current in comparison to the core (or inner strand). This phenomenon is called skin effect.

5. (c)

Since conductors having equilateral spacing will have symmetrical spacing therefore, the receiving end voltage will be balanced. Also, as the conductors are not transposed therefore, it will result into communication interference with the neighbouring communication lines.



CONVENTIONAL BRAIN TEASERS

Q.1 A 3-phase, 50 Hz transmission line at 11 kV delivers a load of 1000 kW at 0.8 p.f. (lagging) over 10 kms. Calculate the line current, receiving end voltage and efficiency of transmission. Resistance and reactance of each line conductor may be assumed to be $0.5 \Omega/\text{km}$ and $0.56 \Omega/\text{km}$ respectively.

1. (Sol)

Here, receiving end voltage is not given.

Sending end voltage (per phase) is,

$$V_S = \frac{11 \times 10^3}{\sqrt{3}} = 6351 \text{ volts or } 6350.8 \text{ V}$$

We know that,

$$V_S - V_R = I_R R \cos \phi_R \pm I_R X_L \sin \phi_R$$

For lagging p.f.,

$$V_S - V_R = I_R R \cos \phi_R + I_R X_L \sin \phi_R$$

Given,

$$R = 0.5 \Omega/\text{km}$$

$$X_L = 0.56 \Omega/\text{km} \text{ (Per phase)}$$

$$\text{Length of line} = 10 \text{ km}$$

So,

$$R = 5 \Omega/\text{phase}; X_L = 5.6 \Omega/\text{phase}$$

Also,

$$I_R = I_S = \frac{1000 \times 10^3}{3 \times V_R \cos \phi_R} = \frac{10^5}{3 \times V_R \times 0.8} = \frac{416.67 \times 10^3}{V_R}$$

Now,

$$6351 - V_R = \frac{416.67 \times 10^3}{V_R} [5 \times 0.8 + 5.6 \times 0.6]$$

or,

$$6351 = V_R + \frac{3066.69 \times 10^3}{V_R}$$

$$\text{or, } V_R^2 - 6351 V_R + 3066.67 \times 10^3 = 0$$

Solving we get,

$$V_R = 5824.5 \text{ V or } 526.5 \text{ V}$$

But, V_R can't be 526.5 volt. So,

$$V_R = 5824.5 \text{ volts}$$

\therefore Line current,

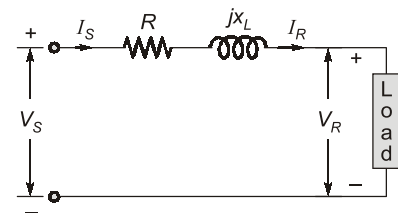
$$I_S = I_R = \frac{416.67 \times 10^3}{5824.5} = 71.5 \text{ A or } 71.537 \text{ A}$$

Receiving end voltage, Line voltage

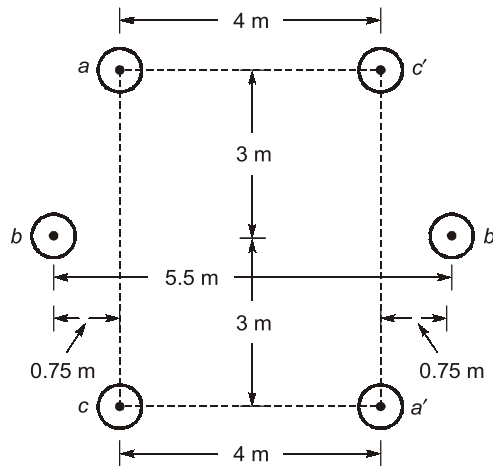
$$V_{RS} = \frac{\sqrt{3} \times 5824.5}{1000} = 10.09 \text{ kV (line value)}$$

Also, efficiency of transmission is,

$$\% \eta = \left(\frac{\text{Output power}}{\text{Output power} + \text{losses}} \right) \times 100 = \frac{1000 \times 10^3}{1000 \times 10^3 + [3 \times (71.5)^2 \times 5]} \times 100 = 92.87\%$$



Q2 A 3-phase double circuit line is arranged as shown below.



The conductors are transposed. The radius of each conductor is 0.75 cm. Phase sequence is *ABC*. Find the inductance per phase per km.

2. (Sol)

Radius of each conductor is : $r = 0.75 \text{ cm}$

\therefore Self GMD for each conductor is

$$= 0.7788r = 0.7788 \times 0.75 \text{ cm} = 0.5841 \text{ cm}$$

Now,

$$d_{bc} = d_{ab} = \sqrt{3^2 + 0.75^2} = 3.092 \text{ m}$$

$$d_{ab'} = \sqrt{4.75^2 + 3^2} = 5.618 \text{ m};$$

$$d_{aa'} = \sqrt{4^2 + 6^2} = 7.211 \text{ m}$$

\therefore Mutual GMD,

$$D_{m1} = (3.092 \times 6 \times 4 \times 5.618)^{1/4} = 4.518 \text{ m} = D_{m3}$$

$$D_{m2} = (3.092 \times 3.092 \times 5.618 \times 5.618)^{1/4} = 4.168 \text{ m}$$

Hence, equivalent mutual GMD is,

$$D_m = (D_{m1} D_{m2} D_{m3})^{1/3} = (4.518 \times 4.168 \times 4.518)^{1/3} = 4.398 \text{ m}$$

Also, self GMD of each phases are

$$D_{s1} = (0.00584 \times 7.211)^{1/2} = 0.2052 \text{ m} = D_{s3}$$

and

$$D_{s2} = (0.00584 \times 5.5)^{1/2} = 0.179 \text{ m}$$

So, equivalent self GMD is

$$D_s = (D_{s1} D_{s2} D_{s3})^{1/3} = (0.2052 \times 0.179 \times 0.2052)^{1/3} = 0.196 \text{ m}$$

\therefore Inductance,

$$L = 2 \times 10^{-4} \ln \left(\frac{D_m}{D_s} \right) \text{ H/km/phase}$$

$$= 2 \times 10^{-4} \ln \left(\frac{4.398}{0.196} \right) \text{ H/km/phase} = 0.622 \text{ mH/km/phase}$$