ELECTRICAL ENGINEERING

POWER SYSTEMS

Comprehensive Theory
with Solved Examples *and* Practice Questions

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Power Systems

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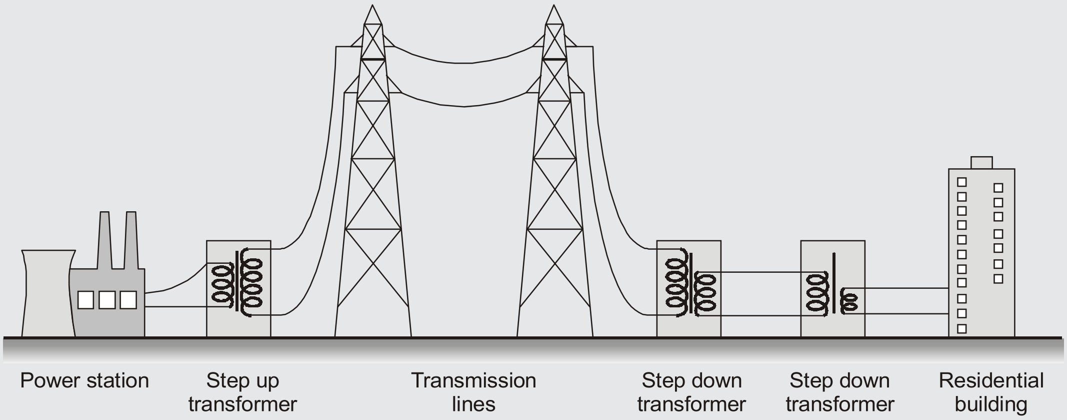
Power Systems

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.



CHAPTER

1

Performance of Transmission Lines, Line Parameters and Corona

1.1 POLY PHASE AC CIRCUITS

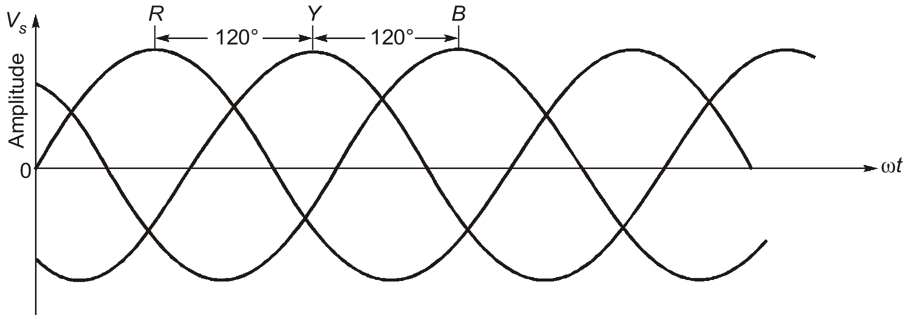
A polyphase system is a means of distributing alternating-current (AC) electrical power where the power transfer is constant during each electrical cycle. Polyphase systems have three or more energized electrical conductors carrying alternating currents with a defined phase between the voltage waves 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 $\frac{360°}{n}$ 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

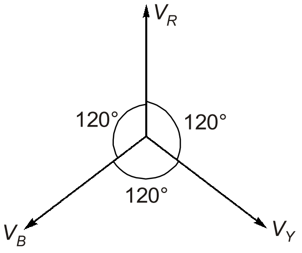


Here, phase sequence = *RYB*

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

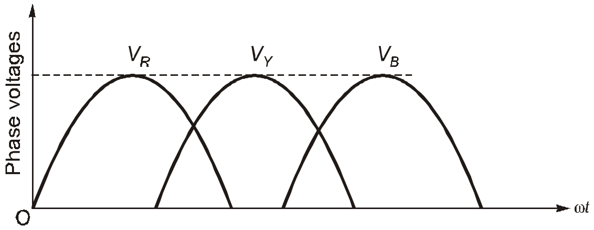
$V_Y = V_m \sin(\omega t - 120°)$ volt $= V\angle -120°$ volt

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

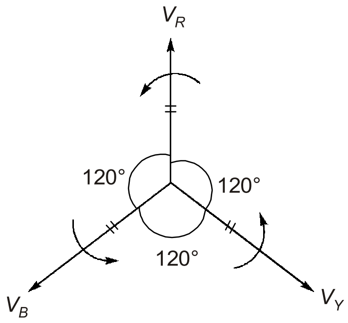
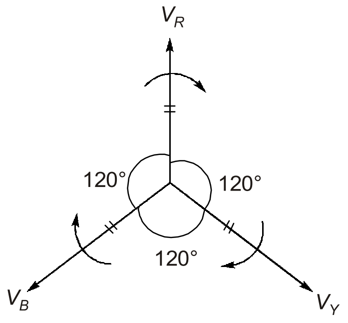
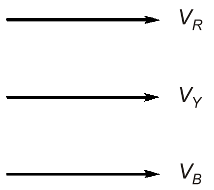


1.2.1 Phase Sequence

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

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:

(*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. Also having better power factor.

(*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 machines.

(*x*) 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. $I_R + I_Y + I_B = I_N = 0$ A

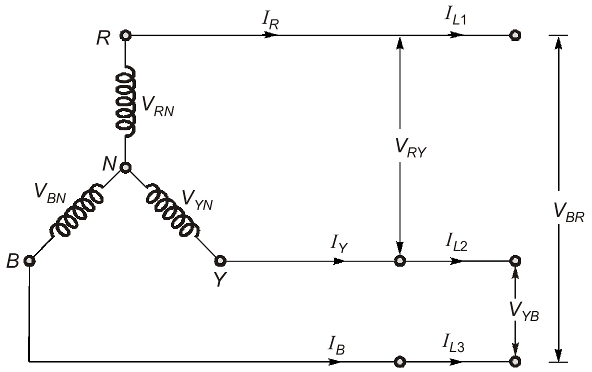
1.3 TYPE OF 3-ϕ CONNECTIONS

1. Star ($\curlyvee$) 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).



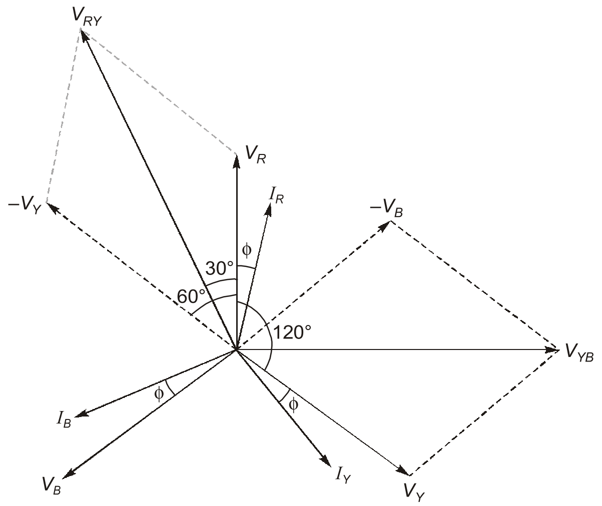
Here,

$\Rightarrow$ $|V_{RN}| = |V_{YN}| = |V_{BN}| = V_{Ph}$ are phase voltages (i.e., 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:

$$I_R = I_Y = I_B = I_{Ph} = \text{Phase current}$$
$$I_{L1} = I_{L2} = I_{L3} = I_L = \text{Line current}$$

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

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

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

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° + ϕ
R load	30°
RC load	30° – ϕ

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

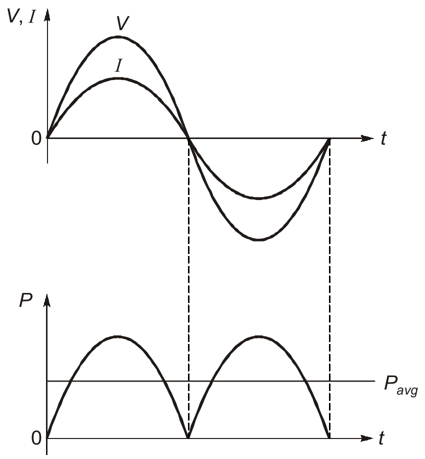
Line voltages are : $V_{RY} = V_L\angle 0^\circ;\quad V_{YB} = V_L\angle -120^\circ;\quad V_{BR} = V_L\angle -240^\circ = V_L\angle 120^\circ$

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

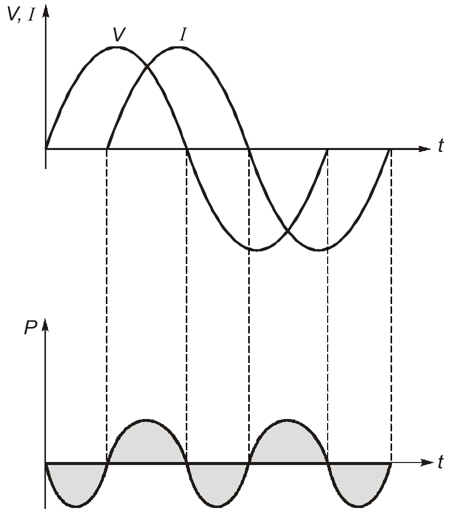
$$V_{RN} = V_L\angle -30^\circ;\quad V_{YN} = V_L\angle -150^\circ;\quad V_{BR} = V_L\angle -270^\circ = V_{Ph}\angle 90^\circ$$

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

R-Load



Pure Inductive load



Advantage of Star Connected System

(i) 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.

(ii) 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.

NOTE

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

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

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

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

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

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 :

$$P_1 = VI_1 \cos\phi \text{ Watts}$$

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

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

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

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

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

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

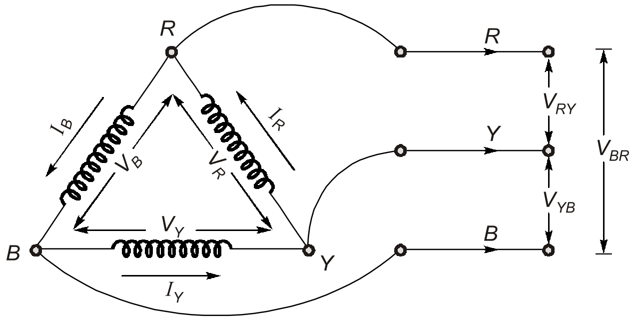
$$\therefore \quad \text{Percentage of additional load} = \frac{P_2 - P_1}{P_1}\times 100 = \frac{P_1}{P_1}\times 100 = 100\%$$

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



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

For parallel connection voltage remains same.

(*ii*) Relation between Line and Phase current

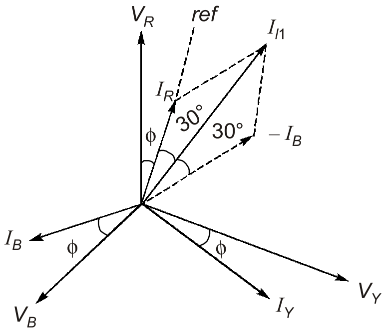
$$I_{L1} = I_R + (-I_B)$$
$$I_{L2} = I_Y + (-I_R)$$
$$I_{L3} = I_B + (-I_Y)$$

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



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)

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

(*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

(i) More torque in motor.
(ii) Protection is simple and less costly.
(iii) While use delta connection, less current per winding for the same power output.
(iv) Construction cost is low.

Disadvantage of Delta Connection

(i) No common neutral point.
(ii) Detecting earth faults is difficult.
(iii) Low voltage connection.

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, $P_{(Y)}$ 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 $\sqrt{3} V_L I_L \cos\phi$.
- If power is kept constant, delta connection has low voltage and high current capacity whereas a star connection has high voltage and low current capacity.

REMEMBER

For a star connected system :

- The line voltages are 120° apart from each other (phase voltages are 120° apart from each other).
- The angle between the line currents and the corresponding line voltage is $(30 + \phi)$ with current lagging by an angle ϕ (for lagging loads).
- Line voltage magnitude is $\sqrt{3}$ times the phase voltage magnitude.
- The current in line and phase are same.

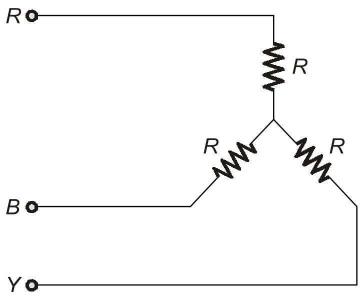
For a delta connected system :

- Line currents are 120° apart from each other as well as phase currents.
- Line currents are 30° behind the respective phase currents.
- The angle between the line currents and corresponding line voltages is $(30 + \phi)$ with the current lagging by an angle ϕ.
- Line voltage and phase voltages being same, the line current is $\sqrt{3}$ times the phase current.

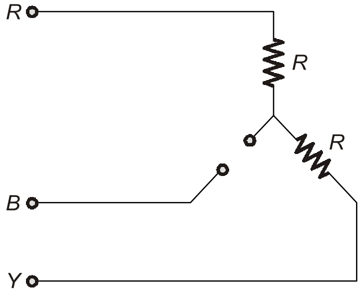
EXAMPLE : 1.3

A 3-ϕ, three wire supply feeds a star connected load consisting of 3 equal resistors. If one of the resistors is to be removed, then what is the reduction in power as compared to the original power?

Solution :



With all 3 resistors,



Power, $$P_1 = \frac{3V_{Ph}^2}{R} = 3\left(\frac{V_L}{\sqrt{3}}\right)^2 \times \frac{1}{R} = \frac{V_L^2}{R}$$

With one resistor removed,

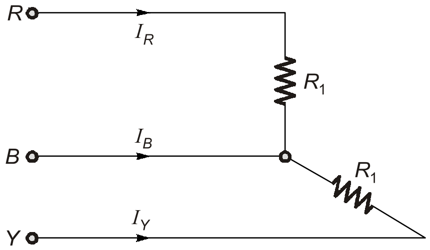
Power, $$P_2 = \frac{V_L^2}{2R} = \frac{P_1}{2}$$

$$\therefore \quad P_2 = \frac{P_1}{2} = 0.5P_1 = 50\% \text{ of } P_1$$

∴ 50% reduction of original power.

EXAMPLE : 1.4

For the 3-ϕ circuit shown in the figure the ratio of the current $I_R : I_Y : I_B$ is given by



(a) $1:1:\sqrt{3}$

(b) 1 : 1 : 2

(c) 1 : 1 : 0

(d) $1:1:\sqrt{\frac{3}{2}}$

Solution : (a)

I_B = Phasor sum of I_R and I_Y at an angle of 120°.

Also, $I_R = I_Y = I_{Ph}$

$$\therefore \quad I_B = \sqrt{I_R^2 + I_Y^2 + 2I_R I_Y \cdot \cos\frac{120^\circ}{2}} = \sqrt{I_{ph}^2 + I_{ph}^2 + 2I_{ph}^2 \cos\frac{120^\circ}{2}} = \sqrt{3}I_{\text{ph}}$$

So, $I_R : I_Y : I_B = I_{Ph} : I_{Ph} : \sqrt{3}I_{Ph} = 1:1:\sqrt{3}$

1.5 INTRODUCTION TO TRANSMISSION LINES

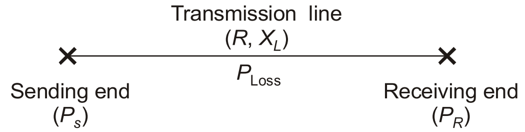
An overhead transmission line consists of a group of conductors running parallel to each other and carried on supports which provide insulation between the different conductors and between each conductor and earth. A transmission line has four parameters – resistance, inductance, capacitance and shunt conductance.

The shunt conductance accounts for leakage currents flowing across insulators and ionized pathways in the air. The leakage currents are negligible as compared to the current flowing in the transmission lines. The series resistance causes a real power loss in the conductor. The resistance of the conductor is very important in transmission efficiency evaluation and economic studies. The power transmission capacity of the transmission line is mainly governed by the series inductance. The shunt capacitance causes a charging current to flow in the line and it is important for medium and long transmission lines. These parameters are uniformly distributed throughout but can be lumped for the purpose of analysis on approximate basis.

The performance of the transmission line can be determined by following two parameters :

1. Percentage efficiency
2. Percentage regulation

Efficiency of a Transmission Line

- Efficiency of a transmission line is defined as the ratio of power delivered at the receiving end to the power sent from the sending end.
- 

- A transmission line is represented by R and X_L as series parameters and P_S, P_R respectively the sending and receiving end powers.

  Losses occurring in the line is : $P_{\text{Loss}} = (P_S - P_R)$

  Hence, percentage efficiency of the transmission line is given by

$$\%\eta = \frac{P_R}{P_S} \times 100 = \frac{(P_S - P_{\text{Loss}})}{P_S} \times 100 = \frac{P_R}{P_R + P_{\text{Loss}}} \times 100$$

NOTE

- Higher the efficiency of the transmission line, better is the performance of the transmission line.
- An ideal transmission line has 100% efficiency (i.e., zero losses) which is not possible practically.

Regulation of a Transmission Line

Voltage regulation of a transmission line is the change in voltage at the receiving end, expressed in percentage of full-load voltage, when full-load at a specified power factor is removed while the sending end voltage is held constant.

$$\%\text{ Voltage regulation } = \left(\frac{V_S - V_R}{V_R}\right) \times 100 = \frac{V' - V_R}{V_R} \times 100$$

where, V' is Sending end voltage and V_R in Receiving end voltage.

REMEMBER

- The lower the voltage regulation, better is the performance of transmission line.
- The voltage at the point of commencement of supply shall not vary by more than
  - ⇒ ± 6% in the case of the low voltage (upto 250 V) and medium voltage (upto 650 V).
  - ⇒ +6% to –9% in the case of high voltage (i.e., upto 33 kV).
  - ⇒ $\pm 12\frac{1}{2}\%$ in the case of extra high voltage (i.e., exceeding 33 kV).
- An ideal transmission line has 0% regulation.

1.6 CLASSIFICATION OF TRANSMISSION LINES

Transmission lines are classified based on three criterion and they are:

1. Length of transmission line
2. Operating voltage
3. Effect of capacitance

The table below summarises the classification of transmission lines based on the above three criterion.

Transmission lines	Length of transmission lines	Operating voltage	Frequency × Length = fl
Short transmission line	(0 – 80) Km	(0 – 20) kV	$fl < 4000$
Medium transmission line	(80 – 160) Km	(20 – 100) kV	$4000 < fl < 10000$
Long transmission line	(160 – 280) Km	(> 100) kV	$fl > 10000$

REMEMBER

- If an overhead line is classified as short, shunt capacitance is so small that it can be omitted entirely with little loss of accuracy, and we need to consider only the series resistance R and the series inductance L for the total length of the line.
- In a medium transmission line capacitance C is lumped/concentrated at a point.
- In a long transmission line parameters of the line are distributed uniformly throughout the length of the line.

1.6.1 The Short Transmission Line

In a short line, the shunt capacitance C and shunt conductance G are neglected. The series resistance R and the series inductance L for the total length of the line is considered. Single phase supply line is usually short in length and operates at relatively low voltages.

The equivalent circuit of a short transmission line is shown in below figure, where I_S and I_R are the sending end and receiving end currents respectively, and V_S and V_R are the sending and receiving end line to neutral voltages.

The circuit is solved as a simple series ac circuit. So,

$$I_S = I_R\,; \qquad V_S = V_R + I_R Z$$

where, Z is zl, the total series impedance of the line (l being the total length of the line).

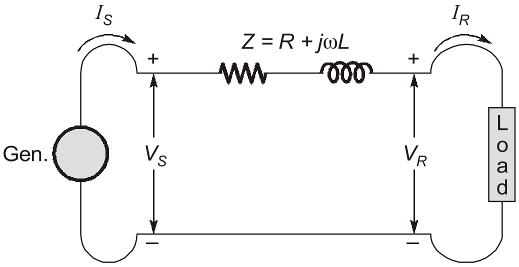


Fig.: *Equivalent circuit of a short transmission line*

The voltage regulation of the short transmission line is given by

$$\%\text{ regulation} = \frac{|V_{R,NL}| - |V_{R,FL}|}{|V_{R,FL}|} \times 100$$

where, $|V_{R,NL}|$ is the magnitude of receiving end voltage at no load and

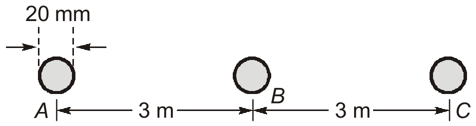
$|V_{R,FL}|$ is the magnitude of receiving end voltage at full load with $|V_S|$ constant

The phasor diagram (see below) is drawn for the same magnitude of the receiving end voltage and current and show that a larger value of the sending end voltage is required to maintain a given receiving end

OBJECTIVE BRAIN TEASERS

Q.1 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 _____.

Q.2 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.3 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.4 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.

Q.5 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.6 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.7 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.8 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.9 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.

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 μF and 1.5 mH, 0.012 μF per km. The voltage rise at the junction due to the surge is ___ kV.

Q.25 A 500 kV, 2 μsec 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

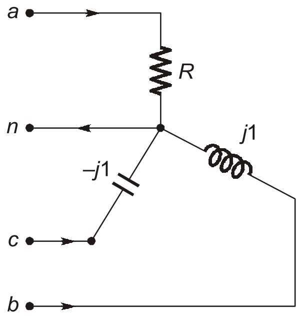
Q.27 A short 3-phase transmission line connected to a 33 kV, 50 Hz generating station at the sending end is required to supply a load of 10 MW at 0.8 lagging power factor at 30 kV at the receiving end. If the minimum transmission efficiency is to be limited to 96%, the per phase value of resistance is ______ 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 μF/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 $V_{an} = 10\angle 0°$ V, $V_{bn} = 10\angle -120°$ V and $V_{cn} = 10\angle 120°$ 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

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

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

and

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

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

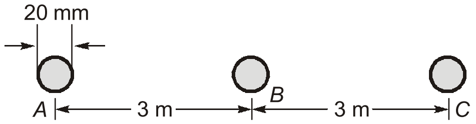
$$\frac{90}{48} = \frac{\left(\frac{112}{\sqrt{3}} - V_{d0}\right)^2}{\left(\frac{96}{\sqrt{3}} - V_{d0}\right)^2}$$

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

∴ Disruptive voltage between lines

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

2. (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

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

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

$$= 9.3737 \text{ pF}$$

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 correct 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 Ω/km and 0.56 Ω/km respectively.

1. (Sol)

Here, receiving end voltage is not given.

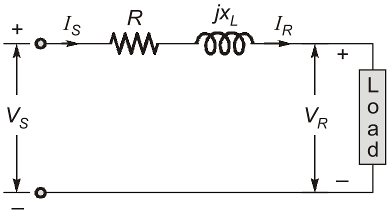
Sending end voltage (per phase) is,

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

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

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

Length of line = 10 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,
$$6351 = V_R + \frac{3066.69\times 10^3}{V_R}$$

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

Solving we get, $V_R = 5824.5 \text{ V or } 526.5 \text{ V}$

But, V_R can't be 526.5 volt. So, $V_R = 5824.5$ volts

∴ 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

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

Also, efficiency of transmission is,

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