Important Instructions to examiners:

1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.

2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.

3) The language errors such as grammatical, spelling errors should not be given more importance (Not applicable for subject English and Communication Skills).

4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.

5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate’s answers and model answer.

6) In case of some questions credit may be given by judgement on part of examiner of relevant answer based on candidate’s understanding.

7) For programming language papers, credit may be given to any other program based on equivalent concept.
1 Attempt any **FIVE** of the following: 10

1 a) Define active power and reactive power for RLC series circuit.
   **Ans:**
   **Active Power (P):**
   Active power (P) is given by the product of voltage, current and the cosine of the phase angle between voltage and current.
   Unit: watt (W) or kilo-watt (kW) or Mega-watt (MW).
   \[ P = VI \cos \phi = I^2 R \text{ watt} \]

   **Reactive Power (Q):**
   Reactive power (Q) is given by the product of voltage, current and the sine of the phase angle between voltage and current.
   Unit: volt-ampere-reactive (VAr), or kilo-volt-ampere-reactive (kVAr) or Mega-volt-ampere-reactive (MVAr)
   \[ Q = VI \sin \phi = I^2 X \text{ volt-amp-reactive.} \]

1 b) Draw impedance triangle and voltage triangle for RL series circuit.
   **Ans:**

   ![Impedance Triangle](image1)
   ![Voltage triangle](image2)

1 c) Define susceptance and admittance for parallel circuit.
   **Ans:**
   **Admittance (Y):**
   Admittance is defined as the ability of the circuit to carry (admit) alternating current through it. It is the reciprocal of impedance Z, i.e. \( Y = \frac{1}{Z} \).
   For parallel circuit consisting two branches having impedances \( Z_1 \) and \( Z_2 \) in parallel, the equivalent impedance of parallel combination is given by,
   \[ \frac{1}{Z} = \frac{1}{Z_1} + \frac{1}{Z_2} \]
   \[ Y = Y_1 + Y_2 \]
   \( Y_1 \) and \( Y_2 \) are the admittances of the two branches respectively.
   If the equivalent impedance is expressed as \( Z = R + jX \), then the admittance is obtained as,
   \[ Y = \frac{1}{Z} = \frac{1}{R + jX} = \frac{R - jX}{(R + jX)(R - jX)} = \frac{R - jX}{R^2 + X^2} \]
   \[ \therefore Y = \frac{R}{R^2 + X^2} - j \frac{X}{R^2 + X^2} = G - jB \]

   **Susceptance (B):**
Susceptance is defined as the imaginary part of the admittance.
It is expressed as,

\[ B = \frac{X}{R^2 + X^2} \]

In DC circuit, the reactance is absent, hence \( X = 0 \) and susceptance equals to zero.

1 d) Define quality factor for parallel resonance and write its mathematical expression.

**Ans:**

**Quality Factor of Parallel AC Circuit at resonance:**
The quality factor or Q-factor of parallel circuit is defined as the ratio of the current circulating between two branches of the circuit to the current taken by the parallel circuit from the source.
It is the current magnification in parallel circuit.

**Formula:**

Quality factor (Q-factor) = Current magnification = \( \frac{1}{R} \sqrt{\frac{L}{C}} \)

Where, \( R \) is the resistance of an inductor in \( \Omega \),
\( L \) is the inductance of an inductor in henry,
\( C \) is capacitance of capacitor in farad,

1 e) Draw sinusoidal waveform of 3 phase emf and indicate the phase sequence.

**Ans –**

\[ \text{Phase sequence is R-Y-B.} \]

1 f) Write the procedure of converting a given current source into voltage source.

**Ans:**

**Conversion of current source into equivalent voltage source:**
Let \( I_S \) be the practical current source magnitude and
\( Z_I \) be the internal parallel impedance.
\( V_S \) be the equivalent practical voltage source magnitude and
\( Z_V \) be the internal series impedance of the voltage source.

\[ V_{OC} = V_S = I_S \times Z_I \]

The open circuit terminal voltage of current source is \( V_{OC} = I_S \times Z_I \)
The open circuit terminal voltage of voltage source is \( V_{OC} = V_S \)
Therefore, we get \( V_S = I_S \times Z_I \) ..............................(1)

The short circuit output current of current source is \( I_{SC} = I_S \)
The short circuit output current of voltage source is \( I_{SC} = V_S / Z_V \)
Therefore, we get \( I_S = V_S / Z_V \) ..............................(2)

On comparing eq. (1) and (2), it is clear that \( Z_I = Z_V = Z \) .............. ......(3)
Thus the internal impedance of both the sources is same, and the magnitudes of the source voltage and current are related by Ohm’s law, \( V_S = I_S \times Z_I \)

1 g) State superposition theorem applied to the d.c. circuits.
Ans:
**Superposition Theorem applied to D.C. circuits:**
Superposition theorem states that in any linear, bilateral, multisource network, the response (voltage across any element or current through any element) of any branch is equal to the algebraic sum of the responses produced in it with each source acting alone, while the other sources are replaced by their internal resistances.

OR

**Any other equivalent valid statement**

2 Attempt any THREE of the following:

Ans –

2 b) Two circuits the impedance of which are given by \( Z_1 = 6 + j8 \) ohm and \( Z_2 = 8 – j6 \) ohm are connected in parallel. If the applied voltage to the combination is 100V, Find:
(i) Current and power factor at each branch.
(ii) Overall current and power factor of the combination.
(iii) Power consumed by each impedance. Draw phasor diagram.
Ans:
Data given:

\[ Z_1 = 6 + j8 = 10 \angle 53.13^\circ \Omega \]
\[ Z_2 = 8 - j6 = 10 \angle -36.87^\circ \Omega \]
\[ V = 100 + j0 = 100 \angle 0^\circ \text{ volt} \]

(i) **Current and power factor at each branch:**

Current of branch 1: \[ I_1 = \frac{V}{Z_1} = \frac{100}{10 \angle 53.13^\circ} = 10 \angle -53.13^\circ \text{ A} \]

Power factor of branch 1: \[ \cos(53.13^\circ) = 0.6 \text{ lagging} \]

Current of branch 2: \[ I_2 = \frac{V}{Z_2} = \frac{100}{10 \angle -36.87^\circ} = 10 \angle 36.87^\circ \text{ A} \]

Power factor of branch 2: \[ \cos(36.87^\circ) = 0.8 \text{ leading} \]

(ii) **Overall current and power factor of the combination:**

Over all current \[ I = I_1 + I_2 = 10 \angle -53.13^\circ + 10 \angle 36.87^\circ = 6 - j8 + 8 + j6 = 14 - j2 = 14 \angle -8.13^\circ \text{ A} \]

Overall power factor: \[ \cos(8.13^\circ) = 0.98 \text{ lagging} \]

(iii) **Power consumed by each impedance:**

Power consumed by \[ Z_1 : \] \[ V.I_1 \cos \phi_1 = (100)(10)(\cos(53.13^\circ)) = 600 \text{ W} \] \[ \text{OR} \]
\[ I_1^2R_1 = (10)^2(6) = 600 \text{ W} \]

Power consumed by \[ Z_2 : \] \[ V.I_2 \cos \phi_2 = (100)(10)(\cos(36.87^\circ)) = 800 \text{ W} \] \[ \text{OR} \]
\[ I_2^2R_2 = (10)^2(8) = 800 \text{ W} \]

(iv) **Phasor diagram:**

2 c) State any four advantages of polyphase circuits over single phase circuit.

**Ans:**

**Advantages of polyphase (3-phase) circuits over Single-phase circuits:**

i) Three-phase transmission is more economical than single-phase transmission. It requires less copper material. \[ 1 \text{ mark for each of any four} \]

ii) Parallel operation of 3-phase alternators is easier than that of single-phase alternators.

iii) Single-phase loads can be connected along with 3-ph loads in a 3-ph system. \[ = 4 \text{ marks} \]
iv) Instead of pulsating power of single-phase supply, constant power is obtained in 3-phase system.

v) Three-phase induction motors are self-starting. They have high efficiency, better power factor and uniform torque.

vi) The power rating of 3-phase machine is higher than that of 1-phase machine of the same size.

vii) The size of 3-phase machine is smaller than that of 1-phase machine of the same power rating.

viii) For same power rating, three-phase motors are cheaper than the single-phase motors.

2 d) Using mesh analysis, find loop currents $I_1$ and $I_2$ in the circuit, as shown in fig. no. 1

![Circuit Diagram](image)

**Ans:**

**Mesh Analysis:**

i) There are two meshes in the network.

![Mesh Diagram](image)

ii) Mesh currents $I_1$ and $I_2$ are marked clockwise as shown.

iii) By tracing mesh 1 clockwise, KVL equation is,

\[
10 - 2I_1 - 3(I_1 - I_2) = 0
\]

\[
5I_1 - 3I_2 = 10 \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 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\ldots \lo
3 Attempt any THREE of the following: 12

3 a) Derive the expression for resonance frequency for a RLC series circuit.
Ans:

Resonant Frequency of Series RLC Circuit:
In RLC series circuit the resonance occurs when the inductive reactance \( X_L \) becomes equal to the capacitive reactance \( X_C \).
Inductive reactance is given by \( X_L = 2\pi f L \)

Capacitive reactance is given by \( X_C = \frac{1}{2\pi f C} \)
The inductive reactance \( X_L \) becomes equal to capacitive reactance \( X_C \) only at one particular frequency, which is known as resonant frequency and it is denoted by \( f_r \).

Hence at resonance,

\[ X_L - X_C = 0 \]
\[ X_L = X_C \]

\[ 2\pi f_r L = \frac{1}{2\pi f_r C} \]

Rearranging above equation,

We get,

\[ (f_r)^2 = \frac{1}{4\pi^2 LC} \]

\[ f_r = \frac{1}{2\pi\sqrt{LC}} \text{ Hz} \quad \text{OR} \quad \omega_r = \frac{1}{\sqrt{LC}} \text{ rad/sec} \]

3 b) Compare series resonance to parallel resonance on the basis of
(i) Resonant frequency (ii) Impedance (iii) Current (iv) Magnification
Ans:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Series Resonant Circuit</th>
<th>Parallel Resonant Circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resonant frequency</td>
<td>( f_r = \frac{1}{2\pi\sqrt{LC}} \text{ Hz} )</td>
<td>( f_r = \frac{1}{2\pi\sqrt{LC}} \text{ Hz} )</td>
</tr>
<tr>
<td>Impedance</td>
<td>Minimum ( Z = R ) ohms</td>
<td>Maximum ( Z = \frac{L}{CR} ) ( \Omega )</td>
</tr>
<tr>
<td>Current</td>
<td>Maximum ( I = \frac{V}{R} ) ( \Omega )</td>
<td>Minimum ( I = \frac{V}{CR} ) ( \Omega )</td>
</tr>
<tr>
<td>Magnification</td>
<td>Voltage magnification</td>
<td>Current magnification</td>
</tr>
</tbody>
</table>

3 c) Compare star and delta connection. (Any four points)
Ans:
### Model Answers

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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Star Connection</th>
<th>Delta Connection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic definition</td>
<td>One terminal of each of the three branches are connected together to form a common point. Such a connection is known as Star Connection.</td>
<td>The three branches of the network are connected in such a way that it forms a closed loop. Such a connection is known as Delta Connection.</td>
</tr>
<tr>
<td>Connection of terminals</td>
<td>The similar ends of the three coils are connected together to form a common point.</td>
<td>The end of each coil is connected to the starting point of the other coil that means the opposite terminals of the coils are connected together to form a closed loop.</td>
</tr>
<tr>
<td>Neutral point</td>
<td>Neutral or the star point exists in the star connection.</td>
<td>Neutral point does not exist in the delta connection.</td>
</tr>
<tr>
<td>Relation between line and phase current</td>
<td>Line current is equal to the Phase current.</td>
<td>Line current is equal to $\sqrt{3}$ times the Phase Current.</td>
</tr>
<tr>
<td>Relation between line and phase voltage</td>
<td>Line voltage is equal to $\sqrt{3}$ times the Phase Voltage.</td>
<td>Line voltage is equal to the Phase voltage.</td>
</tr>
</tbody>
</table>

Diagram

3) d) By using nodal analysis, calculate the current in $110\Omega$ resistor and p.d. across $110\Omega$ resistor as shown in fig. no. 2
Ans: By applying KCL at node A, the node voltage equation can be written as:

\[
\frac{V_A - 10}{100} + \frac{V_A}{110} + \frac{V_A - (-20)}{50} = 0
\]

\[
V_A \left( \frac{1}{100} + \frac{1}{110} + \frac{1}{50} \right) - \left( \frac{10}{100} - \frac{20}{50} \right) = 0
\]

\[
V_A \left( \frac{0.0391}{0.0391} \right) - (-0.3) = 0
\]

\[
V_A = \frac{-0.3}{0.0391} = -7.67 \text{ volt}
\]

\[\therefore \text{ P. D. across 110}\Omega \text{ resistor is } V_A = -7.67 \text{ volt}
\]

(Terminal N is at higher potential than terminal A)

\[\therefore \text{ Current flowing through 110}\Omega \text{ is given by,}
\]

\[
l = \frac{V_A}{110} = -\frac{7.67}{110} = -0.0697A
\]

\[\therefore l = 0.0697A \text{ flowing from terminal N to A}
\]

3 e) Convert following circuit as shown in fig. no. 3 into Thevenin’s circuit across A & B.

Ans: Determination of Thevenin’s Equivalent Voltage Source (V_{Th}):
Thevenin’s equivalent voltage source $V_{Th}$ is the open circuit voltage across the load terminals A-B due to internal sources, as shown in the figure.

By tracing loop in anti-clockwise direction, the voltage equation can be written as:

$$24 - 4I - 4I - 12 = 0$$

Circuit current $I = (24-12)/8 = 1.5 \text{ A}$

The Thevenin’s equivalent voltage is given by,

$$V_{Th} = V_{OC} = 24 - 4I = 24 - 6 = 18 \text{ volt} \quad \text{OR}$$

$$= 12 + 4I = 12 + 6 = 18 \text{ volt}$$

**Determination of Thevenin’s Equivalent Resistance ($R_{Th}$):**

Thevenin’s equivalent resistance is the resistance seen between the open-circuited load terminals while looking back into the network, with internal independent voltage sources replaced by short-circuit and independent current sources replaced by open-circuit, as shown in the following figure.

$$R_{Th} = (4||4) = \frac{4 \times 4}{4 + 4} = 2 \text{ Ω}$$

**Thevenin’s Equivalent Circuit:**

$$V_{Th} = 18 \text{V}, \quad R_{Th} = 2 \text{ Ω}, \quad R_{L} = 5 \text{ Ω}$$

4 Attempt any THREE of the following.

4 a) A resistance of 100Ω, an inductance of 0.2 H and capacitance of 150 μF are connected in series across 230V, 50 Hz ac supply. Calculate the current drawn by the circuit, power factor of the circuit, its nature and power consumed by the circuit.

Ans:

**Given:** $R = 100 \text{ Ω}, \quad L = 0.2 \text{H}, \quad C = 150 \text{ μF} = 150 \times 10^{-6} \text{ F}, \quad V = 230 \text{V}, \quad f = 50 \text{ Hz}$

\[ R = 100 \text{ Ω}, \quad L = 0.2 \text{H}, \quad C = 150 \text{ μF} = 150 \times 10^{-6} \text{ F}, \quad V = 230 \text{V}, \quad f = 50 \text{ Hz} \]
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\[X_L = 2\pi f L = 2 \times \pi \times 50 \times 0.2 = 62.83 \, \Omega\]
\[X_C = \frac{1}{(2\pi f C)} = \frac{1}{(2\pi \times 50 \times 150 \times 10^{-6})} = 21.22 \, \Omega\]
Impedance \(Z = \sqrt{\left[R^2 + (X_L - X_C)^2\right]} = 108.31 \, \Omega\)  
\[= 100 + j(62.83 - 21.22) = 108.31 \angle 22.59^\circ \Omega\]  
(1) Total current \(I = \frac{V}{Z} = 230 \angle 0^\circ / 108.31 \angle 22.59^\circ = 2.123 - 22.59^\circ \, A\)  

(2) Power factor \(= \cos \Phi = \frac{R}{Z} = 100/108.31 = 0.923 \, \text{lagging} \)  
\[= \cos(22.59^\circ) = 0.923 \, \text{lagging}\]  

(3) Nature of power factor is \text{lagging}.

(4) \(P = I^2 R = 2.123^2 \times 100 = 450.7 \, \text{watt} \)  
\[P = V I \cos \Phi = 230 \times 2.123 \times 0.923 = 450.7 \, \text{watt}\]

4 b) Define: (i) Admittance (ii) Susceptance  
(iii) Conductance (iv) State the units of admittance and conductance

Ans:

(i) **Admittance (Y):**
Admittance is defined as the ability of the AC circuit to carry (admit) alternating current. It is also defined as reciprocal of impedance (Y).

\[\text{Admittance (Y)} = \frac{1}{Z} \, \text{mho} (\Omega)\]

(ii) **Susceptance (B):**
It is imaginary part of the admittance (Y). It is defined as the ability of the purely reactive circuit (purely capacitive or purely inductive) to admit alternating current.

\[\text{OR}\]
It is ratio of reactance (X) to squared impedance (\(Z^2\)).

In general, \[\text{Susceptance (B)} = \frac{X}{Z^2} \, \text{siemen}\]

(iii) **Conductance(G):**
It is defined as the real part of the admittance (Y). It is also defined as the ability of the purely resistive circuit to pass the alternating current.

\[\text{OR}\]
It is the ratio of resistance (R) to squared impedance (\(Z^2\))

\[\text{Conductance(G)} = \frac{R}{Z^2} \, \text{siemen}\]

(iv) **Units of admittance and conductance:**

Unit of Admittance (Y) = \text{mho}  
Unit of Conductance (G) = \text{siemen}

4 c) Delta connected induction motor is supplied by 3 phase 400V, 50 Hz supply the line current is 43.03 amp and the total power from the supply is 24 kW. Find the resistance and reactance per phase of the motor.

**Ans:**

**Data Given:**

\(V_L = 400V, \, 3 \phi \, (\text{Delta connected})\)  
\(I_L = 43.03 \, A\)
\(P = 24 \, kW\)  
\(f = 50 \, Hz\)

In Delta connection \(I_L = \sqrt{3} I_{Ph}\)
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\[ I_{ph} = \frac{i_L}{\sqrt{3}} \]
\[ I_{ph} = \frac{43.03}{\sqrt{3}} \]
\[ I_{ph} = 24.84 \text{ A} \]

In Delta connection \( V_L = V_{ph} \)
Hence,
\[ V_{ph} = V_L = 400 \text{ V} \]

Total three-phase power supplied to motor is given by,
\[ P = 3 V_{ph} I_{ph} \cos \phi \]
\[ \cos \phi = \frac{P}{3x V_{ph} I_{ph}} = \frac{24 \times 10^3}{3 \times 400 \times 24.84} = 0.805 \text{ lagging} \]

i) Impedance per phase \( Z_{ph} \):
\[ Z_{ph} = \frac{V_{ph}}{I_{ph}} \]
\[ Z_{ph} = \frac{400}{24.84} \]
Impedance per phase \( Z_{ph} = 16.10 \Omega \)

½ mark

½ mark

\[ \cos \phi = \frac{R_{ph}}{Z_{ph}} \]
\[ R_{ph} = Z_{ph} \cos \phi \]
\[ R_{ph} = 16.10 \times 0.805 \]
\[ R_{ph} = 12.96 \Omega \]

1 mark

ii) Resistance per Phase \( R_{ph} \):
\[ X_{Lph} = \sqrt{(Z_{ph})^2 - (R_{ph})^2} \]
\[ X_{Lph} = \sqrt{(16.10)^2 - (12.96)^2} \]
\[ X_{Lph} = 9.55 \Omega \]

1 mark

(Correct solution by ant other method may please be considered)

4 d) Derive the formulae for star to delta transformation.
Ans:
Star-delta Transformation:

![Star-delta Transformation Diagram]

If the star circuit and delta circuit are equivalent, then the resistance between any two terminals of the circuit must be same.

For star circuit, resistance between terminals 1 & 2, say \( R_{1-2} = R_1 + R_2 \)

For delta circuit, resistance between terminals 1 & 2, \( R_{1-2} = R_{12} || (R_{31} + R_{23}) \)
\[ \therefore R_1 + R_2 = R_{12} || (R_{31} + R_{23}) = \frac{R_{12}(R_{31} + R_{23})}{R_{12} + (R_{31} + R_{23})} = \frac{R_{12}(R_{31} + R_{23})}{R_{12} + R_{23} + R_{31}} \]
\[ \therefore R_1 + R_2 = \frac{R_{12}R_{31} + R_{12}R_{23}}{R_{12} + R_{23} + R_{31}} \] (1)

Similarly, the resistance between terminals 2 & 3 can be equated as,
Subtracting eq. (2) from eq. (1),
\[ R_1 - R_3 = \frac{R_{12}R_{31} - R_{23}R_{31}}{R_{12} + R_{23} + R_{31}} \] .......................... (4)

Adding eq. (3) and eq. (4) and dividing both sides by 2,
\[ \frac{R_1 R_{31}}{R_{12} + R_{23} + R_{31}} = \frac{R_{12}R_{31}}{R_{12} + R_{23} + R_{31}} + \frac{R_{12}R_{31}}{R_{12} + R_{23} + R_{31}} \] .......................... (5)

Similarly, we can obtain,
\[ R_2 = \frac{R_{12}R_{31}}{R_{12} + R_{23} + R_{31}} \] .......................... (6)
\[ R_3 = \frac{R_{12}R_{31}}{R_{12} + R_{23} + R_{31}} \] .......................... (7)

Multiplying each two of eq. (5), (6) and (7),
\[ R_1 R_2 = \frac{(R_{12})^2 R_{31} R_{23}}{(R_{12} + R_{23} + R_{31})^2} \] .......................... (8)
\[ R_2 R_3 = \frac{(R_{12})^2 R_{31} R_{12}}{(R_{12} + R_{23} + R_{31})^2} \] .......................... (9)
\[ R_3 R_1 = \frac{(R_{31})^2 R_{12} R_{23}}{(R_{12} + R_{23} + R_{31})^2} \] .......................... (10)

Adding the three equations (8), (9) and (10),
\[ R_1 R_2 + R_2 R_3 + R_3 R_1 = \frac{(R_{12})^2 R_{31} R_{23} + (R_{23})^2 R_{31} R_{12} + (R_{31})^2 R_{12} R_{23}}{(R_{12} + R_{23} + R_{31})^2} = \frac{R_{12}R_{31} R_{23} (R_{12} + R_{23} + R_{31})}{(R_{12} + R_{23} + R_{31})^2} \] .......................... (11)

Dividing eq. (11) by eq. (6), (dividing by respective sides)
\[ R_1 + R_3 + \frac{R_3 R_1}{R_2} = R_{31} \] .......................... (12)

Similarly, we can obtain,
\[ R_{12} = R_1 + R_2 + \frac{R_1 R_2}{R_3} \] .......................... (13)
\[ R_{23} = R_2 + R_3 + \frac{R_2 R_3}{R_1} \] .......................... (14)

Thus using known star connected resistors R_1, R_2 and R_3, the unknown resistors R_{12}, R_{23} and R_{31} of equivalent delta connection can be determined.
5 Attempt any TWO of the following: 12

5 a) A choke coil has a resistance of 4Ω and inductance of 0.07H is connected in parallel with another coil of resistance 10Ω and inductance 0.12H. The combination is connected to 230V, 50Hz supply. Determine total current and current through each branch.

Ans:
Data Given: \( R_1 = 4 \, \Omega \) \( L_1 = 0.07 \, H \) \( R_2 = 10 \, \Omega \) \( L_2 = 0.12 \, H \) \( V = 230 \, V \), \( f = 50 \, Hz \)

\[
X_{L1} = 2\pi f L_1 = 2\pi (50)(0.07) = 21.99 \approx 22 \, \Omega \\
X_{L2} = 2\pi f L_2 = 2\pi (50)(0.12) = 37.7 \, \Omega \\
Z_1 = R_1 + j X_{L1} = (4+j22) = 22.35 \angle 79.7^\circ \, \Omega \\
Z_2 = R_2 + j X_{L2} = (10+j37.7) = 39 \angle 75.144^\circ \, \Omega \\
\]

Branch 1 current is given by,
\[
I_1 = \frac{V}{Z_1} = \frac{230 \angle 0^\circ}{22.35 \angle 79.7^\circ} = 10.3 \angle -79.7^\circ A = (1.84 - j10.13) \, A
\]

Branch 2 current is given by,
\[
I_2 = \frac{V}{Z_2} = \frac{230 \angle 0^\circ}{39 \angle 75.144^\circ} = 5.89 \angle -75.144^\circ A = (1.51 - j5.7) \, A
\]

Total current is,
\[
I = I_1 + I_2 = (1.84 - j10.13) + (1.51 - j5.7) \\
I = (3.35 - j15.825) A = 16.17 \angle -78.04^\circ \, A
\]

5 b) Determine the current in 40Ω and 10Ω as shown in fig. no. 4 by node voltage analysis method.

Ans:
Node Voltage Analysis Method:
Step I: Mark the nodes and reference node.

Let the nodes be A, B, C, D, E and reference node is N. From the above circuit diagram we can write,
\[
V_A = 50 \\
V_E = 15 \\
V_B - V_C = 20 \\
:\quad V_C = V_B - 20
\]

Only two unknown voltages are \( V_B \) and \( V_D \).
Step II: Apply KCL at nodes with unknown voltages

Since there is a voltage source of 20V between nodes B and C, for writing KCL equations, let us treat nodes B and C with source as “Supernode”, encircled by dotted line.

By KCL at this supernode, we can write

\[ \frac{15}{V_B - V_A} + \frac{10}{V_B} + \frac{20}{(V_B - 20) - V_D} = 0 \]
\[ \frac{15}{V_B} + \frac{10}{V_B} + \frac{20}{20} = 0 \]
\[ V_B \left[ \frac{1}{15} + \frac{1}{10} + \frac{1}{20} \right] - \frac{50}{15} - \frac{20}{20} - \frac{1}{20} = 0 \]

(0.217)V_B - (0.05)V_D = 4.33 \hspace{1cm} \text{....(i)}

By KCL at node D, we write

\[ \frac{20}{V_D - V_C} + \frac{40}{V_D} + \frac{30}{V_D - V_E} = 0 \]
\[ \frac{20}{V_D} + \frac{40}{V_D} + V_D \left[ \frac{1}{20} + \frac{1}{40} + \frac{1}{30} \right] = 0 \]

(0.05)V_B + (0.1083)V_D = -0.5 \hspace{1cm} \text{....(ii)}

Step III: Solving Simultaneous equations

Expressing eq. (i) and (ii) in matrix form,

\[
\begin{bmatrix}
0.217 & -0.05 \\
0.05 & -0.1083
\end{bmatrix}
\begin{bmatrix}
V_B \\
V_D
\end{bmatrix}
= \begin{bmatrix}
4.33 \\
0.5
\end{bmatrix}
\]

\[ \Delta = \begin{vmatrix}
0.217 & -0.05 \\
0.05 & -0.1083
\end{vmatrix} = -0.0235 - (-0.0025) = -0.021 \]

By Cramer’s rule,

\[ V_B = \frac{\begin{vmatrix}
4.33 & -0.05 \\
0.05 & -0.1083
\end{vmatrix}}{-0.021} = -0.444 \]
\[ V_B = 21.143 \text{ volt} \]

\[ V_D = \frac{\begin{vmatrix}
0.217 & 4.33 \\
0.05 & 0.5
\end{vmatrix}}{-0.021} = -0.108 \]
\[ V_D = 5.143 \text{ volt} \]

Step IV: Solving for currents

Current in 40Ω resistor is given by,

\[ I_{40} = \frac{V_D}{40} = \frac{5.143}{40} = 0.1286 \text{ A} \]
Current in 10Ω resistor is given by,
\[ I_{10} = \frac{V_B}{10} = \frac{21.143}{10} = 2.1143 \, A \]

5 c) Use Norton’s theorem to find the current through 3Ω resistance, for the circuit shown in fig. no. 5

Ans:

Solution by Norton’s Theorem:
According to Norton’s theorem, the circuit between load terminals excluding load resistance can be represented by simple circuit consisting of a current source \( I_N \) in parallel with a resistance \( R_N \), as shown in the following figure.

**Determination of Norton’s Equivalent Current Source (\( I_N \))**:
Norton’s equivalent current source \( I_N \) is the current flowing through a short-circuit across the load terminals due to internal sources, as shown in fig.(a).
Total resistance across 10V source is,
\[ R = 4 + (5||2) = 4 + \frac{5 \times 2}{5 + 2} = 5.43 \, \Omega \]
Therefore, current supplied by source,
\[ I = \frac{V}{R} = \frac{10}{5.43} = 1.84 \, A \]
The resistances 2Ω and 5Ω are in parallel. By current division, the current flowing through 5Ω is same as \( I_N \).
\[ I_N = \frac{2}{2 + 5} = (1.84) \frac{2}{7} = 0.526 \, A \]

**Determination of Norton’s Equivalent Resistance (\( R_N \))**:
Norton’s equivalent resistance is the resistance seen between the load terminals while looking back into the network, with internal independent voltage sources replaced by short-circuit and independent current sources replaced by open-circuit. Referring to fig.(b),
Determination of Load Current ($I_L$):
Referring to fig.(c), the load current is

$$I_L = I_N \frac{R_N}{R_N + R_L} = 0.526 \frac{6.33}{6.33 + 3} = 0.357 \text{ A}$$

6 Attempt any TWO of the following: 12

6 a) Voltage across a coil is 146.2V and across series resistance is 150V, when they are connected across 220V, 50Hz supply. If supply current is 10 amp, find:

i) Resistance of coil
ii) Inductance of coil
iii) Power consumed by coil
iv) Power factor of total circuit

Ans:
Data given:
$V_S = 220\text{V}, \ f = 50\text{Hz}, \ V_{\text{Coil}} = 146.2\text{V}, \ V_R = 150\text{V}, \ I = 10\text{A}$

Referring to the phasor diagram above,

$$V_\phi = \sqrt{V_R^2 + V_{\text{Coil}}^2 + 2V_R V_{\text{Coil}} \cos\theta}$$

$$\therefore \cos\theta = \frac{V_R^2 - V_{\text{Coil}}^2}{2V_R V_{\text{Coil}}} = \frac{(220)^2 - (150)^2 - (146.2)^2}{2(150)(146.2)} = 0.1032$$

$$\therefore \text{Phase angle of circuit } \theta = \cos^{-1}(0.1032) = 84.07^\circ$$

.$\therefore$ Voltage across resistance of coil, $V_r = V_{\text{Coil}} \cos\theta = (146.2)(0.1032) = 15.087 \text{ volt}$
.. Voltage across inductance of coil, $V_L = V_{\text{Coil}} \sin\theta = (146.2)\sin(84.07^\circ) = 145.42\text{volt}$

(i) Resistance of Coil:
Resistance of coil, $r = V_r / I = 15.087 / 10 = 1.5087\Omega$

(ii) Inductance of Coil:
Inductive Reactance of Coil, $X_L = V_L / I = 145.42 / 10 = 14.54\Omega$

.$\therefore$ Inductance of Coil, $L = X_L / (2\pi f) = 14.54 / (2\pi \times 50) = 0.0462\text{H}$

(iii) Power consumed by coil:
$P = \frac{1}{2} r = (10)^2 (1.5087) = 150.87 \text{ watt}$

(iv) Power factor of total circuit:
Referring to the phasor diagram above,
$V_S \cos\phi = (V_r + V_R)$

.$\therefore$ Power factor of total circuit, $\cos\phi = (V_r + V_R) / V_S = (15.087 + 150) / 220$

.$\therefore \cos\phi = 0.75 \text{ lagging}$

6 b) In a 3 phase star connected system, derive the relationship $V_L = \sqrt{3} V_{\phi\text{h}}$. 
Ans:

**Relationship Between Line Voltage and Phase Voltage in Star Connected System:**

Let \( V_R, V_Y \) and \( V_B \) be the phase voltages.

\( V_{RY}, V_{YB} \) and \( V_{BR} \) be the line voltages.

The line voltages are expressed as:

\[
\begin{align*}
V_{RY} &= V_R - V_Y \\
V_{YB} &= V_Y - V_B \\
V_{BR} &= V_B - V_R
\end{align*}
\]

In phasor diagram, the phase voltages are drawn first with equal amplitude and displaced from each other by 120°. Then line voltages are drawn as per the above equations. It is seen that the line voltage \( V_{RY} \) is the phasor sum of phase voltages \( V_R \) and \( -V_Y \). We know that in parallelogram, the diagonals bisect each other with an angle of 90°.

Therefore in \( \Delta OPS \), \( \angle P = 90° \) and \( \angle O = 30° \).

\[
[OP] = [OS] \cos 30°
\]

Since \( [OP] = \frac{V_l}{2} \) and \( [OS] = V_{ph} \)

\[
\frac{V_l}{2} = V_{ph} \cos 30°
\]

\[
V_l = 2V_{ph} \frac{\sqrt{3}}{2}
\]

\[
V_l = \sqrt{3} V_{ph}
\]

Thus **Line voltage = \( \sqrt{3} \) (Phase Voltage)**

6 c) State the Thevenin’s theorem. Also write stepwise procedure for applying Thevenin’s theorem to simple circuits.

**Ans:**

**Thevenin’s Theorem:**

Any two terminal circuit having number of linear impedances and sources (voltage, current, dependent, independent) can be represented by a simple equivalent circuit consisting of a single voltage source \( V_{Th} \) in series with an impedance \( Z_{Th} \), where the source voltage \( V_{Th} \) is equal to the open circuit voltage appearing across the two terminals due to internal sources of circuit and the series impedance \( Z_{Th} \) is equal to the impedance of the circuit while looking back into the circuit across the two terminals, when the internal independent voltage sources are replaced by short-circuits and independent current sources by open circuits.

**Stepwise Procedure for applying Thevenin’s theorem to simple circuits:**

**Step I:** Identify the load branch \( (R_L) \): It is the branch whose current is to be determined.

**Step II:** Calculation of \( V_{Th} \): Remove \( R_L \) and find open circuit voltage across the load terminals A and B, which are now open due to removal of \( R_L \).

**Step III:** Calculation of \( R_{Th} \): It is the resistance between the open circuited load terminals A & B while looking back into the network with all independent voltage sources replaced by short-circuit & all independent current sources
replaced by open-circuit.

**Step IV:** Thevenin’s equivalent circuit:

![Thevenin Equivalent Circuit](image)

**Step V:** Determination of Load current:

\[
I_L = \frac{V_{Th}}{R_{Th} + R_L}
\]