RRB-JE 2024

Railway Recruitment Board

Junior Engineer Examination

Electrical Engineering

Generation, Transmission and Distribution

Well Illustrated **Theory** *with*

Solved Examples and **Practice Questions**

MADE EASY PUBLICATIONS

Generation, Transmission & Distribution

Contents

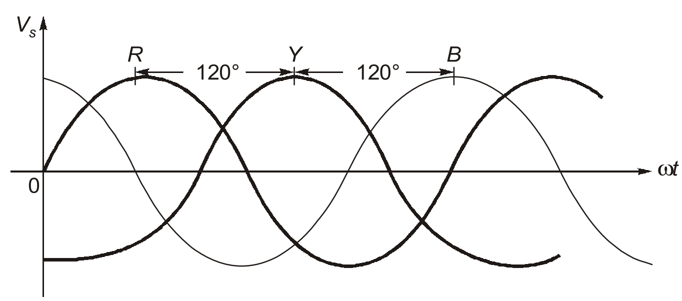
Chapter 1

Introduction

1.1 Polyphase AC Circuits

- A 3-ϕ circuit has an ac voltage generator (alternator) that produces three sinusoidal voltages that are identical except for a phase angle difference of 120° electrical.
- Generally *n*-phase systems are 360°/*n* apart in space.

Three-Phase System



Phase sequence = RYB

$$V_R = V_m \sin\omega t = V\angle 0° \text{ Volt}$$

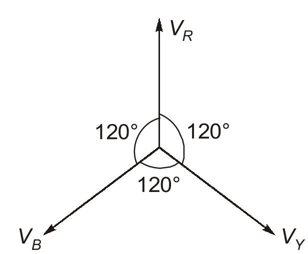
$$V_Y = V_m \sin(\omega t - 120°)$$

$$= V\angle -120° \text{ Volt}$$

$$V_B = V_m \sin(\omega t - 240°)$$

$$= V\angle -240° \text{ Volt}$$

$$= V\angle +120° \text{ Volt}$$



Phase Sequence

- It is the order by which the phase voltages attains their peak value. The phase sequence may be positive, negative or zero (no particular sequence).
- RYB is a universally adopted phase sequence.
- For a 3-ϕ system phase sequence must be defined.
  (a) Positive phase sequence: i.e. RYB, YBR, BRY
  (b) Negative phase sequence: i.e. RBY
  (c) Zero phase sequence: No particular order of phase sequence
- For balanced 3-ϕ system: $I_R + I_Y + I_B = 0$
  For unbalanced 3-ϕ system: $I_R + I_Y + I_B \neq 0$

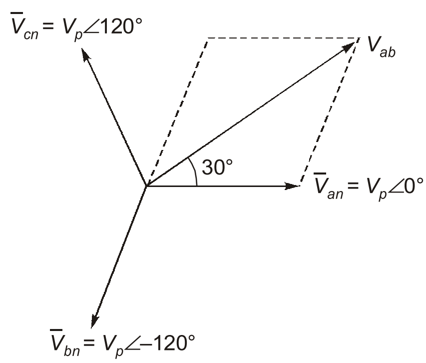
Terminology

(i) Phase voltage (V_p): It is the voltage between any one of the phase and neutral.
(ii) Line voltage (V_L): Voltage measured between any two phases is known as line voltage.
(iii) Phase current (I_P): The current flowing in any one phase is called phase current.
(iv) Line current (I_L): The current flowing in the line is line current.

Type of 3-ϕ Connections

(a) Star (Y) connection
(b) Delta (Δ) connection

(a) Star (Y) connection:



Phase and Magnitude Relations between the Phase and Line Voltage of a Y-Connection

- The set of voltage V_{ab}, V_{bc} and V_{ca} are called the ***line voltages***, and the set of voltages V_{an}, V_{bn} and V_{cn} are referred as the ***phase voltages***.
- For a balanced system, each phase voltage has the same magnitude

$$|V_{an}| = |V_{bn}| = |V_{cn}| = V_p$$

where V_p denotes the effective magnitude of the phase voltage

$$V_{ab} = \sqrt{3}\, V_p\angle 30°$$

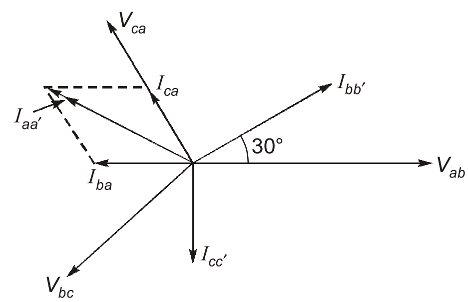
$$V_{bc} = \sqrt{3}\, V_p\angle -90°$$

$$V_{ca} = \sqrt{3}\, V_p\angle 150°$$

Remember

- The line voltages (V_L) constitute a balanced three-phase voltage system whose magnitudes are $\sqrt{3}$ times the phase voltages (V_p); $\boxed{V_L = \sqrt{3}\, V_p}$.
- The line current (I_L) and the phase current (I_p) have the same magnitude; $\boxed{I_L = I_p}$

(b) Delta (Δ) connection:



Relations between Phase and Line Currents in a Δ–Connection

Remember

- The line and phase voltages have the same magnitude;

$$|V_L| = |V_p|$$

- A set of balanced three phase currents yields a corresponding set of balanced line currents that are $\sqrt{3}$ times the phase value;

$$I_L = \sqrt{3}\, I_p\,.$$

Power Calculations

Single-phase power, $P_{1\text{-}\phi} = V_{ph} I_{ph} \cos\phi$

Three-phase power, $P_{3\text{-}\phi} = 3\, V_{ph} I_{ph} \cos\phi$

For Y(star) connection: $P_{(3\text{-}\phi)\,Y} = 3 \cdot \dfrac{V_L}{\sqrt{3}} \cdot I_L \cos\phi = \sqrt{3} V_L I_L \cos\phi$

For Δ(delta) connection: $P_{(3\text{-}\phi)\,\Delta} = 3 \cdot V_L \cdot \dfrac{I_L}{\sqrt{3}} \cos\phi = \sqrt{3} V_L I_L \cos\phi$

NOTE: For both Y-connection and Δ-connection, three phase power is same.

Three-phase reactive power:

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

Total apparent power: $S = \sqrt{3} V_L I_L$

REMEMBER:

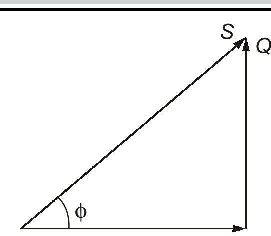
With star system protection can be provided by connecting a protective device between neutral and earth for the detection of earth fault.

Complex Power

$$S = V \cdot I^*$$

$$S = P + jQ$$

$$\phi = \text{Power factor angle}$$



Example - 1.1 Determine the value of phase current (in A) for a balanced delta connected system, when the value of line current is 8.7 A.

(a) 8.60 (b) 7.04
(c) 6.40 (d) 5.02

Solution: (d)

Line current $= I_L = 8.7$ A

For Δ-connected system: $I_P = \frac{I_L}{\sqrt{3}} = \frac{8.7}{\sqrt{3}} = 5.02$ A

Example - 1.2 What is the apparent power of a 3-phase star-connected system having a line voltage of 250 V and line current of 40 A and the phase difference between the voltage and current is 36.87 deg?

(a) 13856 kW (b) 13.856 kVA
(c) 17.32 kW (d) 17.32 kVA

Solution: (d)

Given: $I_R = 40$ A, $\phi = 36.87°$

$V_L = 250$ V

For Y-connection: $V_P = \frac{V_L}{\sqrt{3}} = \frac{25}{\sqrt{3}}$ V

$I_P = I_L = 40$ A

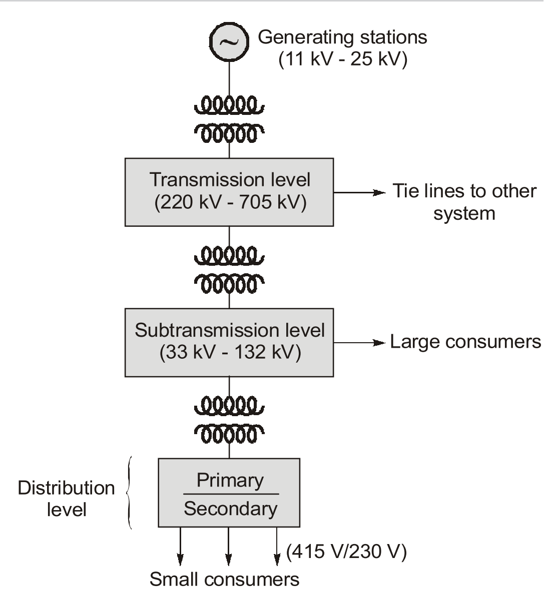
Apparent power (S) $= 3\, V_P I_P$

$= 3 \times \frac{250}{\sqrt{3}} \times 40$

$= 17.32$ kVA

1.2 Electric Supply System

- The conveyance of electric power from a power station to consumer's premises is electric supply system.
- An electric supply system consists of three principles components i.e. power station, the transmission and the distribution system.
- Now-a-day, 3-phase 3-wire ac system is universally adopted for generation and transmission of electric power.
- However, distribution of electric power is done by 3-phase 4-wire ac system.
- Schematic diagram depicting power system structure.



Generating Station

- Station where the electric power is produced.
- The usual generation voltage is from (11-25 kV).
- Due to several advantages of high voltage transmission, the generation voltage is stepped up at the generating station.

Primary Transmission

- Generally the primary transmission is carried at 66 kV, 132 kV, 220 kV, 400 kV or 765 kV with help of 3-phase 3-wire overhead system from power plant after stepping up voltage to above mentioned voltage levels to receiving stations at the outskirts of city.

Secondary Transmission

- The primary transmission lines terminate at receiving station and here the voltage is reduced to 33 kV/66 kV for further distribution, by step down transformers.

Primary Distribution

- The secondary transmission line terminates at the substation (ss) where the voltage is reduced from 33 kV to 11 kV, 3-phase, 3-wire system.
- Large consumers are generally supplied power at 11 kV for further handling with their own substations.

Secondary Distribution

- The electric power from primary distribution line (11 kV) is delivered to distribution substations (DS).
- The substations near consumer step down the voltage to 415 V, 3-phase 4-wire for secondary distribution.

Example - 1.3 A 3-phase 4-wire system is commonly used on ______.

(a) Primary transmission (b) Secondary transmission
(c) Primary distribution (d) Secondary distribution

Solution: (d)

Example - 1.4 The highest transmission voltage used in India is ______.

(a) 400 kV (b) 220 kV
(c) 132 kV (d) 765 kV

Solution: (d)

Various 765 kV lines are there in Indian electricity grid. e.g.: 765 kV (Agra - Gwalior).

Elements of Transmission Line

(a) **Conductors:** Usually ACSR conductors are used.
(b) **Insulators:** Mechanically support the line conductors and isolate them electrically from the ground.
(c) **Transformers:** At sending and receiving ends, step up and step down transformers are used to transfer power with less losses and hence higher efficiency.
(d) **Support:** Generally they are steel towers and provide support to the conductors.
(e) **Protective devices:** Such as lightning arrestors, circuit breaker relays etc.

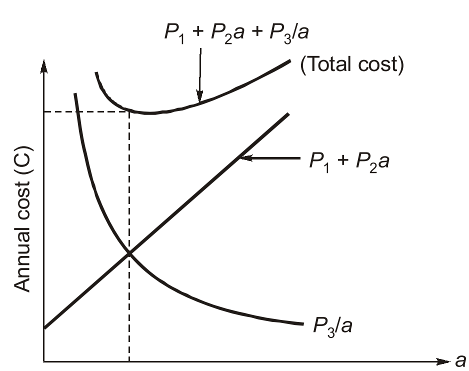
Economics of Power Transmission

Economic Choice of Conductor Size

- Most economical area of conductor is that for which the total annual cost of transmission line is minimum. This is also called as Kelvin's law.
- Total annual cost of transmission line can be divided into two parts broadly.
  (i) **Annual charge on capital outlay:** This is on account of interest and depreciation on the capital cost of complete installation of transmission line.
  Annual charge on an overhead line can be expressed as:
  $$\text{Annual charge} = P_1 + P_2 a$$
  where P_1 and P_2 are constants and a is area of cross-section of the conductor.
  (ii) **Annual cost of energy wasted:** This is on account of energy lost mainly due to I^2R loss in conductor.
  - As resistance $R \propto \frac{1}{a}$

    Thus annual cost of energy wasted in an overhead transmission line $= \frac{P_3}{a}$
  - Total cost C annually $= P_1 + P_2 a + \frac{P_3}{a}$
  - For economical area of conductor:
    $$\frac{dC}{da} = 0$$
    i.e. $$\frac{d}{da}\left(P_1 + P_2 a + \frac{P_3}{a}\right) = 0$$
    i.e. $$P_2 a = \frac{P_3}{a}$$
    Variable part of annual charge = Annual cost of energy wasted

    Kelvin's Law:



Economic Choice of Transmission Voltage

- The transmission voltage for which the cost of conductors, cost of insulators, transformers, switchgear and other apparatus is minimum is called economical transmission voltage.

■■■■

Student's Assignments

1. In a three-phase system, the volt ampere rating is given by
   (a) $3V_LI_L$ (b) $\sqrt{3}V_LI_L$
   (c) V_LI_L (d) $V_{ph}I_{ph}$

2. The economic size of conductor is determined by
   (a) Kelvin's law (b) Kirchoff's law
   (c) Faraday's law (d) All of these

3. Which of the following is not a standard transmission voltage in India?
   (a) 33 kV (b) 66 kV
   (c) 99 kV (d) 220 kV

4. Advantage of transmitting power at high voltage is
   (a) magnitude of current will be small.
   (b) power loss will be less.
   (c) it will reduce voltage loop in the impedance.
   (d) all of the above

5. The active and reactive power of an inductive circuit are 30 W and 40 VAR respectively. The power factory of the circuit is
   (a) 0.5 lag (b) 0.8 lag
   (c) 0.6 lag (d) 0.8 lead

6. Under over excitation, synchronous phase modifier works as a:
   (a) shunt capacitor (b) series capacitor
   (c) shunt reactor (d) any of the above

7. In a star connected system, the current flowing through the line is
   (a) greater than the phase current
   (b) equal to phase current
   (c) lesser than phase current
   (d) none of these

8. If the power factor is high, then the consumer maximum KVA demand:
   (a) increases
   (b) becomes zero
   (c) remains constant
   (d) decreases

9. A 3-phase Y-connected system is supplied by a line voltage of 400 V. The value of phase current is 20 A. What will be the power consumed by the system if the current lags the voltage by 45 degrees?
   (a) 25.6 kW (b) 9.8 kW
   (c) 5.6 kW (d) 18.6 kW

10. For a 3-phase load balanced condition, each phase has the same value of
    (a) impedance
    (b) resistance
    (c) power factor
    (d) all options are correct

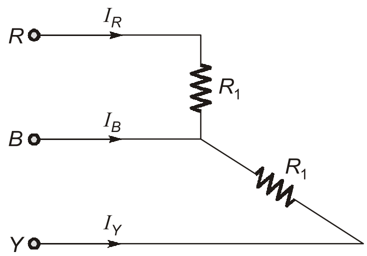
11. In a Y-Y source/load configuration, the
    (a) phase current and the line current are in phase, and both are 120° out of phase with load current.
    (b) phase current, the line current, and the load current 120° out of phase.
    (c) line current and the load current are in phase, and both are out of phase with the phase current.
    (d) phase current, the line current, and the load current are all equal in each phase.

12. The power factor of industrial loads is generally
    (a) unity (b) lagging
    (c) leading (d) zero

13. The rated voltage of a 3-phase power system is given as _____.
    (a) rms phase voltage
    (b) peak phase voltage
    (c) rms line to line voltage
    (d) peak line to line voltage

14. A balanced delta connected load has an impedance of $6\angle 60°\ \Omega$ per phase. The impedance per phase of its equivalent star?
    (a) $36\angle 30°$ (b) $6\angle 60°$
    (c) $2\angle 30°$ (d) $2\angle 60°$

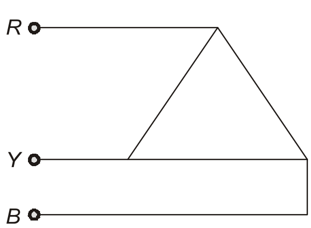
15. For the 3-phase circuit shown in the figure the ratio of current, $I_R : I_Y : I_B$ is



(a) $1:1:\sqrt{3}$ (b) 1 : 1 : 2
(c) 1 : 1 : 1 (d) $1:1:\dfrac{\sqrt{3}}{2}$

16. For unbalanced 3-phase system
(a) $I_R + I_Y + I_B = 0$ (b) $I_R + I_Y + I_B \neq 0$
(c) Both (a) and (b) (d) $I_R + I_Y = I_B$

17. The phase sequence of 3-phase system shown in figure is



(a) RYB (b) RBY
(c) BRY (d) YBR

18. Which of the following can be the generating voltage and frequency in India?
(a) 11 kV and 60 Hz
(b) 11 kV and 50 Hz
(c) 220 kV and 60 Hz
(d) 220 kV and 50 Hz

19. A star-connected load has three equal impedance each of $(40 + 30j)\ \Omega$. If the line current is 5 A, then value of line voltage is
(a) 250 V (b) $250\sqrt{3}$
(c) 200 V (d) $250\sqrt{3}$ V

20. A balanced star-connected load with impedance of $30\angle{-30°}\ \Omega$ is supplied from a 3-phase 4 wire, 415 V system, the voltages to neutral being $240\angle{-90°}$, $240\angle{-30°}$ and $240\angle{-150°}$. The current in neutral wire is
(a) 5 A (b) 10 A
(c) zero (d) 8 A

21. Phase voltages of a star-connected alternator are $E_R = 240\angle 0°$ V, $E_Y = 240\angle{-120°}$ V and $E_B = 240\angle 120°$ V. What is the phase sequence of the system?
(a) RYB (b) RBY
(c) YBR (d) BYR

22. A balanced three-phase Y-connected load is fed from a 208 V, 3-ϕ supply. Each load has resistance of 35 Ω. The total power is approximately
(a) 516 W (b) 630 W
(c) 1235 W (d) 1080 W

23. Delta connection is also known as,
(a) Y-connection
(b) Mesh connection
(c) either Y-connection or mesh connection
(d) neither Y-connection nor mesh connection

24. In high voltage transmission lines, the top most conductor is
(a) R-phase conductor
(b) Y-phase conduction
(c) B-phase conduction
(d) Earth conductor

STUDENT'S ASSIGNMENTS — ANSWER KEY

1. (b)	**2.** (a)	**3.** (c)	**4.** (d)	**5.** (c)
6. (a)	**7.** (b)	**8.** (d)	**9.** (b)	**10.** (d)
11. (d)	**12.** (b)	**13.** (c)	**14.** (d)	**15.** (a)
16. (b)	**17.** (b)	**18.** (b)	**19.** (b)	**20.** (c)
21. (a)	**22.** (c)	**23.** (b)	**24.** (d)	

STUDENT'S ASSIGNMENTS — EXPLANATIONS

1. (b)

$$S_{3\text{-}\phi} = \sqrt{3}\, V_L I_L \text{ (VA rating)}$$

3. **(c)**

The standard voltages of transmission in India are 33 kV, 66 kV, 132 kV, 220 kV, 400 kV, 765 kV.

4. **(d)**

All the options are advantages of high transmission voltages.

5. **(c)**

p.f. angle, $\phi = \tan^{-1}\left(\frac{Q}{P}\right)$

$= \tan^{-1}\left(\frac{40}{30}\right) = 53.13°$

$\cos\phi$ = power factor

$= \cos(53.13°) = 0.6$ (lag)

6. **(a)**

Synchronous phase modifier is basically a synchronous motor operating under overexcitation works similar to a shunt capacitor. It is used for power factor improvement.

7. **(b)**

For Y-connection,

$I_P = I_L$

i.e. phase current is equal to line current.

8. **(d)**

If power factor is high, p.f. angle will be low.

Hence, $\text{KVA} \propto \frac{1}{\cos\phi}$

i.e. for $\phi_1 > \phi_2$

$\cos\phi_1 < \cos\phi_2$

$S_1 > S_2$

9. **(b)**

3-ϕ power, $(P) = \sqrt{3} V_L I_L \cos\phi$

$V_L = 400$ V

$I_P = I_L = 20$ A

$\cos\phi = \cos(45°) = \frac{1}{\sqrt{2}}$

$P = \sqrt{3} \times 400 \times 20 \times \frac{1}{\sqrt{2}}$

$= 9.8$ kW

10. **(d)**

For three-phase balanced load, R, X_L and X_C in each phase and pf is same for each phase.

11. **(d)**

For Y-connection, phase current (I_P) = line current (I_L)

12 **(b)**

Generally, industrial loads (mainly induction motors) are lagging load.

13. **(c)**

Rated voltage is rms line to line voltage.

14. **(d)**

$\because \quad Z_Y = \frac{Z_\Delta}{3} = \frac{6\angle 60°}{3} = 2\angle 60°$

15. **(a)**

$I_R = I_Y = I_{ph}$

I_B = phasor sum of I_R and I_Y at angle of 120°

$I_B = \sqrt{I_R^2 + I_Y^2 + 2 I_R I_Y \cos\left(\frac{120}{2}\right)}$

Put, $I_R = I_Y = I_{ph}$

$I_B = \sqrt{3} I_{ph}$

16. **(b)**

For unbalanced system,

$I_R + I_Y + I_B \neq 0$

18. **(b)**

The generation voltage is about 11 kV – 25 kV due to insulation problems in alternator and frequency of Indian electricity grid is 50 Hz.

19. **(b)**

$Z_P = \sqrt{R^2 + X^2}$

$= \sqrt{40^2 + 30^2} = 50\,\Omega$

Phase voltage,

$V_P = I_L \times Z_P = 250$ V

For Y-connected,

Line voltage (V_L) = $\sqrt{3} V_P = 250\sqrt{3}$ V