

Electrical Circuits and Network (313332)

MSBTE K-Scheme · Model Question Paper — Set A · Model Answers

Q.1

a) Frequency and phase difference.

2 M

- **Frequency (f):** The number of cycles completed per second. Unit: hertz (Hz). $f = 1/T$. (In India supply frequency = 50 Hz.)
- **Phase difference:** The angle between the zero (or maximum) values of two alternating quantities of the same frequency. The quantity reaching its maximum first is said to lead the other. e.g. $v = V_m \sin \omega t$ and $i = I_m \sin(\omega t - \phi)$: current lags voltage by ϕ .

(Each definition 1 M)

b) Admittance and susceptance.

2 M

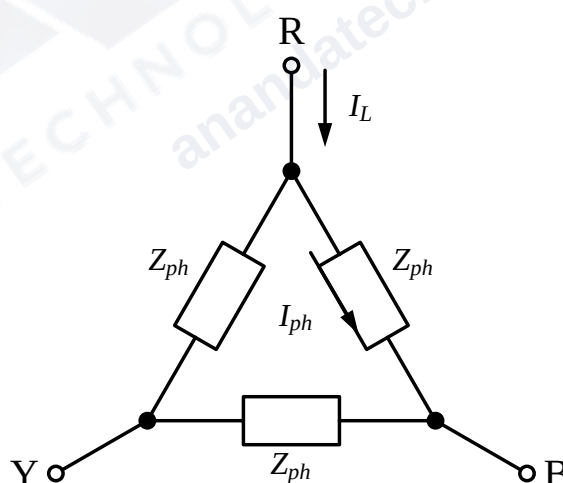
- **Admittance (Y):** reciprocal of impedance, $Y = 1/Z = I/V$; it indicates how easily the circuit allows AC to flow. Unit: siemens (S) or mho (Ω).
- **Susceptance (B):** the imaginary (reactive) component of admittance, $Y = G \pm jB$; $B = X/Z^2$. Unit: siemens (S) or mho.

(Each definition with unit 1 M)

c) Line and phase relations in balanced delta.

2 M

- Line voltage = phase voltage: $V_L = V_{ph}$
- Line current = $\sqrt{3} \times$ phase current: $I_L = \sqrt{3} I_{ph}$
- Line currents lag the corresponding phase currents by 30° .

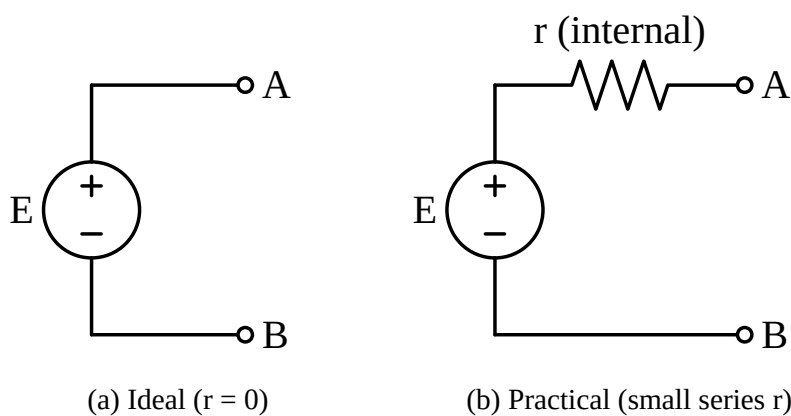


Delta connection

(Each relation 1 M)

d) Ideal and practical voltage source.

2 M



Voltage sources

- Ideal voltage source: internal resistance = 0Ω ; terminal voltage constant for any load.
- Practical voltage source: small internal resistance r in series; terminal voltage $V = E - Ir$.

(Symbols 1 M, internal resistance 1 M)

e) Node and mesh.

2 M

- **Node:** A point (junction) in a network where two or more circuit elements are joined. (A, B, C, D in figure.)
- **Mesh:** A closed path in a network which does not contain any other closed path inside it (e.g. path with E1, R1, R3, R2 — mesh I1).

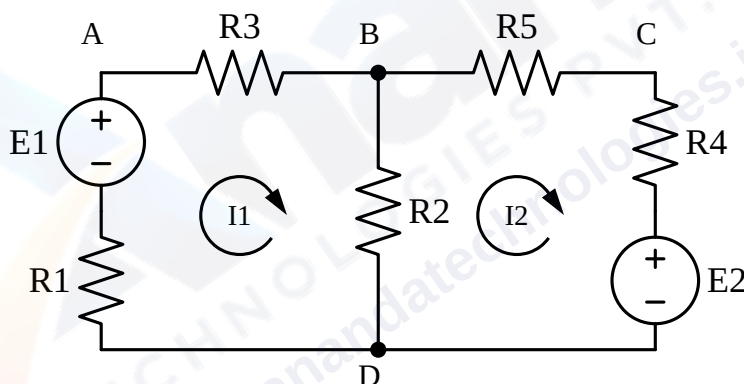


Fig.: Network showing nodes, branches, loops and meshes

(Each definition 1 M)

f) Norton's theorem.

2 M

Any linear, bilateral, active two-terminal network can be replaced by an equivalent circuit consisting of a current source I_N (short-circuit current through A-B) in parallel with a resistance R_N (resistance seen from A-B with all sources replaced by their internal resistances).

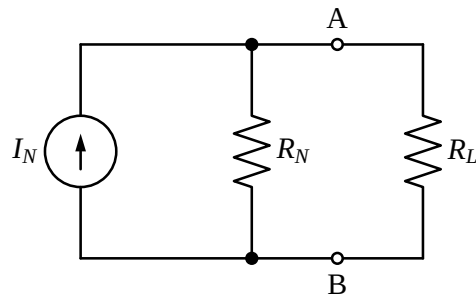


Fig.: Norton's equivalent circuit

(Statement 2 M)

g) Maximum power transfer theorem (DC).

2 M

A resistive load connected to a DC network receives **maximum power** when the load resistance is equal to the Thevenin's (internal) resistance of the network as seen from the load terminals: $R_L = R_{Th}$.

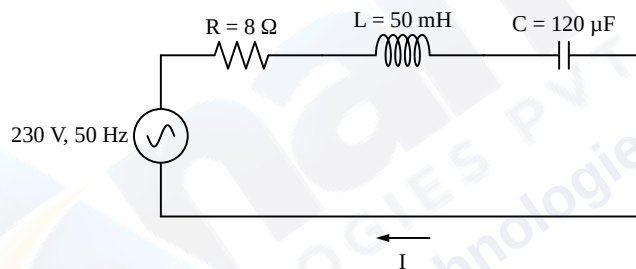
Maximum power $P_{max} = V_{Th}^2 / (4R_L)$.

(Statement 2 M)

Q.2

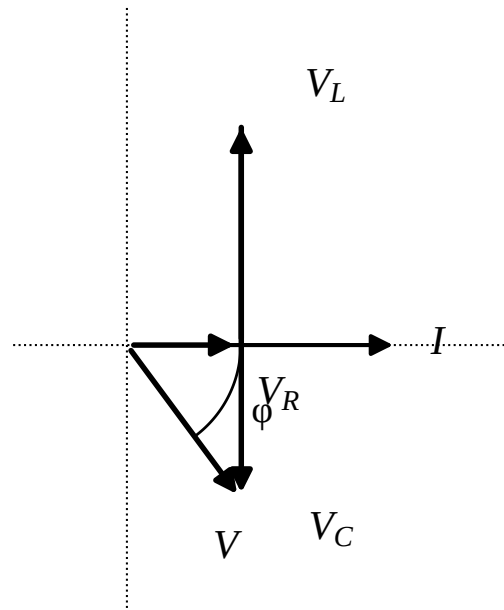
a) Series R-L-C: $R = 8 \Omega$, $L = 0.05 \text{ H}$, $C = 120 \mu\text{F}$, 230 V, 50 Hz.

4 M



Circuit diagram

1. Inductive reactance $X_L = 2\pi fL = 2\pi \times 50 \times 0.05 = \mathbf{15.708 \Omega}$
2. Capacitive reactance $X_C = 1/(2\pi fC) = 1/(2\pi \times 50 \times 120 \times 10^{-6}) = \mathbf{26.526 \Omega}$
3. Impedance $Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{8^2 + 10.818^2} = \mathbf{13.455 \Omega}$ [$Z = (8 - j10.818) \Omega = 13.455 \angle -53.52^\circ \Omega$]
4. Current $I = V/Z = 230/13.455 = \mathbf{17.0945 \text{ A}}$
5. Power factor $\cos \phi = R/Z = 8/13.455 = \mathbf{0.5946 \text{ leading}}$ ($\phi = 53.52^\circ$)
6. Active power $P = VI \cos \phi = I^2 R = 17.0945^2 \times 8 = \mathbf{2337.78 \text{ W}}$
7. Reactive power $Q = VI \sin \phi = 230 \times 17.0945 \times 0.804 = \mathbf{3161.23 \text{ VAR}}$ (leading)
8. Apparent power $S = VI = 230 \times 17.0945 = \mathbf{3931.74 \text{ VA}}$



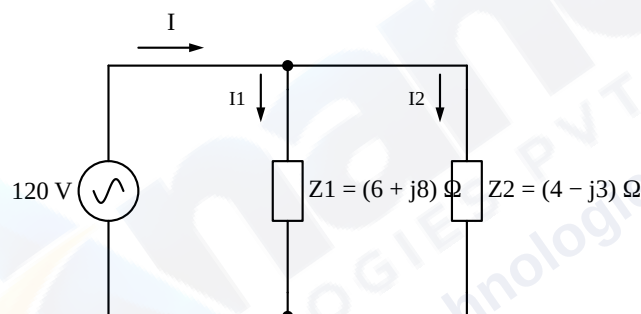
Phasor diagram (current I as reference) — $\phi = 53.52^\circ$

(Reactances 1 M, Z and I 1 M, p.f. 1 M, power 1 M)

$Z = 13.455 \, \Omega$, $I = 17.095 \, \text{A}$, p.f. = 0.5946 leading, $P = 2337.8 \, \text{W}$

b) Parallel impedances $(6 + j8) \, \Omega$ and $(4 - j3) \, \Omega$ across 120 V.

4 M

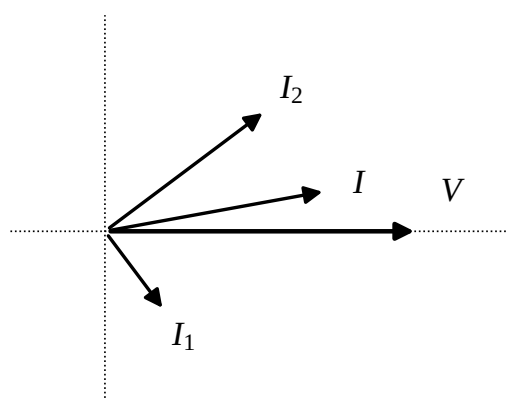


Circuit diagram

- $Z_1 = (6 + j8) \, \Omega = 10 \angle 53.13^\circ \, \Omega$
- $Z_2 = (4 - j3) \, \Omega = 5 \angle -36.87^\circ \, \Omega$
- $Z_1 + Z_2 = (10 + j5) = 11.18 \angle 26.57^\circ$
- Equivalent impedance $Z = Z_1 Z_2 / (Z_1 + Z_2) = (10 \angle 53.13^\circ)(5 \angle -36.87^\circ) / (11.18 \angle 26.57^\circ) = 4.472 \angle -10.3^\circ \, \Omega = (4.4 - j0.8) \, \Omega$
- Branch current $I_1 = V/Z_1 = 120 \angle 0^\circ / 10 \angle 53.13^\circ = 12 \angle -53.13^\circ \, \text{A} = (7.2 - j9.6) \, \text{A}$
- Branch current $I_2 = V/Z_2 = 120 \angle 0^\circ / 5 \angle -36.87^\circ = 24 \angle 36.87^\circ \, \text{A} = (19.2 + j14.4) \, \text{A}$
- Total current $I = I_1 + I_2 = (26.4 + j4.8) \, \text{A} = 26.833 \angle 10.3^\circ \, \text{A}$
- p.f. of branch 1 = $\cos \phi_1 = R_1/|Z_1| = 6/10 = 0.6$ lagging
- p.f. of branch 2 = $\cos \phi_2 = R_2/|Z_2| = 4/5 = 0.8$ leading
- Overall p.f. = $\cos(\text{angle between } V \text{ and } I) = \cos 10.3^\circ = 0.9839$ leading
- Power taken by branch 1: $P_1 = I_1^2 R_1 = 12^2 \times 6 = 864 \, \text{W}$

5. Power taken by branch 2: $P_2 = I_2^2 R_2 = 24^2 \times 4 = \mathbf{2304 \text{ W}}$

6. Total power $P = P_1 + P_2 = 3168 \text{ W}$ (check: $VI \cos \phi = 120 \times 26.8328 \times 0.9839 = 3168 \text{ W} \checkmark$)



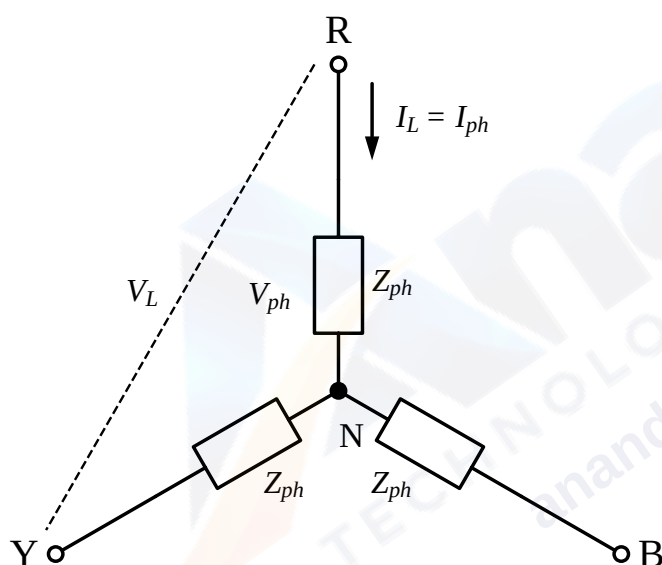
Phasor diagram (V as reference)

(Branch currents 2 M, total current/p.f. 2 M, power/phasor diagram 2 M)

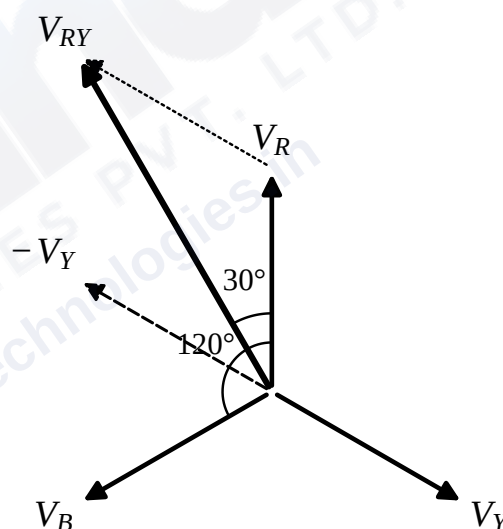
$I_1 = 12 \angle -53.13^\circ \text{ A}, I_2 = 24 \angle 36.87^\circ \text{ A}, I = 26.833 \angle 10.3^\circ \text{ A}, \text{p.f.} = 0.9839 \text{ leading}$

c) Derive $V_L = \sqrt{3} V_{ph}$ for star connection.

4 M



Star connected load



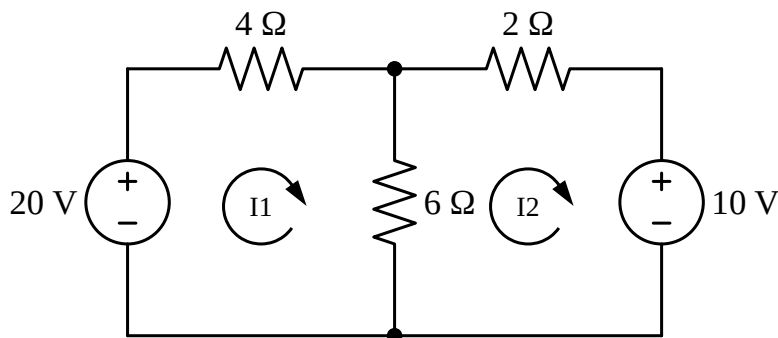
Phasor diagram ($V_{RY} = V_R - V_Y$)

- In star connection each line is in series with its phase winding, so $I_L = I_{ph}$.
- Line voltage between lines R and Y: $V_{RY} = V_R - V_Y = V_R + (-V_Y)$ (phasor difference).
- V_R and $-V_Y$ are equal in magnitude (V_{ph}) and the angle between them is 60° , so their resultant bisects this angle (30° from V_R).
- $V_{RY} = 2 V_{ph} \cos(60^\circ/2) = 2 V_{ph} \cos 30^\circ = 2 V_{ph} \times (\sqrt{3}/2)$
- $V_L = \sqrt{3} V_{ph}$; similarly $V_{YB} = V_{BR} = \sqrt{3} V_{ph}$; line voltages lead the respective phase voltages by 30° .

(Diagram 1 M, phasor diagram 1 M, derivation 2 M)

d) Mesh analysis — current in 6 Ω (Fig. No. 1).

4 M



Mesh currents assumed clockwise

Assume clockwise mesh currents I_1 , I_2 as shown. Applying KVL to each mesh (voltage drops = emf in the mesh):

Mesh 1: $6(I_1 - I_2) + 4 I_1 = 20$

Mesh 2: $6(I_2 - I_1) + 2 I_2 = -10$

Simplifying:

$$10 I_1 - 6 I_2 = 20 \quad \dots(1)$$

$$-6 I_1 + 8 I_2 = -10 \quad \dots(2)$$

Solving by Cramer's rule: $\Delta = \begin{vmatrix} 10 & -6 \\ -6 & 8 \end{vmatrix} = 44$

$$\Delta_1 = \begin{vmatrix} 20 & -6 \\ -10 & 8 \end{vmatrix} = 100 \Rightarrow I_1 = \Delta_1 / \Delta = 100 / 44 = \mathbf{2.2727 \text{ A}}$$

$$\Delta_2 = \begin{vmatrix} 10 & 20 \\ -6 & -10 \end{vmatrix} = 20 \Rightarrow I_2 = \Delta_2 / \Delta = 20 / 44 = \mathbf{0.4545 \text{ A}}$$

Current in 6 Ω resistor (common to mesh 1 and mesh 2) = $I_1 - I_2 = 2.2727 - (0.4545) = \mathbf{1.8182 \text{ A}}$

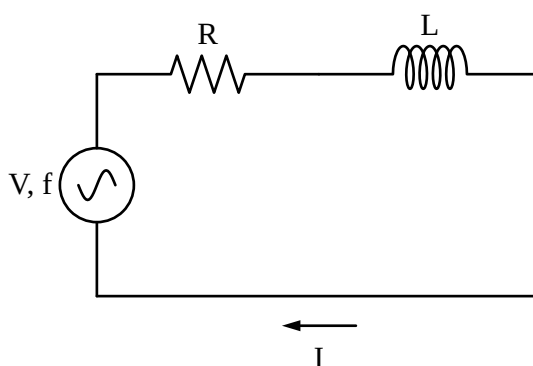
Current through 6 Ω resistor = 1.8182 A, flowing downward

(KVL equations 2 M, solution 1 M, answer 1 M)

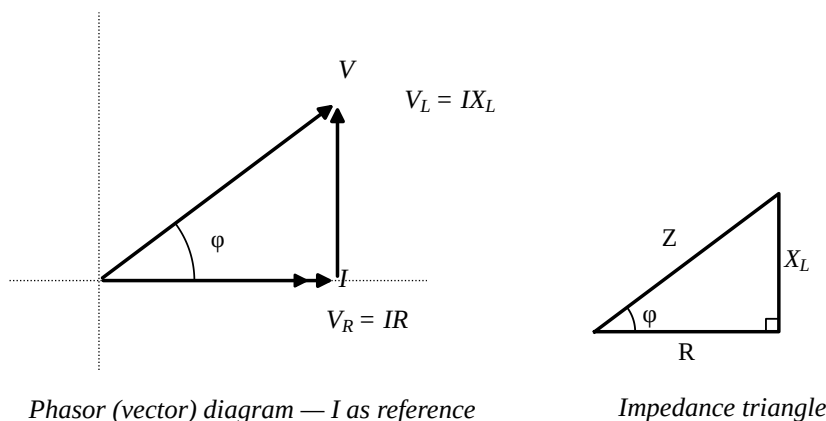
Q.3

a) R-L series circuit — phasor diagram, impedance triangle and equations.

4 M



R-L series circuit



Phasor (vector) diagram — I as reference

Impedance triangle

- Same current I flows through R and L . $V_R = IR$ is in phase with I ; $V_L = IX_L$ leads I by 90° .
- $V = \sqrt{(V_R^2 + V_L^2)}$; $Z = \sqrt{(R^2 + X_L^2)}$; $\tan \phi = X_L/R$; $\cos \phi = R/Z$ (lagging).

Equations: $v = V_m \sin \omega t$ and $i = I_m \sin(\omega t - \phi)$, where $I_m = V_m/Z$ and $\phi = \tan^{-1}(X_L/R)$. Current lags voltage by ϕ .

(Phasor diagram 1 M, impedance triangle 1 M, equations 2 M)

b) Series resonance vs parallel resonance.

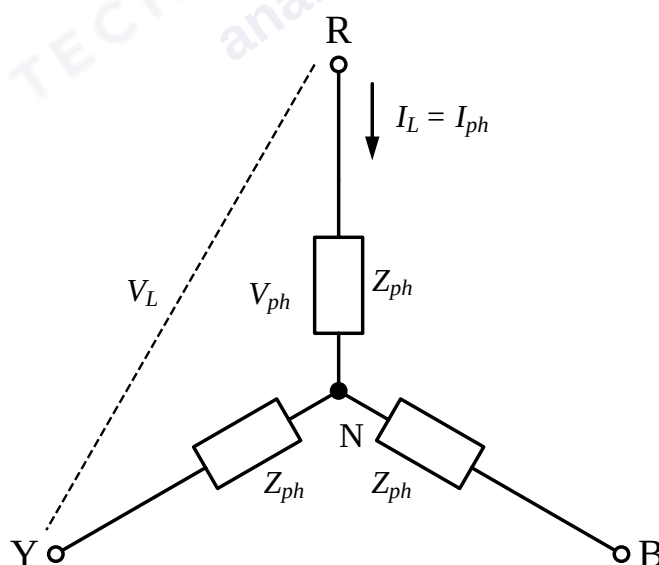
4 M

Point	Series resonance	Parallel resonance
Impedance at resonance	Minimum, $Z = R$	Maximum, $Z_D = L/CR$ (dynamic impedance)
Current at resonance	Maximum, $I = V/R$	Minimum, $I = V/Z_D = VCR/L$
Magnification	Voltage magnification: $V_L = V_C = QV$	Current magnification: $I_C = QI$
Resonant frequency	$f_r = 1/(2\pi\sqrt{LC})$	$f_r = (1/2\pi)\sqrt{(1/LC - R^2/L^2)}$

(Each point 1 M)

c) Star load $(12 + j16) \Omega$ per phase on 400 V.

4 M



Balanced star connected load, $Z_{ph} = (12 + j16) \Omega$

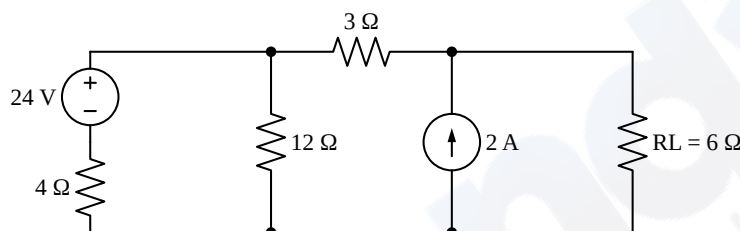
1. Star connection: $V_{ph} = V_L/\sqrt{3} = 400/\sqrt{3} = \mathbf{230.94\text{ V}}$
2. Impedance per phase $Z_{ph} = (12 + j16)\ \Omega$; $|Z_{ph}| = \sqrt{(12^2 + 16^2)} = \mathbf{20\ \Omega}$
3. Phase current $I_{ph} = V_{ph}/Z_{ph} = 230.94/20 = \mathbf{11.547\text{ A}}$
4. Line current $I_L = I_{ph} = \mathbf{11.547\text{ A}}$ (star)
5. Power factor $\cos \phi = R_{ph}/Z_{ph} = 12/20 = \mathbf{0.6\text{ lagging}}$
6. Total active power $P = \sqrt{3} V_L I_L \cos \phi = \sqrt{3} \times 400 \times 11.547 \times 0.6 = \mathbf{4800\text{ W}}$ (check: $3I_{ph}^2 R_{ph} = 4800\text{ W}$)
7. Total reactive power $Q = \sqrt{3} V_L I_L \sin \phi = \mathbf{6400\text{ VAR}}$
8. Total apparent power $S = \sqrt{3} V_L I_L = \mathbf{8000\text{ VA}}$

(V_{ph} and Z_{ph} 1 M, I_{ph} and I_L 2 M, p.f. 1 M, power 2 M)

$I_L = 11.547\text{ A}$, p.f. = 0.6 lagging, $P = 4800\text{ W}$, $Q = 6400\text{ VAR}$

d) Source transformation — current in R_L (Fig. No. 2).

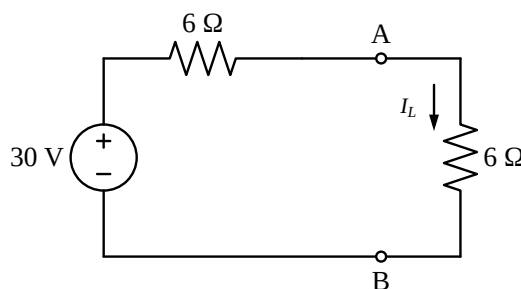
4 M



Given network

Reduce the network to the left of the load step by step using source transformation:

1. Voltage source 24 V in series with 4 Ω $\rightarrow$ current source $I = 24/4 = 6\text{ A}$ in parallel with 4 Ω .
2. 12 Ω resistor is in parallel with the source(s).
3. Combining the parallel elements: $I_{eq} = 6\text{ A}$, $R_{eq} = 3\ \Omega$ $\rightarrow$ converting back to voltage source:
 $V_{eq} = I_{eq} \times R_{eq} = 18\text{ V}$ in series with 3 Ω .
4. Adding series resistance 3 Ω : $V_{eq} = 18\text{ V}$ in series with $R_{eq} = 6\ \Omega$.
5. Convert again to current source: $18/6 = 3\text{ A}$ in parallel with 6 Ω .
6. Current source of 2 A is kept as it is (acting upwards).
7. Combining the parallel elements: $I_{eq} = 5\text{ A}$, $R_{eq} = 6\ \Omega$ $\rightarrow$ converting back to voltage source:
 $V_{eq} = I_{eq} \times R_{eq} = 30\text{ V}$ in series with 6 Ω .



Final equivalent circuit

Load current $I = 30/(6 + 6) = 2.5 \text{ A}$

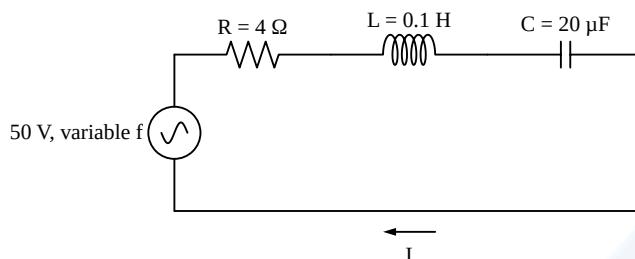
Current through $R_L = 6 \Omega = 2.5 \text{ A}$

(Each conversion step 1 M, final current 1 M)

Q.4

a) Series resonance: $R = 4 \Omega$, $L = 0.1 \text{ H}$, $C = 20 \mu\text{F}$, 50 V .

4 M



Series R-L-C circuit

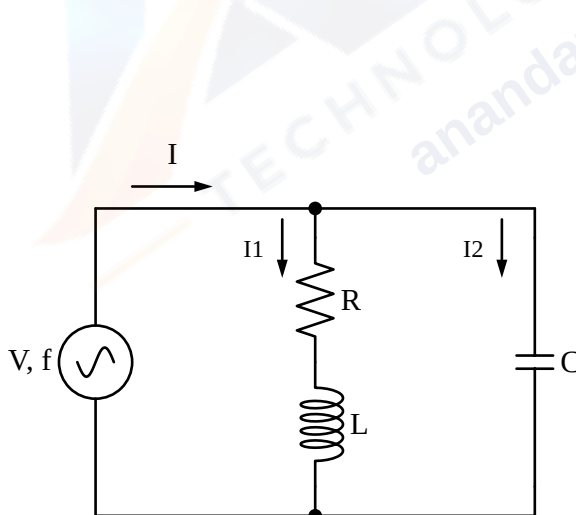
1. Resonant frequency $f_r = 1/(2\pi\sqrt{LC}) = 1/(2\pi\sqrt{0.1 \times 20 \times 10^{-6}}) = 112.54 \text{ Hz}$
2. At resonance $X_L = X_C = 2\pi f_r L = 70.711 \Omega$ and $Z = R = 4 \Omega$
3. Current at resonance $I_0 = V/R = 50/4 = 12.5 \text{ A}$
4. Quality factor $Q = X_L/R = (1/R)\sqrt{L/C} = 70.711/4 = 17.6777$
5. Bandwidth $BW = R/(2\pi L) = 4/(2\pi \times 0.1) = 6.366 \text{ Hz} (= f_r/Q)$

(f_r 1 M, I 1 M, Q/BW 1 M, voltages 1 M)

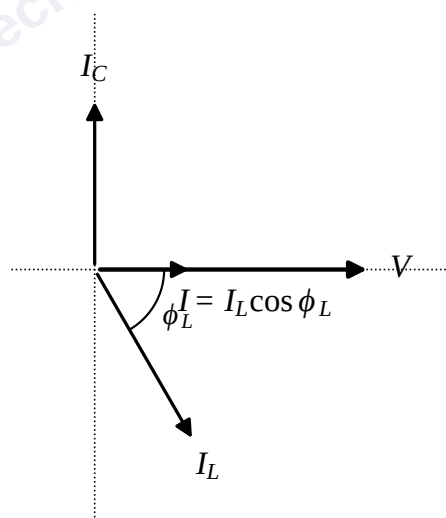
$f_r = 112.54 \text{ Hz}$, $I_0 = 12.5 \text{ A}$, $Q = 17.678$, $BW = 6.366 \text{ Hz}$

b) Current magnification in parallel resonance.

4 M



Coil (R-L) in parallel with capacitor C



Phasor diagram at resonance

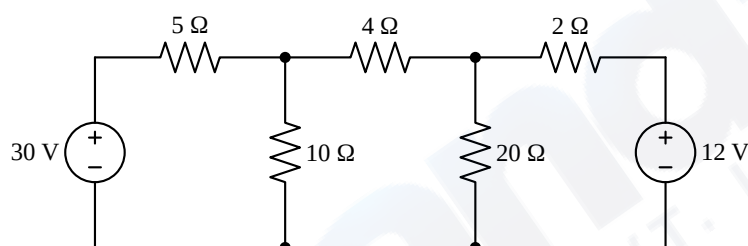
- Coil current $I_L = V/Z_L$, $Z_L = \sqrt{R^2 + X_L^2}$, lags V by ϕ_L ; capacitor current $I_C = V/X_C$ leads V by 90° .

- At resonance the supply current is in phase with V , so the reactive (quadrature) components cancel: $I_C = I_L \sin \phi_L$.
- $V/X_C = (V/Z_L)(X_L/Z_L) \Rightarrow Z_L^2 = X_L X_C = L/C \Rightarrow R^2 + (2\pi f_r L)^2 = L/C$
- $f_r = (1/2\pi)\sqrt{(1/LC - R^2/L^2)}$; if R is negligible, $f_r = 1/(2\pi\sqrt{LC})$.
- Supply current $I = I_L \cos \phi_L = (V/Z_L)(R/Z_L) = VR/Z_L^2 = VRC/L$.
- **Dynamic impedance $Z_D = V/I = L/(CR)$** — purely resistive and maximum; so line current is minimum.
- **Current magnification:** at resonance the current circulating in the L-C loop (I_C) is many times larger than the small supply current I .
- Current magnification $= I_C/I = (V/X_C)/(VCR/L) = \omega_r L/R$ (since $X_C \approx \omega_r L$) = **Q-factor of the coil**.
- Hence $I_C = Q \times I$; e.g. with $Q = 20$ and $I = 0.5$ A, $I_C \approx 10$ A circulates between L and C.

(Circuit and phasor 1 M, derivation of I 1 M, current magnification 2 M)

c) Nodal analysis — current in 4 Ω (Fig. No. 3).

4 M



Node voltages marked w.r.t. bottom reference node

Take the bottom line as reference node (0 V). Unknown node voltage(s): V_1, V_2 . Applying KCL at each node (sum of currents leaving the node = 0):

At node V_1 : $V_1/10 + (V_1 - 30)/5 + (V_1 - V_2)/4 = 0$

At node V_2 : $V_2/20 + (V_2 - V_1)/4 + (V_2 - 12)/2 = 0$

Simplifying:

$$11 V_1 - 5 V_2 = 120 \quad \dots(1)$$

$$-5 V_1 + 16 V_2 = 120 \quad \dots(2)$$

Solving: $V_1 = 16.6887$ V, $V_2 = 12.7152$ V

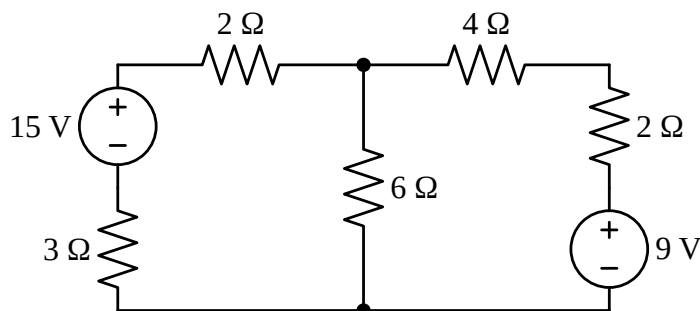
Current in 4 Ω resistor (from left node to right node) $= (V_1 - V_2)/4 = (16.6887 - 12.7152)/4 = 0.9934$ A

I = 0.9934 A, flowing from left to right through 4 Ω resistor

(KCL equations 2 M, solution 1 M, answer 1 M)

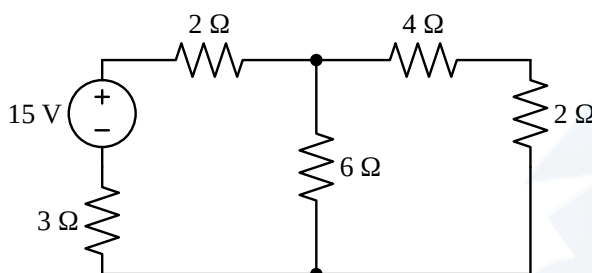
d) Superposition — current in 6 Ω (Fig. No. 4).

4 M



Given network

Step 1: 15 V source acting alone (other voltage source short-circuited):

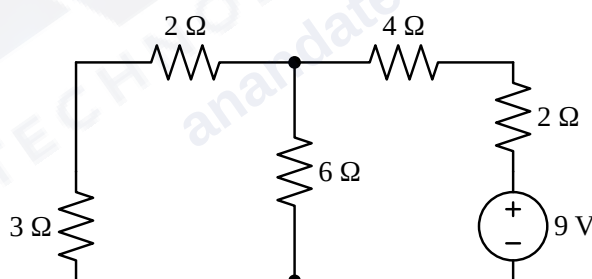


15 V source acting alone

- $4 + 2 = 6\ \Omega$ (series)
- $6 \parallel 6 = (6 \times 6)/(6 + 6) = 3\ \Omega$
- $2 + 3 = 5\ \Omega$ (series)
- Current supplied by 15 V source = $15/(3 + 5) = 1.875\text{ A}$
- Current in the required branch = $1.875 \times 6/(6 + 6) = 0.9375\text{ A}$

I_1' in 6 Ω = 0.9375 A downward

Step 2: 9 V source acting alone (other voltage source short-circuited):



9 V source acting alone

- $2 + 3 = 5\ \Omega$ (series)
- $6 \parallel 5 = (6 \times 5)/(6 + 5) = 2.727\ \Omega$
- $4 + 2.727 = 6.727\ \Omega$ (series)
- Current supplied by 9 V source = $9/(2 + 6.727) = 1.0312\text{ A}$
- Current in the required branch = $1.0312 \times 5/(5 + 6) = 0.4688\text{ A}$

I_2' in 6 Ω = 0.4688 A downward

Total current (algebraic sum, taking downward as positive):

Source acting	Current in 6 Ω
15 V source	0.9375 A downward
9 V source	0.4688 A downward
Total	1.4062 A downward

Current through 6 Ω = 1.4062 A (downward)

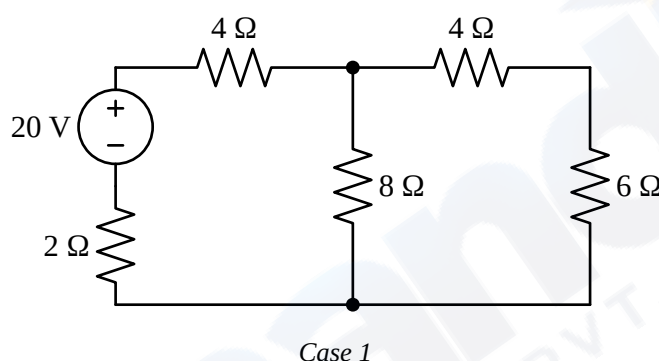
(Each source acting alone 2 M each, total 2 M)

e) Reciprocity theorem — statement and verification (Fig. No. 5).

4 M

In any linear, bilateral, passive network containing a single source, if an emf E in branch 1 produces a current I in branch 2, then the same emf E placed in branch 2 will produce the **same current I** in branch 1. The ratio E/I (transfer resistance) remains the same when the positions of source and ammeter are interchanged.

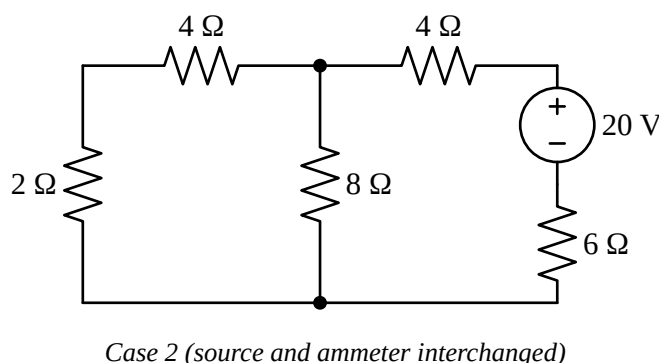
Case 1: Source in source (2 Ω) branch, current measured in 6 Ω branch.



- $4 + 6 = 10 \Omega$ (series)
- $8 \parallel 10 = (8 \times 10)/(8 + 10) = 4.444 \Omega$
- $4 + 4.444 = 8.444 \Omega$ (series)
- Current supplied by 20 V source = $20/(2 + 8.444) = 1.9149 \text{ A}$
- Current passing on to the next section (current divider) = $1.9149 \times 8/(8 + 10) = 0.8511 \text{ A}$

Current in 6 Ω branch $I_1 = \mathbf{0.8511 \text{ A}}$

Case 2: Source shifted to 6 Ω branch, current measured in source (2 Ω) branch.



- $4 + 2 = 6 \Omega$ (series)
- $8 \parallel 6 = (8 \times 6)/(8 + 6) = 3.429 \Omega$

- $4 + 3.429 = 7.429 \Omega$ (series)
- Current supplied by 20 V source = $20/(6 + 7.429) = 1.4894 \text{ A}$
- Current passing on to the next section (current divider) = $1.4894 \times 8/(8 + 6) = 0.8511 \text{ A}$

Current in source (2Ω) branch $I_2 = \mathbf{0.8511 \text{ A}}$

Since $I_1 = I_2 = 0.8511 \text{ A}$, the transfer resistance $E/I = 20/0.8511 = 23.5 \Omega$ is the same in both cases.

Hence reciprocity theorem is verified.

Comment: The network is linear, bilateral and contains a single source, so interchanging the source and the response (ammeter) does not change the current.

(Statement 1 M, case 1: 1 M, case 2: 1 M, verification 1 M)

Q.5

a) Graphical representation of series resonance.

6 M

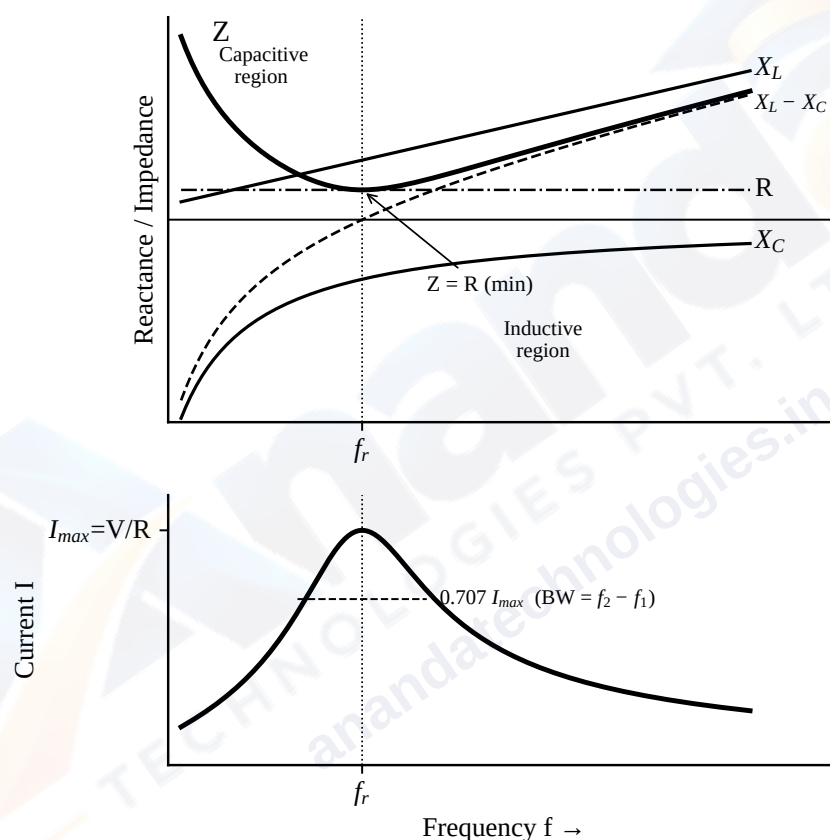


Fig.: Variation of X_L , X_C , X , R , Z (top) and current I (bottom) with frequency in series R-L-C circuit

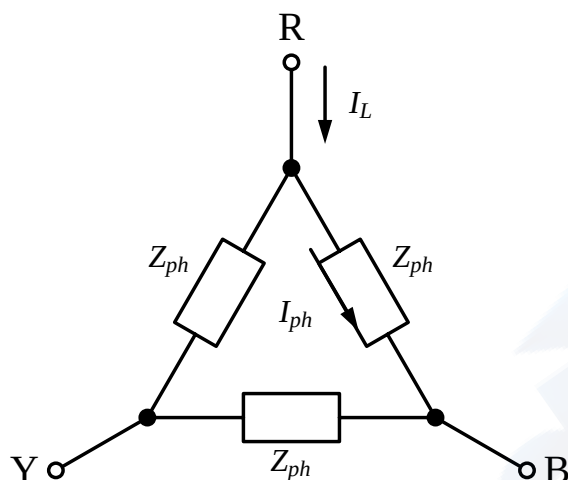
- $X_L = 2\pi fL$: increases linearly with frequency (straight line through origin).
- $X_C = 1/(2\pi fC)$: inversely proportional to frequency (rectangular hyperbola, drawn negative).
- Net reactance $X = X_L - X_C$: negative (capacitive) below f_r , zero at f_r , positive (inductive) above f_r .
- R : independent of frequency (horizontal line).
- Impedance $Z = \sqrt{R^2 + X^2}$: very high at low frequency, **minimum** = R at f_r , increases again above f_r .

- **Current $I = V/Z$:** maximum $I_{\max} = V/R$ at f_r and falls on both sides; the bell shaped curve is the resonance curve.
- **$f_r = 1/(2\pi\sqrt{LC})$:** resonant frequency where $X_L = X_C$; p.f. = 1.
- **Bandwidth** = $f_2 - f_1$ (half-power frequencies where $I = 0.707 I_{\max}$) = $R/(2\pi L)$.

(Graph 3 M, explanation of terms 3 M)

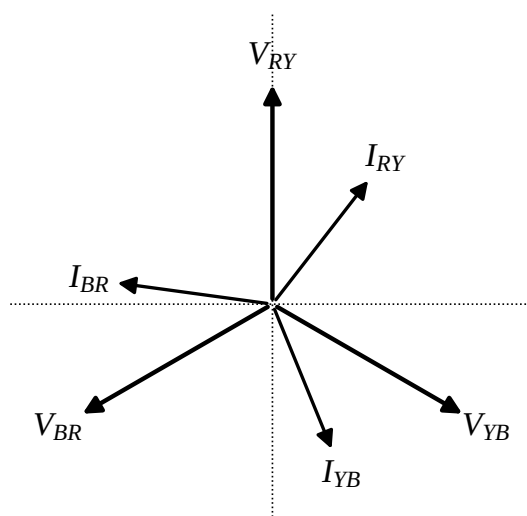
b) Delta load: $R = 20 \Omega$, $L = 0.1 \text{ H}$, $C = 200 \mu\text{F}$ per phase, 415 V.

6 M



Balanced delta connected load, $Z_{ph} = (20 + j15.5) \Omega$

1. $X_L = 2\pi fL = 2\pi \times 50 \times 0.1 = 31.416 \Omega$
2. $X_C = 1/(2\pi fC) = 1/(2\pi \times 50 \times 200 \times 10^{-6}) = 15.915 \Omega$
3. $Z_{ph} = R + j(X_L - X_C) = (20 + j15.5) \Omega = 25.303 \angle 37.78^\circ \Omega$
4. Delta connection: $V_{ph} = V_L = 415 \text{ V}$
5. Impedance per phase $Z_{ph} = (20 + j15.5) \Omega$; $|Z_{ph}| = \sqrt{(20^2 + 15.5^2)} = 25.303 \Omega$
6. Phase current $I_{ph} = V_{ph}/Z_{ph} = 415/25.303 = 16.4009 \text{ A}$
7. Line current $I_L = \sqrt{3} I_{ph} = \sqrt{3} \times 16.4009 = 28.4073 \text{ A}$ (delta)
8. Power factor $\cos \phi = R_{ph}/Z_{ph} = 20/25.303 = 0.7904$ lagging
9. Total active power $P = \sqrt{3} V_L I_L \cos \phi = \sqrt{3} \times 415 \times 28.4073 \times 0.7904 = 16139.45 \text{ W}$ (check: $3I_{ph}^2 R_{ph} = 16139.45 \text{ W}$)
10. Total reactive power $Q = \sqrt{3} V_L I_L \sin \phi = 12508.42 \text{ VAR}$
11. Total apparent power $S = \sqrt{3} V_L I_L = 20419.17 \text{ VA}$



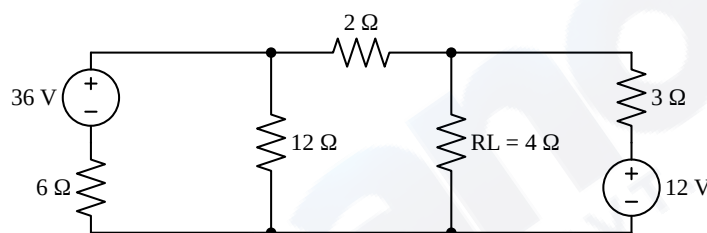
Phasor diagram: phase currents lag phase voltages by 37.78° ($V_L = V_{ph}$)

(V_{ph} and Z_{ph} 1 M, I_{ph} and I_L 2 M, p.f. 1 M, power 2 M)

$Z_{ph} = 25.303 \Omega$, $I_{ph} = 16.401 \text{ A}$, $I_L = 28.407 \text{ A}$, p.f. = 0.7904 lagging, $P = 16.139 \text{ kW}$

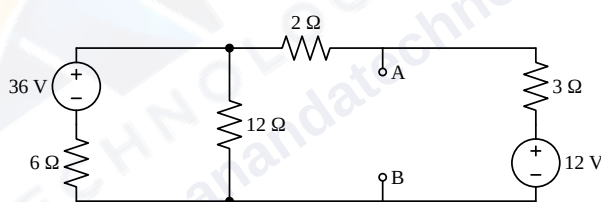
c) Thevenin's theorem — current in $R_L = 4 \Omega$ (Fig. No. 6).

6 M



Given network

Step 1: Find V_{Th} . Remove $R_L = 4 \Omega$ and mark terminals A-B:



Load removed (A-B open)

Take the bottom line as reference node (0 V). Unknown node voltage(s): V_1 , V_2 . Applying KCL at each node (sum of currents leaving the node = 0):

At node V_1 : $(V_1 - 36)/6 + V_1/12 + (V_1 - V_2)/2 = 0$

At node V_2 : $(V_2 - 12)/3 + (V_2 - V_1)/2 = 0$

Simplifying:

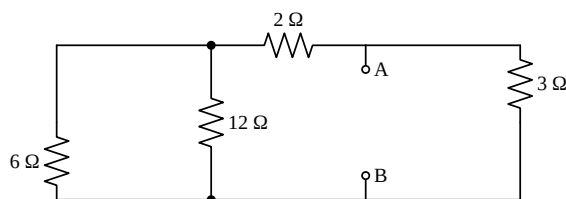
$$3V_1 - 2V_2 = 24 \quad \dots(1)$$

$$-3V_1 + 5V_2 = 24 \quad \dots(2)$$

Solving: $V_1 = 18.6667 \text{ V}$, $V_2 = 16 \text{ V}$

V_{Th} = voltage of the open-circuited terminal node = 16 V

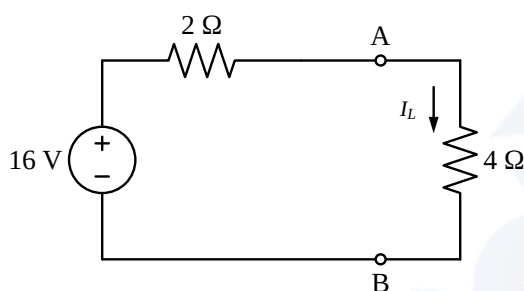
Step 2: Find R_{Th} . Replace voltage sources by short circuits and current sources by open circuits:



Sources replaced by internal resistances

- $12 \parallel 6 = (12 \times 6)/(12 + 6) = 4 \Omega$
- $2 + 4 = 6 \Omega$ (series)
- $R_{Th} = 6 \parallel 3 = (6 \times 3)/(6 + 3) = 2 \Omega$

Step 3: Thevenin equivalent circuit and load current:



Thevenin equivalent with load

$$I_L = V_{Th}/(R_{Th} + R_L) = 16/(2 + 4) = \mathbf{2.6667 \text{ A}}$$

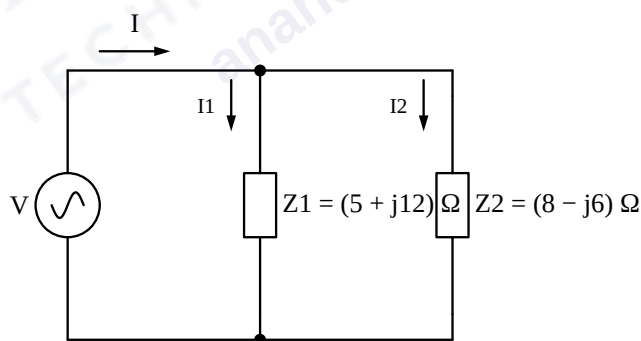
Current through $R_L = 4 \Omega = 2.6667 \text{ A}$ (downward)

(V_{Th} 2 M, R_{Th} 2 M, equivalent circuit and I_L 2 M)

Q.6

a) Parallel impedances $(5 + j12) \Omega$ and $(8 - j6) \Omega$, total current 20 A.

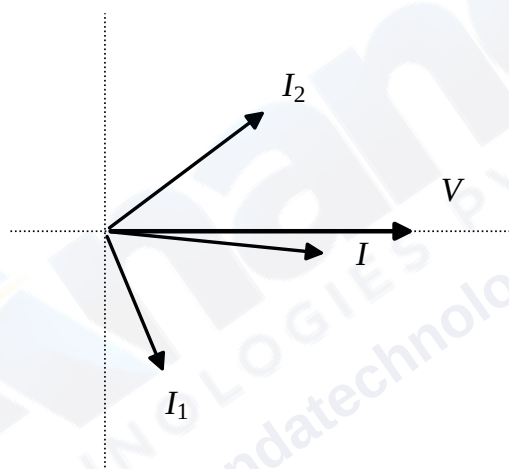
6 M



Circuit diagram

1. $Z_1 = (5 + j12) \Omega = 13 \angle 67.38^\circ \Omega$
2. $Z_2 = (8 - j6) \Omega = 10 \angle -36.87^\circ \Omega$
3. $Z_1 + Z_2 = (13 + j6) = 14.318 \angle 24.78^\circ$

4. Equivalent impedance $Z = Z_1 Z_2 / (Z_1 + Z_2) = (13 \angle 67.38^\circ)(10 \angle -36.87^\circ) / (14.318 \angle 24.78^\circ) = \mathbf{9.08 \angle 5.74^\circ \Omega} = (9.034 + j0.907) \Omega$
5. Supply voltage $V = I \times |Z| = 20 \times 9.08 = \mathbf{181.592 \text{ V}}$ (taking V as reference, $V = 181.592 \angle 0^\circ$ V)
6. Branch current $I_1 = V/Z_1 = 181.592 \angle 0^\circ / 13 \angle 67.38^\circ = \mathbf{13.969 \angle -67.38^\circ \text{ A}} = (5.373 - j12.894) \text{ A}$
7. Branch current $I_2 = V/Z_2 = 181.592 \angle 0^\circ / 10 \angle -36.87^\circ = \mathbf{18.159 \angle 36.87^\circ \text{ A}} = (14.527 + j10.896) \text{ A}$
8. Total current $I = I_1 + I_2 = (19.9 - j1.999) \text{ A} = \mathbf{20 \angle -5.74^\circ \text{ A}}$
1. p.f. of branch 1 = $\cos \phi_1 = R_1/|Z_1| = 5/13 = \mathbf{0.3846 \text{ lagging}}$
2. p.f. of branch 2 = $\cos \phi_2 = R_2/|Z_2| = 8/10 = \mathbf{0.8 \text{ leading}}$
3. Overall p.f. = $\cos(\text{angle between } V \text{ and } I) = \cos 5.74^\circ = \mathbf{0.995 \text{ lagging}}$
4. Power taken by branch 1: $P_1 = I_1^2 R_1 = 13.9686^2 \times 5 = \mathbf{975.61 \text{ W}}$
5. Power taken by branch 2: $P_2 = I_2^2 R_2 = 18.1592^2 \times 8 = \mathbf{2638.05 \text{ W}}$
6. Total power $P = P_1 + P_2 = 3613.66 \text{ W}$ (check: $VI \cos \phi = 181.592 \times 20 \times 0.995 = 3613.66 \text{ W}$ ✓)



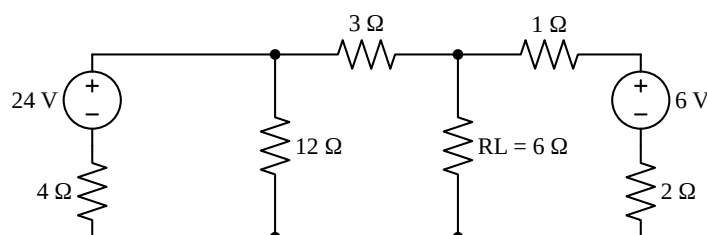
Phasor diagram (V as reference)

(Branch currents 2 M, total current/p.f. 2 M, power/phasor diagram 2 M)

V = 181.59 V; P₁ = 975.6 W, P₂ = 2638 W; p.f. combination = 0.995 lagging

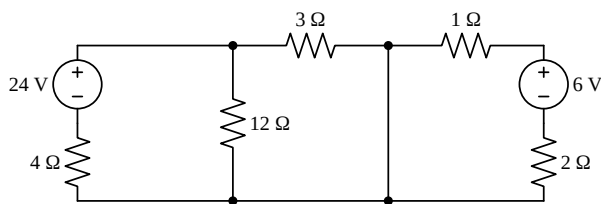
b) Norton's theorem — current in R_L = 6 Ω (Fig. No. 7).

6 M



Given network

Step 1: Find I_N. Remove R_L = 6 Ω and short-circuit its terminals:



Load terminals short-circuited

Take the bottom line as reference node (0 V). Unknown node voltage(s): V_1 , V_3 . Applying KCL at each node (sum of currents leaving the node = 0):

At node V_1 : $(V_1 - 24)/4 + V_1/12 + V_1/3 = 0$

At node V_3 : $(V_3 - 6)/2 + V_3/1 = 0$

Simplifying:

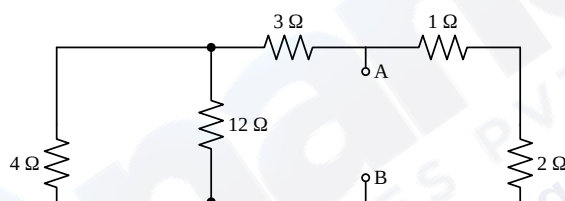
$$2 V_1 = 18 \quad \dots(1)$$

$$3 V_3 = 6 \quad \dots(2)$$

Solving: $V_1 = 9 \text{ V}$, $V_3 = 2 \text{ V}$

Short-circuit current (sum of currents flowing into the shorted terminals): $I_N = I_{SC} = (V_1)/3 + (V_3)/1 = (9)/3 + (2)/1 = 5 \text{ A}$

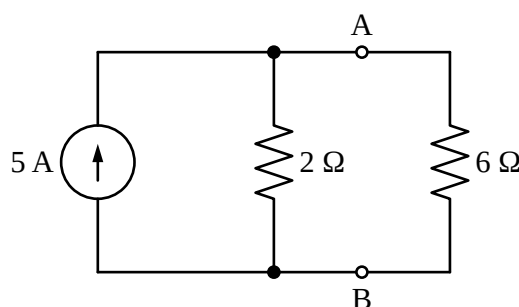
Step 2: Find R_N . Open the load terminals and replace sources by internal resistances:



Sources replaced by internal resistances

- $12 \parallel 4 = (12 \times 4)/(12 + 4) = 3 \Omega$
- $3 + 3 = 6 \Omega$ (series)
- $1 + 2 = 3 \Omega$ (series)
- $R_N = 6 \parallel 3 = (6 \times 3)/(6 + 3) = 2 \Omega$

Step 3: Norton equivalent and load current:



Norton equivalent with load

By current divider: $I_L = I_N \times R_N/(R_N + R_L) = 5 \times 2/(2 + 6) = 1.25 \text{ A}$

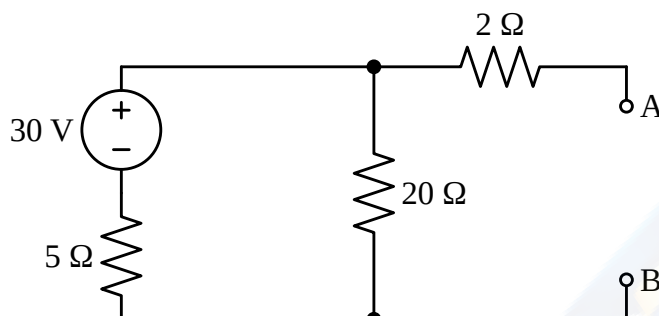
Current through $R_L = 6 \Omega = 1.25 \text{ A}$ (downward)

($I_N 2 \text{ M}$, $R_N 2 \text{ M}$, equivalent circuit and $I_L 2 \text{ M}$)

c) Maximum power transfer — R_L and $P_{\max}$ (Fig. No. 8).

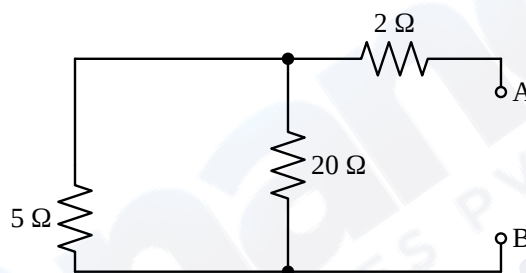
6 M

A resistive load connected to a DC network receives **maximum power** when the load resistance is equal to the Thevenin's (internal) resistance of the network as seen from the load terminals: $R_L = R_{Th}$.



Given network (variable load across A-B)

Step 1: R_{Th} (sources replaced by internal resistances):



Sources killed

- $20 \parallel 5 = (20 \times 5)/(20 + 5) = 4 \Omega$
- $2 + 4 = 6 \Omega$ (series)
- $R_{Th} = 6 \Omega$

Step 2: V_{Th} (open-circuit voltage across A-B):

Take the bottom line as reference node (0 V). Unknown node voltage(s): V_1, V_2 . Applying KCL at each node (sum of currents leaving the node = 0):

At node V_1 : $(V_1 - 30)/5 + V_1/20 + (V_1 - V_2)/2 = 0$

At node V_2 : $(V_2 - V_1)/2 = 0$

Simplifying:

$$3 V_1 - 2 V_2 = 24 \quad \dots(1)$$

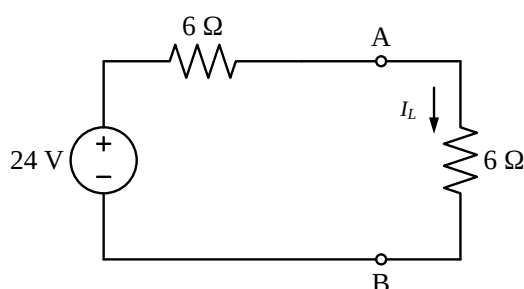
$$- V_1 + V_2 = 0 \quad \dots(2)$$

Solving: $V_1 = 24 \text{ V}$, $V_2 = 24 \text{ V}$

V_{Th} = voltage of the open-circuited terminal node = 24 V

Step 3: For maximum power transfer, $R_L = R_{Th} = 6 \Omega$

$$P_{\max} = V_{Th}^2 / (4R_L) = 24^2 / (4 \times 6) = 24 \text{ W}$$



Thevenin equivalent with $R_L = R_{Th}$

$$R_L = 6 \Omega, P_{\max} = 24 \text{ W}$$

($R_{Th} 2 M, V_{Th} 2 M, R_L$ and $P_{\max} 2 M$)

Note: This is a **model question paper prepared by Ananda Technologies** only for practice and exam preparation, based on the pattern of previous MSBTE question papers and the K-scheme syllabus. It is **not an official MSBTE paper**, and it does **not** mean that these questions will come in the exam. Answers follow standard textbook points; marks shown are indicative. Free for students — anandatechnologies.in