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# HINGA MUNA!!!

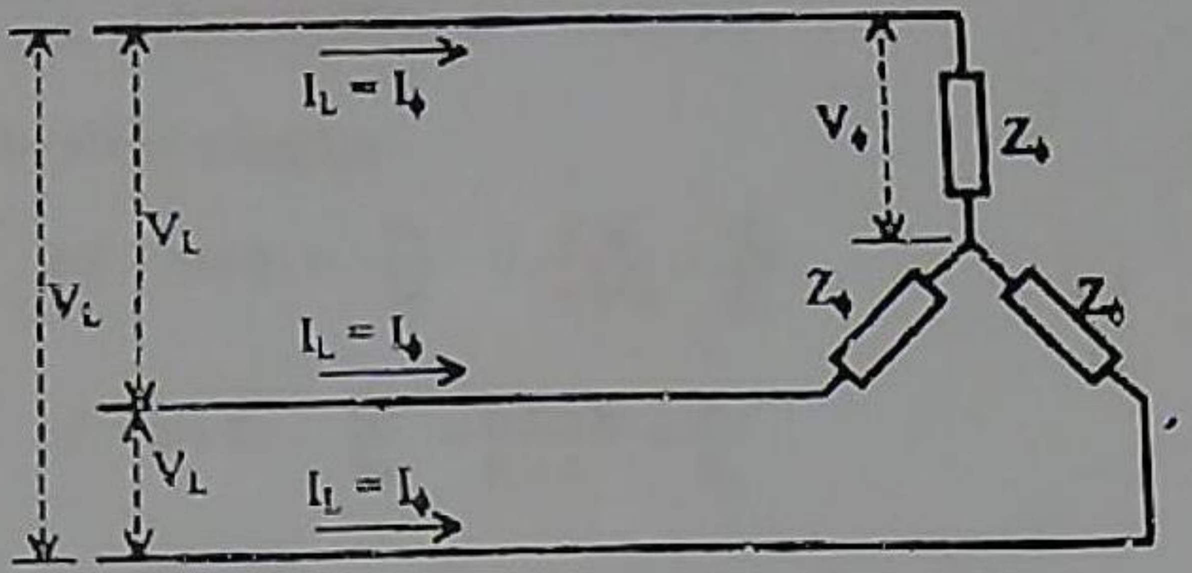
# IEE1-(AC Circuits Part 2)
# Review Materials for EE subject

# AC Circuits Part 2
# Three Phase Circuits / Systems

- same parameters
- same power factor

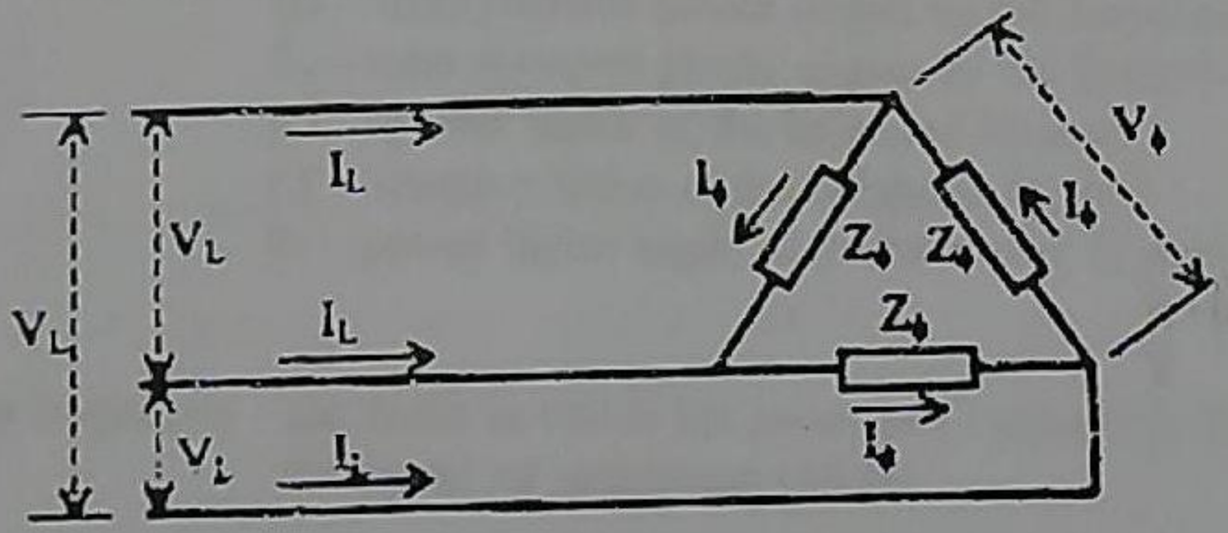
**Balanced 3ϕ Circuits/ Systems:**

1. **Wye (Star) Connected System**




**Relationships :** $I_\phi = I_L$ ; $V_\phi = \frac{V_L}{\sqrt{3}}$

## 2. Delta (Mesh) Connected System:




**Relationships:** $V_\phi = V_L$ ; $I_\phi = \frac{I_L}{\sqrt{3}}$

where:

$V_\phi$ – phase voltage
$I_\phi$ – phase current
$V_L$ – line voltage
$I_L$ – line current

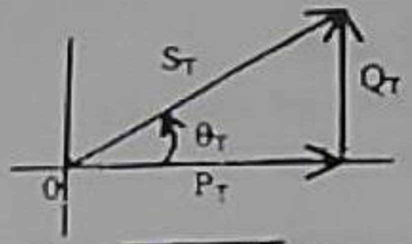
## Power in Balanced 3ϕ Circuits/Systems
(Whether Wye or Delta connected)

$$P_T = \sqrt{3}\, V_L I_L (p.f.) = 3 V_\phi I_\phi (p.f.) = 3\, I_\phi^2 R_\phi \text{ watts}$$

$$Q_T = \sqrt{3}\, V_L I_L (r.f.) = 3\, V_\phi I_\phi (r.f.) = 3\, I_\phi^2 X_\phi \text{ vars}$$

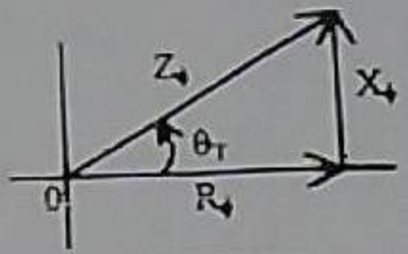
$$S_T = \sqrt{3}\, V_L I_L = 3 V_\phi I_\phi = 3 I_\phi^2 Z_\phi = \sqrt{P_T^2 + Q_T^2} \text{ va}$$

**Power Triangle:**




$S_T = \sqrt{P_T^2 + Q_T^2}$ va

**Impedance Triangle:**




$Z_\phi = \sqrt{R_\phi^2 + X_\phi^2}\ \Omega$

phase system

From the above triangles:

$$p.f = \cos\theta_T = \frac{P_T}{S_T} = \frac{KW}{KVA} = \frac{R_\phi}{Z_\phi}$$

$$r.f. = \sin\theta_T = \frac{Q_T}{S_T} = \frac{KVAR}{KVA} = \frac{X_\phi}{Z_\phi}$$

$$\tan\theta_T = \frac{Q_T}{P_T} = \frac{KVAR}{KW} = \frac{X_\phi}{R_\phi}$$

where:

$P_T$ – total real power drawn by the balanced $3\phi$ load
$Q_T$ – total reactive power drawn by the balanced $3\phi$ load
$S_T$ – total apparent power drawn by the balanced $3\phi$ load
p.f. – power factor of the balanced $3\phi$ load
r.f. – reactive factor of the balanced $3\phi$ load
$\theta_T$ – power factor angle of the balanced $3\phi$ load

Phase Sequence – the order in which the generated voltages in the phase windings of an alternator reach or attain their peak or maximum values.

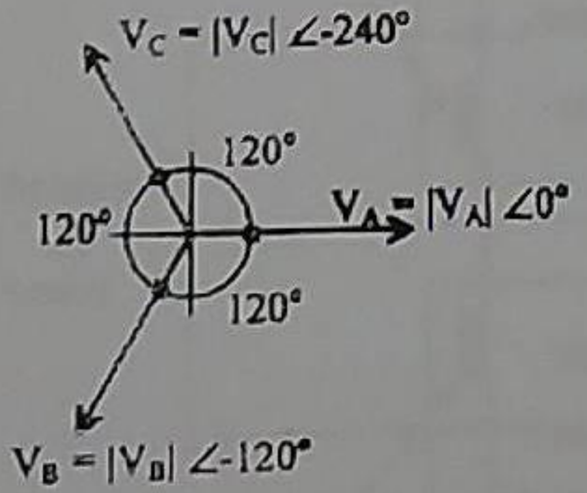
a. **Positive Phase Sequence**

$$ABC \rightarrow BCA \rightarrow CAB$$

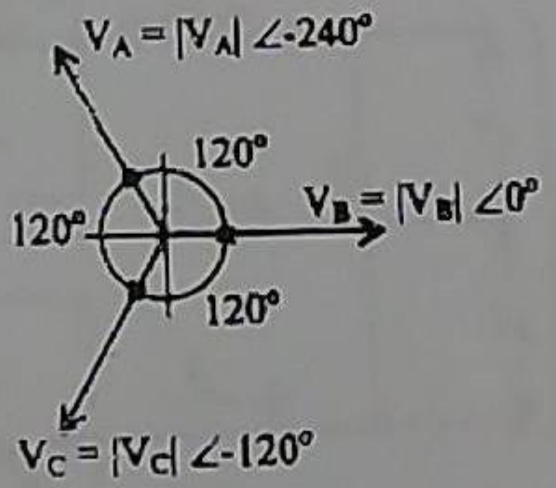
$$AB - BC - CA \rightarrow BC - CA - AB \rightarrow CA - AB - BC$$

$$AN - BN - CN \rightarrow BN - CN - AN \rightarrow CN - AN - BN$$

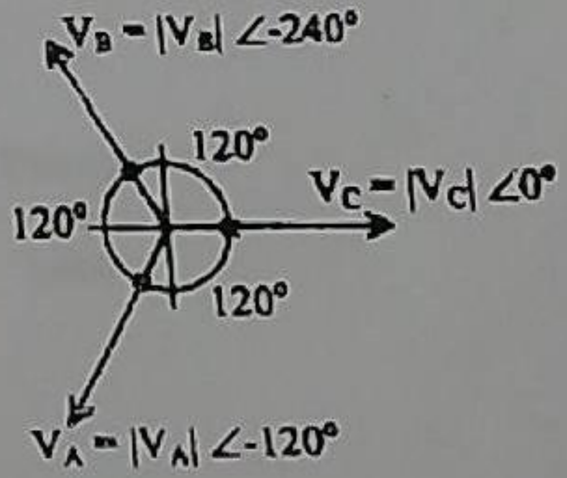
Examples of Vector Representations




**Sequence ABC**




**Sequence BCA**




**Sequence CAB**

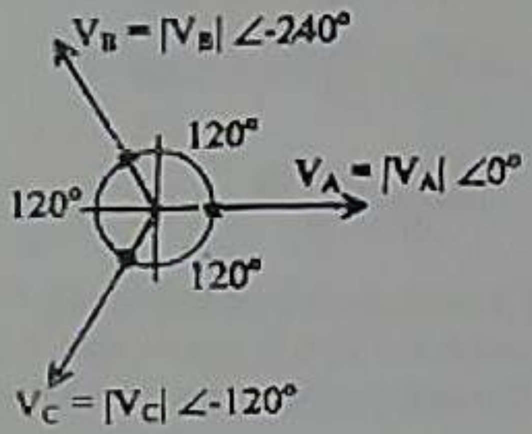
b. **Negative Phase Sequence**

$$ACB \rightarrow CBA \rightarrow BAC$$

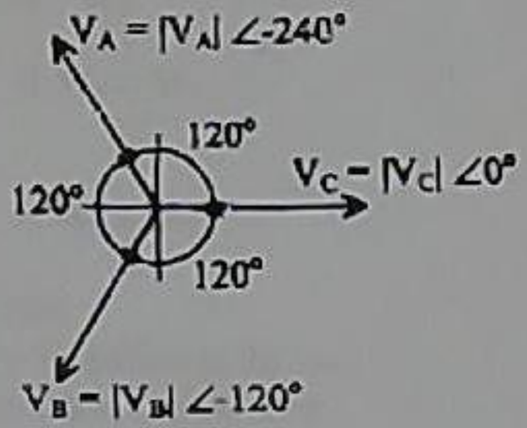
$$AB - CA - BC \rightarrow CA - BC - AB \rightarrow BC - AB - CA$$

$$AN - CN - BN \rightarrow CN - BN - AN \rightarrow BN - AN - CN$$

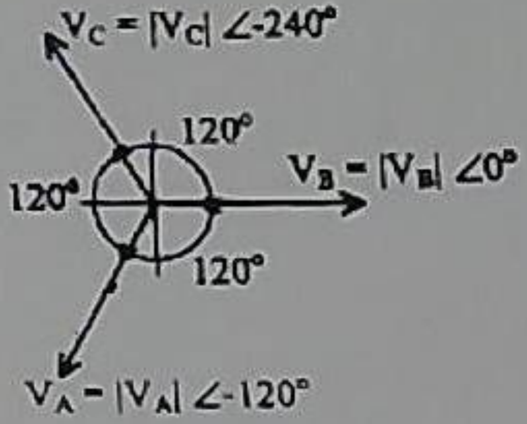
Examples of Vector Representations




**Sequence ACB**




**Sequence CBA**




**Sequence BAC**

If the phase sequence is not given, assume a positive phase sequence. Three phase ($3\phi$) alternators are designed to operate with positive phase sequence voltages.

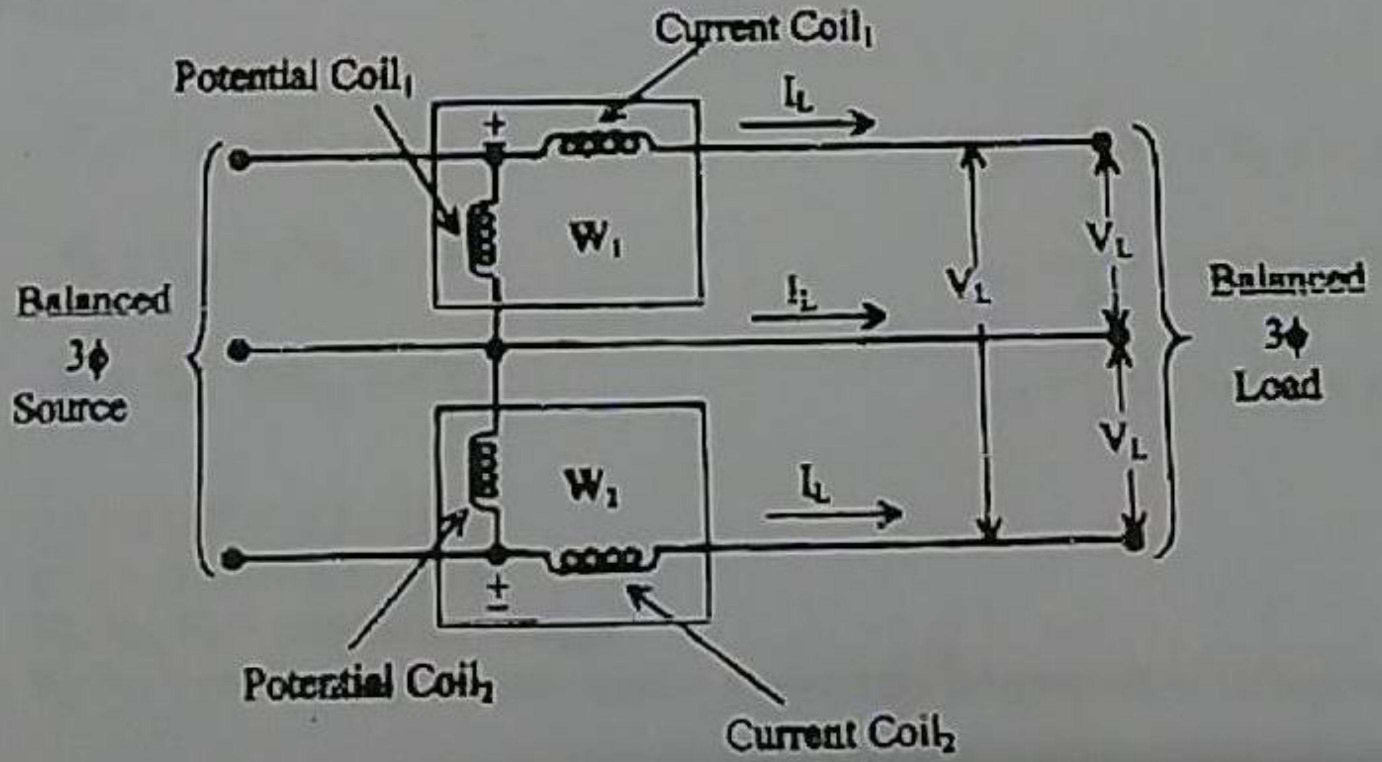
**Power Measurements in three Phase (3ϕ) Systems**

1. **One-wattmeter Method** – used to measure the total real power in a balanced three-phase system with a single wattmeter.

   Methods employed:

   a. Potential – lead shift Method
   b. Artificial – neutral Method
   c. T Method
   d. Current-transformer Method

2. **Two-wattmeter Method** – usually used to measure the real power being drawn by a three-phase (3ϕ), 3-wire system.



$$W_1 = V_L I_L \cos|30° \pm \theta|$$

$$W_2 = V_L I_L \cos|30° \mp \theta|$$

$$P_T = W_1 + W_2 \rightarrow \text{added algebraically}$$

$$Q_T = \sqrt{3}\,(W_1 - W_2), \quad \text{if } W_1 > W_2$$

$$Q_T = \sqrt{3}\,(W_2 - W1), \quad \text{if } W_2 > W_1$$

$$\tan\theta = \frac{\sqrt{3}\,(W_1 - W_2)}{W_1 + W_2}, \quad \text{if } W_1 > W_2$$

$$\tan\theta = \frac{\sqrt{3}\,(W_2 - W_1)}{W_1 + W_2}, \quad \text{if } W_2 > W_1$$

where: $\theta$ = power factor of the balanced $3\phi$ load
$P_T$ = total real or true power drawn by the balanced $3\phi$ load
$Q_T$ = total reactive power drawn by the balanced $3\phi$ load

Notes:

1. At unity p.f., the two wattmeters have equal reading. That is $W_1 = W_2$
2. At 0.866 p.f., one wattmeter reading is twice the other
3. At 0.5 p.f., one wattmeter reads zero while the other registers the total circuit power
4. At less than 0.5 p.f., one wattmeter gives a negative reading and the other positive.

## Symmetrical Components

Fortescue's Theorem: A set of n unbalanced related phasors may be resolved into n systems of balanced phasors called the **symmetrical components**.

For three-phase systems, we have:

a. positive sequence component
b. negative sequence component
c. zero sequence component

For Voltages:

$$V_A = V_{A0} + V_{A1} + V_{A2}$$

$$V_B = V_{A0} + a^2 V_{A1} + a V_{A2}$$

$$V_C = V_{A0} + a V_{A1} + a^2 V_{A2}$$

$$V_{A0} = \frac{1}{3}\left(V_A + V_B + V_C\right)$$

$$V_{A1} = \frac{1}{3}\left(V_A + a V_B + a^2 V_C\right)$$

$$V_{A2} = \frac{1}{3}\left(V_A + a^2 V_B + a V_C\right)$$

where: $a = 1\angle 120^\circ = -0.5 + j0.866$
$a^2 = 1\angle 240^\circ = -0.5 - j0.866$
$V_A, V_B, V_C$ = unbalanced voltages
$V_0, V_1, V_2$ = zero, positive and negative symmetrical components of voltage respectively

For Currents

$$I_A = I_{A0} + I_{A1} + I_{A2}$$

$$I_B = I_{A0} + a^2 I_{A1} + a I_{A2}$$

$$I_C = I_{A0} + a I_{A1} + a^2 I_{A2}$$

$$I_N = I_A + I_B + I_C$$

$$I_{A0} = \frac{1}{3}\left(I_A + I_B + I_C\right)$$

$$I_{A1} = \frac{1}{3}\left(I_A + a I_B + a^2 I_C\right)$$

$$I_{A2} = \frac{1}{3}\left(I_A + a^2 I_B + a I_C\right)$$

where: $I_A$, $I_B$, $I_C$ = unbalanced currents
$I_0$, $I_1$, $I_2$ = zero, positive and negative symmetrical components of current respectively
$I_N$ = neutral current

EXERCISES:

## PART 2 – POLYPHASE SYSTEM

**REE – Sept. 2013**

1. Power in a three-phase delta system with balanced load is equal to
   A. $\sqrt{3}\, V_L I_L$ (p.f.)   B. $\sqrt{3}\, V_\phi I_\phi$ (p.f.)   C. $3 V_\phi I_L$ (p.f.)   D. $3 V_L I_L$ (p.f.)

2. In a balanced three-phase Y-connected system, the line voltage and the corresponding phase voltage are displaced from each other by ________.
   A. 0°   B. 30°   C. 90°   D. 120°

3. In balanced star (wye) connected system, the line voltage is ________
   A. 0.707 times the phase voltage   B. 1.414 times the phase voltage
   C. phasor sum of two phase voltages   D. phasor difference of two phase voltages

**REE – Sept. 2017**

4. What is $V_{BN}$ in this balanced three-phase in which $V_{AN} = 7200\angle 20^\circ$ and $V_{CN} = 7200\angle -100^\circ$?
   A. $7200\angle -80^\circ$   B. $7200\angle 120^\circ$   C. $7200\angle 90^\circ$   D. $7200\angle 140^\circ$

**REE – April 2002**

5. Three 10-ohm resistors connected in wye are supplied from a balanced three phase source where phase a line voltage is given by 230 sin377t. What is the phase a line current?
   A. 13.28 sin377t   B. 13.28 sin(377t - 30°)
   C. 23 sin (377t – 30°)   D. 40 sin(377t + 30°)

**REE – April 2016**

6. A balanced delta load of 3 + j4 Ω per phase is connected to a balanced 110 v source. Find the line current

A. 22 A B. 38.1 A C. 11 A D. 19.05 A

**REE – Sept. 2011**

7. A balanced three-phase 4,157 v rms source supplies a balanced three-phase delta-connected load of 38.4 + j28.8 Ω. Find the current in line A with $V_{an}$ as reference

A. 120 – j90 A B. 120 + j90 A C. –120 + j90 A D. –120 – j90 A

**REE – Sept. 2017**

8. Find the average power absorbed by a balanced three-phase load in an ABC circuit in which $V_{CB} = 208\angle 15°$ and $I_B = 3\angle 110°$?

A. 1,080 W B. 624 W C. 358 W D. 620 W

9. A system consists of three equal resistors connected in delta and is fed from a balanced three-phase supply. How much power is reduced if one of the resistors is disconnected?

A. 33% B. 50% C. 25% D. 0%

**REE – April 2005**

10. Three heater units each taking 1,500 watts are connected delta to a 120 volt three phase line. What is the resistance of each unit in ohms?

A. 9.6 B. 5.4 C. 8.6 D. 7.5

11. The resistance between any two terminals of a balanced delta-connected load is 12 ohms. The resistance of each phase is ________

A. 12 ohms B. 18 ohms C. 6 ohms D. 36 ohms

**REE – Sept. 2013**

12 A 240 v balanced 3Φ source supplies a purely resistive impedance of 11.52 ohms per phase. What is the total power drawn if it is Y-connected?

A. 5 kW B. 15 kW C. 20 kW D. 30 kW

**REE – March 1998**

13 Three impedances, - j10, j10 and 10Ω are wye connected. Determine the impedance of an equivalent delta.

A. 12.5, j12.5, - 12.5 Ω B. 10, j10, - j10 Ω
C. j8.5, j12.5, 8 Ω D. 5, 5j, - j5 Ω

**REE – Sept. 2015 / Sept. 2016**

14 Convert the delta connected impedances of $12\angle 36°$ Ω to balanced wye connected impedances.

A. $3\angle 36°$ Ω B. $6\angle 36°$ Ω C. $4\angle 36°$ Ω D. $12\angle 36°$ Ω

15. Three identical capacitances, each of 150 μF are connected in star. The value of capacitance in each phase of the equivalent delta connected load would be ________.

A. 150 μF B. 450 μF C. 50 μF D. 300 μF

**REE – Sept. 2007**

16 A balanced three-phase, wye-connected load of 150 kw takes a leading current of 100 A, when the line is 2,400 v, 60 HZ. What is the capacitance per phase?

A. 21 mF B. 21 μF C. 205 mF D. 205 μF

**REE – April 2004**

17 It is required to increase the power factor of a 750 KW three-phase balanced load from 70% lagging to 90% lagging. The line voltage is 6,900 volts, 60 Hz. Specify the capacitor required to increase the power factor of this wye-connected load in microfarad per phase.

A. 20.45 B. 22.39 C. 18.58 D. 17.22

**REE – May 2010**

18 A balanced three-phase source serves three loads:

Load 1: 24 KW, 0.6 lagging p.f.
Load 2: 10 KW, unity p.f.
Load 3: 14 KVA, 0.8 leading p.f.

If the line voltage of the load is 208 v rms at 60 Hz, find the line current.

A. 143 A B. 139 A C. 141 A D. 137 A

19. Two balanced loads are connected in parallel to a three phase 460-volt source. Load A is 90 kVA at a power factor of 0.6 lagging and load B is 25 kVA at unity power factor. What is the new power factor of the system?

A. 0.74 lagging B. 0.74 leading C. 0.80 lagging D. 0.80 leading

**REE – Sept. 2009**

20 In two-wattmeter method of power measurement, the readings of the two wattmeters were 6,717 watts and 2,658 watts, respectively. Find the power factor.

A. 0.90 B. 0.70 C. 0.60 D. 0.80

**REE – April 2005**

21. The total power consumed by a balanced 3Φ load is 3,000 watts at 80% power factor. Two wattmeters $W_A$ and $W_B$ are connected to the line. What is the reading of $W_A$?

A. 2,150 watts B. 2,000 watts C. 1,500 watts D. 2,500 watts

**REE – Sept. 2008**

22. In a balanced three – phase 230 V circuit, the line current is 90 A. The power is measured by two – wattmeter method. If the power factor is 100% and the line current is the same, what is the reading on each wattmeter?

A. 25.6 kW B. 30.4 kW C. 17.9 kW D. 20.7 kW

**REE – Sept. 2016**

23. The type of ac distribution system commonly used to supply both light and power is the

A. open delta system
B. three-phase delta system
C. three-phase wye system with neutral wire
D. three-phase wye system without neutral wire

**REE – Sept. 2015**

24. For an unbalanced load which connection is suitable?

A. 3 – wire open delta
B. 4 – wire wye connection
C. 3 – wire delta connection
D. 3 – wire wye connection

**REE – Sept. 2009**

25. A three-phase, wye-connected system with 240-v per phase is connected to three loads: 10 ohms, 18.79 + j6.84 ohms, 9.83 – j6.88 ohms to phases A,B, and C, respectively. Find the current in phase C.

A. 1.74 + j19.92 A B. –1.74 + j19.92 A C. –1.74 – j19.92 A D. 1.74 – j19.92 A

26. A three-phase, four-wire system has the following unbalanced loads: $Z_a = 10 + j10\Omega$, $Z_b = 13 - j2\Omega$, $Z_c = 7.5 + j10\Omega$. Determine the total power delivered to the load if the line voltage is 208 V.

A. 4.48 kW B. 1.48 kW C. 2.49 kW D. 2.90 kW

**REE – April 2005**

27. A 3-phase 4-wire system has the following unbalanced loads $Z_1 = 10 + j5\,\Omega$, $Z_2 = 8 + j4\,\Omega$, and $Z_3 = 20 + j0\,\Omega$. The line to neutral voltage of the system is 120 volts. What is the reading of the wattmeter in watts in $Z_3$?

    A. 900 B. 720 C. 1,000 D. 1,050

**REE – March 1998**

28. The three unbalanced currents are $I_a$ = 10 cis(- 30°), $I_b$ = 0, $I_c$ = 10 cis 150°. Find the negative sequence of phase A current.

    A. 8.66 cis 30° A B. 5.77 cis (-60°) A C. – 5.77 A D. 5.77 A

**REE – Oct. 1998**

29. The load of a wye connected transformer are: $I_a$ = 10 cis(-30°), $I_b$ = 12 cis 215°. $I_c$ = 15 cis 82°. What is the neutral current?

    A. 1.04 cis 72.8° B. 0.92 cis 62.5° C. 2.21 cis (-30°) D. 3.11 cis 72.8°

**REE – Sept. 2007**

30. For the following phase currents $I_a$ = 34.64, $I_b$ = –10 – j17.32, $I_c$ = –10 + j17.32. What is the positive sequence for phase c?

    A. 12.44 – j21.55 B. 12.44 + j21.55 C. –12.44 + j21.55 D. –12.44 – j21.55

31. A wye-connected, three phase system has the following sequence components of current:

Zero sequence current = 12.5 cis 30°

Positive sequence current = 28 cis (- 45°)

Negative sequence current = 20 cis (-32°)

Determine the current flowing in the neutral wire

A. 4.17 cis 30° B. 37.5 cis 30° C. 35.7 cis (-60°) D. 22.5 cis 10°

**REE – April 2007**

32. Given the following sets of symmetrical components, determine the phase current for phase B

$I_{a0}$ = 1 at 75 deg $I_{a1}$ = 1 at 15 deg $I_{a2}$ = 1 at –45 deg

A. 0.259 + j0.966 B. 0.516 + j1.931 C. 1.932 + j0.518 D. 1.414 + j1.414

**REE – Sept. 2006 / April 2017**

33. One conductor of a three-phase line is open. The current flowing to the delta-connected load through line a is 20 A. With the current in line a as reference and assuming that line c is open, what is the negative sequence current of phase a?

A. 10 + j5.78 B. 10 – j5.78 C. j11.55 D. −10 + j5.78