K. J. SOMAIYA COLLEGE OF ENGINEERING
DEPARTMENT OF ELECTRONICS ENGINEERING
ELECTRONIC CIRCUITS
DC CIRCUITS

Numerical 1: Find i and V_o in the following circuit:

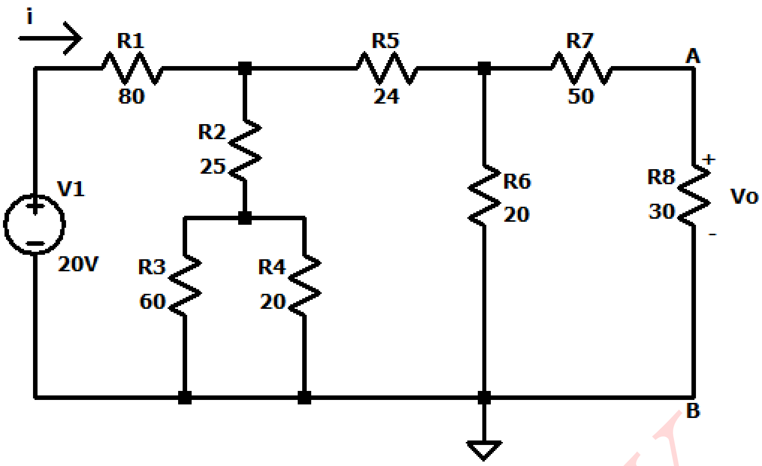

Figure 1: Circuit 1

Solution:

We will first use series - parallel reduction techniques to simplify the circuit. Then we will apply KVL to the loops generated to find i.

60Ω and 20Ω are connected in parallel.

$$\therefore R_p = 60 \,||\, 20 = \frac{60 \times 20}{60+20} = 15\Omega$$

∴ The circuit is simplified as shown in figure 2:

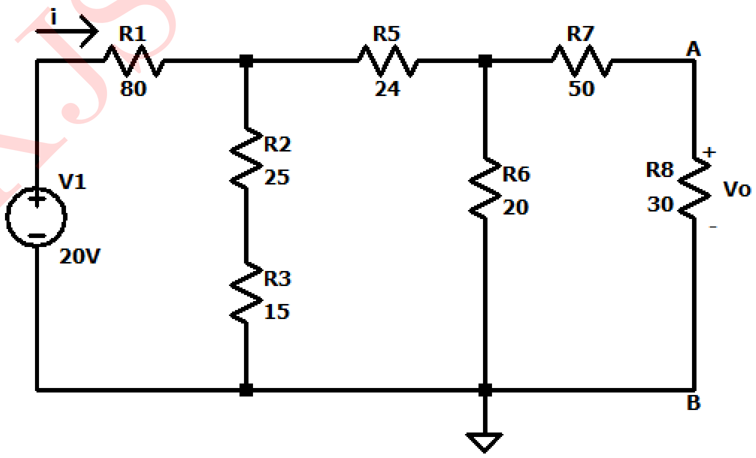

Figure 2: Simplified Circuit 1a for figure 1

25Ω and 15Ω resistors are connected in series

$\therefore R_s = 25 + 15 = 40\Omega$

∴ The circuit is further simplified as shown in figure 3:

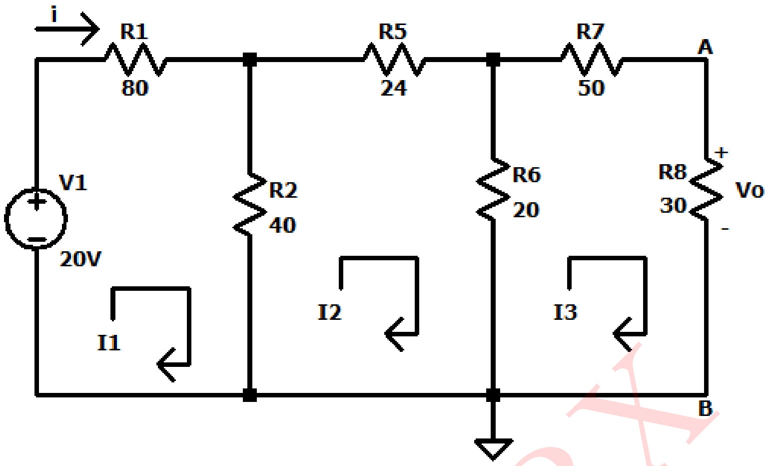

Figure 3: Simplified Circuit 1b for figure 2

We will now use Mesh Analysis to find i

Assume mesh currents I_1, I_2 and I_3 flowing through loops 1, 2 and 3 in clockwise direction

Applying KVL to loop 1, we get:

$20 - 80I_1 - 40(I_1 - I_2) = 0$

$\therefore -120I_1 + 40I_2 = -20$ ......(i)

Applying KVL to loop 2, we get:

$-24I_2 - 20(I_2 - I_3) - 40(I_2 - I_1) = 0$

$\therefore 40I_1 - 84I_2 + 20I_3 = 0$ ......(ii)

Applying KVL to loop 3, we get:

$-20(I_3 - I_2) - 50I_3 - 30I_3 = 0$

$\therefore 20I_2 - 100I_3 = 0$ ......(iii)

Solving (i), (ii), (iii) we get

$I_1 = 0.2A$, $I_2 = 0.1A$, $I_3 = 0.02A$

$\therefore i = I_1 = 0.2A$

Now $I_{30\Omega} = I_3$

$$\therefore V_o = I_{30\ \Omega} \times 30$$
$$= 0.2 \times 30$$
$$= 0.6\text{V}$$

$\therefore$ **i = 0.2A**
$\therefore$ **$\mathbf{V_o}$ = 0.6V**

SIMULATED RESULTS:

The given circuit is simulated in LTspice and the results obtained are as follows:

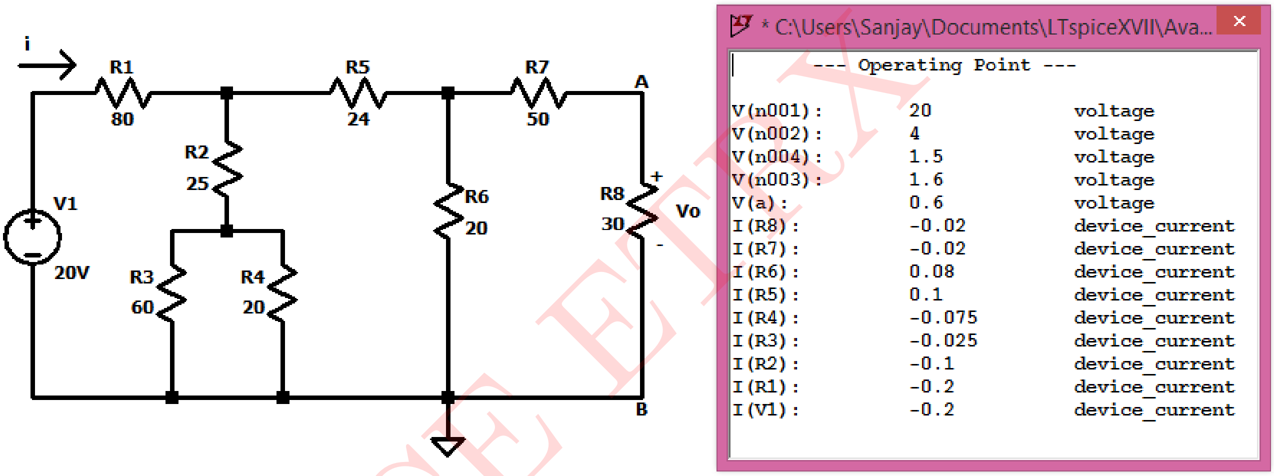

Figure 4: Circuit Schematic and Simulated Results

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
i	0.2A	0.2A
V_o	0.6V	0.6V

Table 1: Numerical 1

Numerical 2: Obtain the equivalent resistance between the terminals a-b for each of the circuits:

(a)

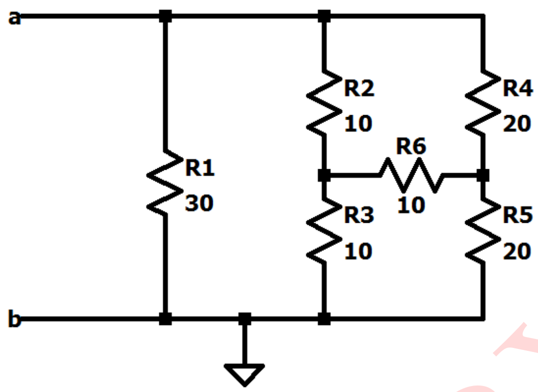

Figure 5: Circuit 2a

Solution:

We will use series - parallel and star-delta reduction techniques to obtain the equivalent resistance between terminals a and b.

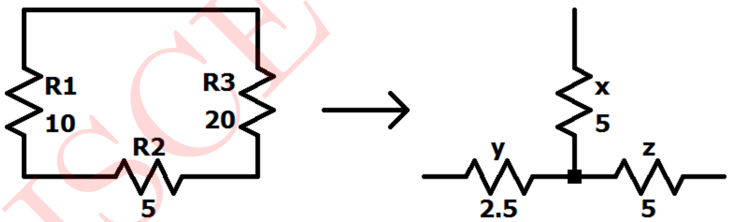

Figure 6: Delta - Star Conversion

The resistors 10Ω, 10Ω and 20Ω are connected in delta.

Converting delta to star, we have:

$$x = \frac{10 \times 20}{10 + 10 + 20} = 5\Omega$$

$$y = \frac{10 \times 10}{10 + 10 + 20} = 2.5\Omega$$

$$z = \frac{20 \times 10}{10 + 10 + 20} = 5\Omega$$

$\therefore$ The circuit is simplified as shown in figure 7:

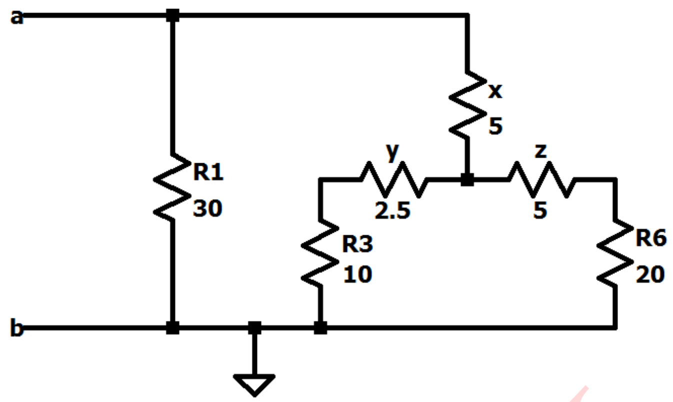

Figure 7: Simplified Circuit 2a.1 for figure 6

The resistors 10Ω and 2.5Ω are connected in series.

$\therefore R_s = 10 + 2.5 = 12.5\Omega$

The resistors 20Ω and 5Ω are connected in series.

$\therefore R_s = 20 + 5 = 20\Omega$

$\therefore$ The circuit is further simplified as shown in figure 8:

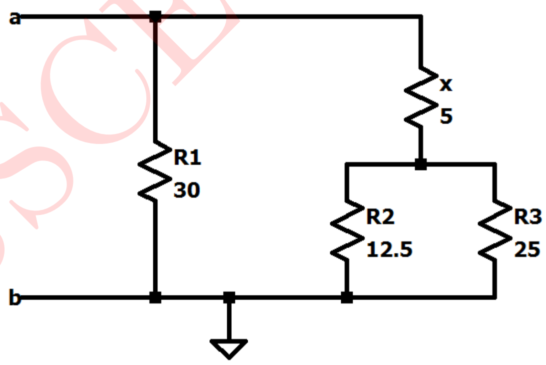

Figure 8: Simplified Circuit 2a.2 for figure 7

The resistors 12.5Ω and 25Ω are connected in parallel.

$$\therefore R_p = 12.5 \,||\, 25$$

$$= \frac{12.5 \times 25}{12.5 + 25}$$

$$= 8.33\Omega$$

$\therefore$ The circuit is further simplified as shown in figure 9:

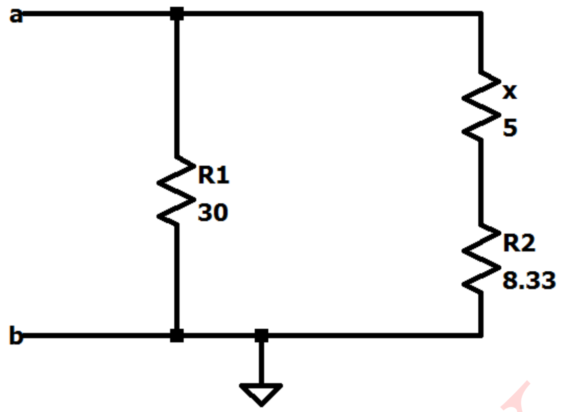

Figure 9: Simplified Circuit 2a.3 for figure 8

The resistors 8.33Ω and 5Ω are connected in series.

$\therefore R_s = 8.33 + 5 = 13.33\Omega$

$\therefore$ The circuit is further simplified as showin figure 10:

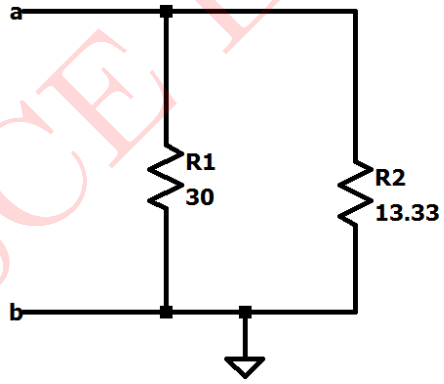

Figure 10: Simplified Circuit 2a.4 for figure 9

The resistors 30Ω and 13.33Ω are connected in parallel.

$$\therefore R_{ab} = 30 \,||\, 13.33 = \frac{30 \times 13.33}{30 + 13.33} = 9.23\Omega$$

$$\therefore \mathbf{R_{ab} = 9.23\Omega}$$

SIMULATED RESULTS:

The given circuit is simulated in LTspice and the results obtained are as follows:

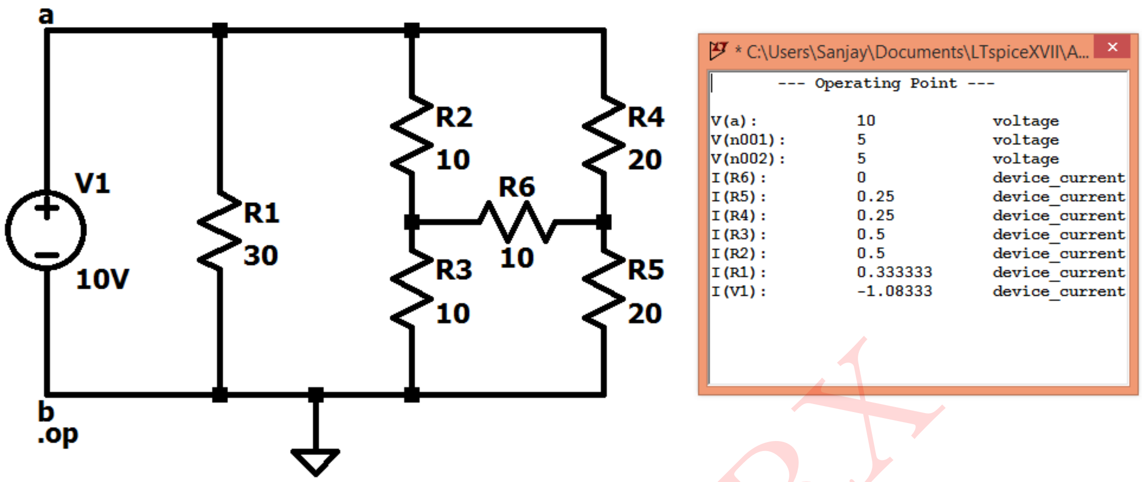

Figure 11: Circuit Schematic and Simulated Results

$$\therefore R_{\text{ab}} = \frac{V1}{I(V1)} = \frac{10}{1.0833} = 9.2308\Omega$$

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
R_{ab}	9.23Ω	9.2308Ω

Table 2: Numerical 2a

(b)

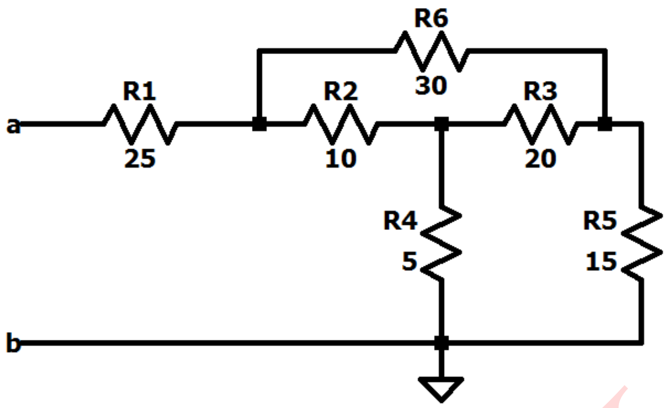

Figure 12: Circuit 2b

Solution:

We will use series - parallel and star-delta reduction techniques to obtain the equivalent resistance between terminals a and b.

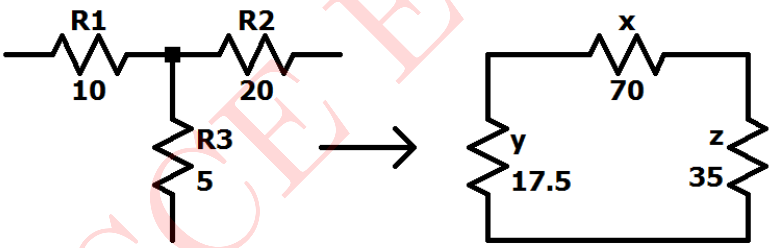

Figure 13: Star - Delta Conversion

The resistors 10Ω, 20Ω and 5Ω are connected in delta.

Converting star to delta, we have:

$$\text{x} = 10 + 20 + \frac{10 \times 20}{5} = 70\Omega$$

$$\text{y} = 10 + 5 + \frac{10 \times 5}{20} = 17.5\Omega$$

$$\text{z} = 20 + 5 + \frac{20 \times 5}{10} = 35\Omega$$

$\therefore$ The circuit is simplified as shown in figure 14:

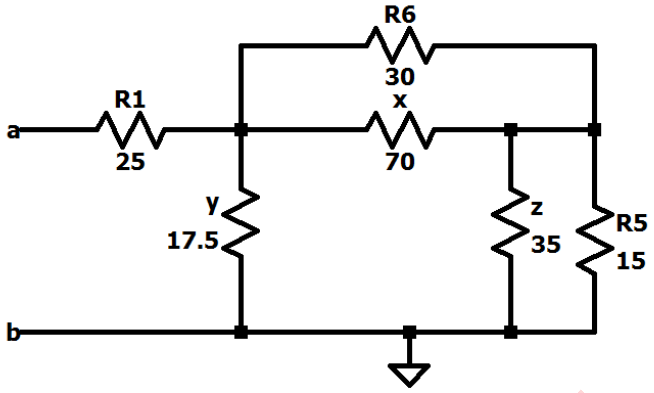

Figure 14: Simplified Circuit 2b.1 for figure 13

The resistors 30Ω and 70Ω are connected in parallel.

$$\therefore R_{\mathrm{p}} = 30 \,||\, 70$$
$$= \frac{30 \times 70}{30 + 70}$$
$$= 21\Omega$$

Similarly,the resistors 35Ω and 15Ω are connected in parallel.

$$\therefore R_{\mathrm{p}} = 35 \,||\, 15$$
$$= \frac{35 \times 15}{35 + 15}$$
$$= 10.5\Omega$$

$\therefore$ The circuit is further simpified as shown in figure 15:

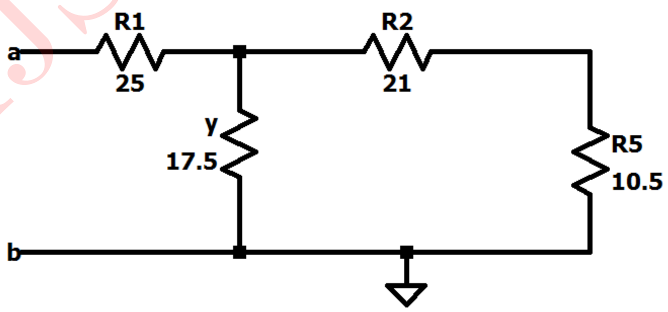

Figure 15: Simplified Circuit 2b.2 for figure 14

The resistors 21Ω and 10.5Ω are connected in series.

$$\therefore R_{\mathrm{s}} = 21 \,+\, 10.5 = 31.5\Omega$$

$\therefore$ The circuit is further simpified as shown in figure 16:

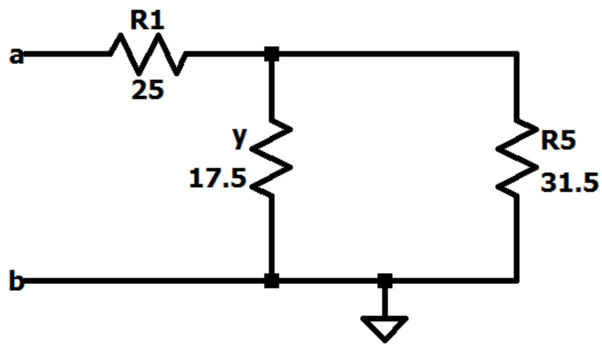

Figure 16: Simplified Circuit 2b.3 for figure 15

The resistors 17.5Ω and 31.5Ω are connected in parallel.

$$\begin{aligned}\therefore R_{\text{p}} &= 17.5 \,||\, 31.5\\ &= \frac{17.5 \times 31.5}{17.5 + 31.5}\\ &= 11.25\Omega\end{aligned}$$

So, the circuit is further simplified as shown in figure 17:

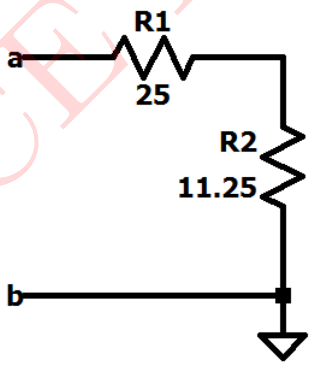

Figure 17: Simplified Circuit 2b.4 for figure 16

The resistors 25Ω and 11.25Ω are connected in series.

$\therefore R_{\text{ab}} = 25 \, + \, 11.25 = 36.25\Omega$

$\therefore$ $\mathbf{R_{ab} = 36.25\Omega}$

SIMULATED RESULTS:

The given circuit is simulated in LTspice and the results obtained are as follows:

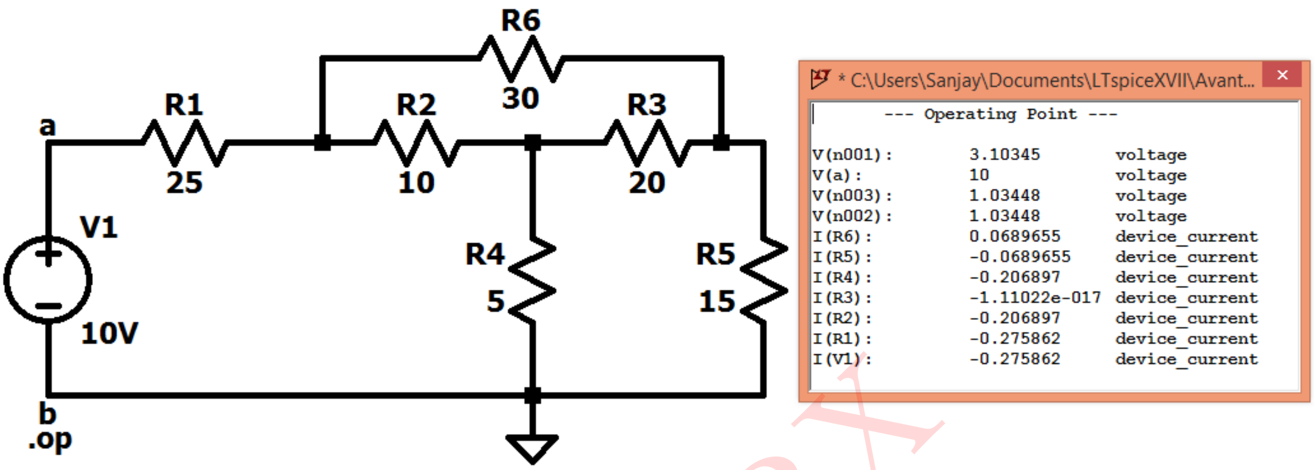

Figure 18: Circuit Schematic and Simulated Results

$$\therefore R_{\mathrm{ab}} = \frac{V1}{I(V1)} = \frac{10}{0.275862} = 36.250\Omega$$

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
R_{ab}	36.25Ω	36.250Ω

Table 3: Numerical 2b

Numerical 3: For the circuit, use superposition theorem to find i and calculate the power delivered by the 4Ω resistor :

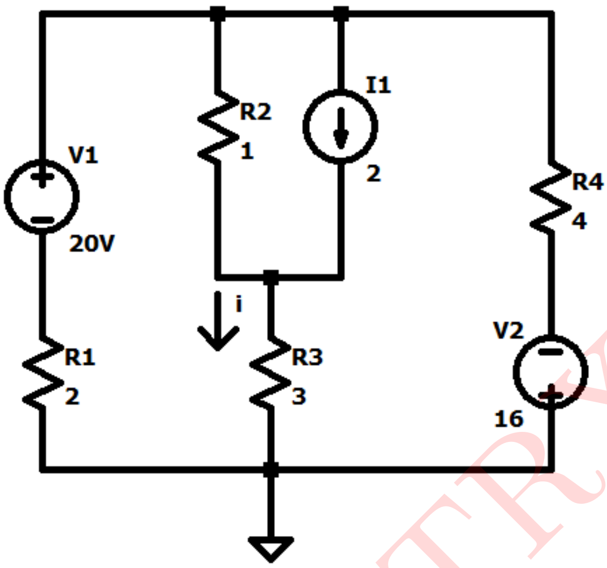

Figure 19: Circuit 3

Solution:

We will use Superposition theorem to find i.

Case 1: We will first consider the 20V source alone and replace the other sources by their internal resistances

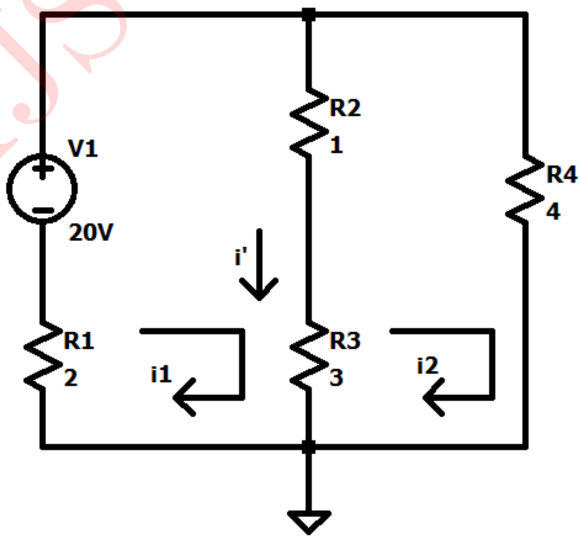

Figure 20: Case 1 - Considering only 20V source acting alone

We will now use Mesh Analysis to find i′

Assume mesh currents i_1 and i_2 flowing through loops 1 and 2 in clockwise direction

Applying KVL to loop 1, we get:

$20 - 1(i_1 - i_2) - 3(i_1 - i_2) - 2i_1 = 0$

$\therefore -6i_1 + 4i_2 = -20$ ......(i)

Applying KVL to loop 2, we get:

$-3(i_2 - i_1) - 1(i_2 - i_1) - 4i_2 = 0$

$\therefore 4i_1 - 8i_2 = 0$ ......(ii)

Solving (i) and (ii) we get

$i_1 = 5A$ and $i_2 = 2.5A$,

$\therefore \mathbf{i' = i_1 - i_2 = 5 - 2.5 = 2.5A \downarrow}$

Case 2: We will now consider the 16V source alone and replace the other sources by their internal resistances

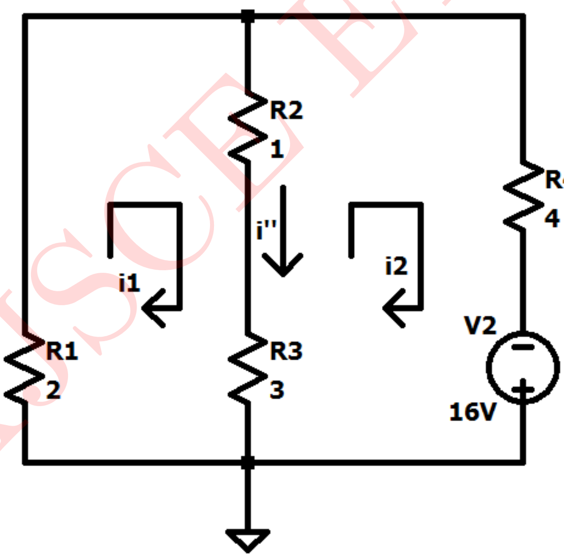

Figure 21: Case 2 - Considering only 16V source acting alone

We will now use Mesh Analysis to find i″

Assume mesh currents i_1 and i_2 flowing through loops 1 and 2 in clockwise direction

Applying KVL to loop 1, we get:

$-2i_1 - 1(i_1 - i_2) - 3(i_1 - i_2) = 0$

$\therefore -6i_1 + 4i_2 = 0$ ......(i)

Applying KVL to loop 2, we get:

$-3(i_2 - i_1) - 1(i_2 - i_1) - 4i_2 + 16 = 0$

$\therefore 4i_1 - 8i_2 = -16$ ......(ii)

Solving (i) and (ii) we get

$i_1 = 2A$ and $i_2 = 3A$,

$\therefore \mathbf{i'' = i_1 - i_2 = -1A \downarrow}$

Case 3: We will now consider the 2A source alone and replace the other sources by their internal resistances

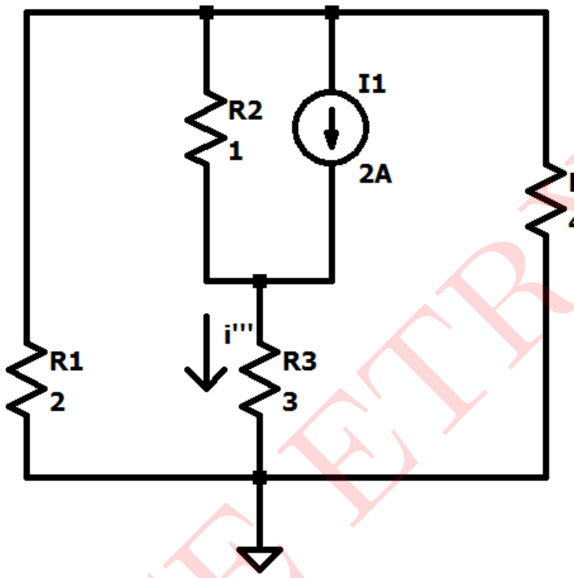

Figure 22: Case 3 - Considering only 2A source acting alone

The resistors 2Ω and 4Ω are connected in parallel.

$$\therefore R_p = 2 \,||\, 4 = \frac{2 \times 4}{2 + 4} = 1.333\Omega$$

$\therefore$ The circuit is simplified as shown in figure 23:

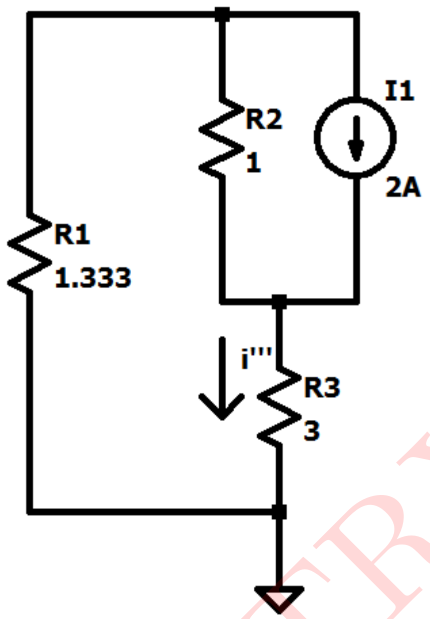

Figure 23: Simplified Circuit 3a for figure 22

$\therefore$ The circuit can be redrawn as shown in figure 24 :

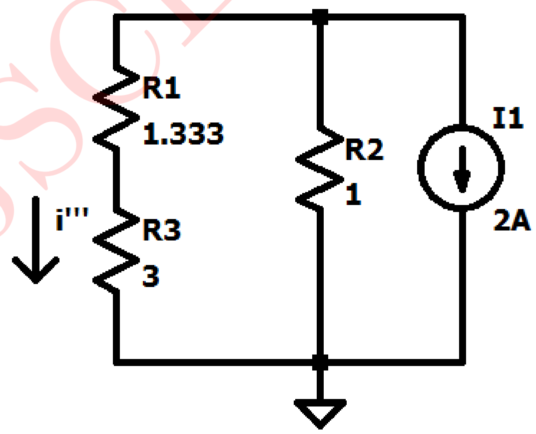

Figure 24: Simplified Circuit 3b for figure 23

By current division rule, we get:

$\therefore \mathrm{i}''' = \dfrac{2 \times 1}{1.333 + 3 + 1}$

$\therefore \mathbf{i''' = 0.3750A} \downarrow$

$$\begin{aligned} \therefore \mathrm{i} &= \mathrm{i}' + \mathrm{i}'' + \mathrm{i}''' \\ &= 2.5\!\downarrow + (-1)\!\downarrow + 0.3750\!\downarrow \\ &= 1.875\mathrm{A}\!\downarrow \end{aligned}$$

$\therefore P = \mathrm{i}^2 \times \mathrm{R}_3$

$= 1.875^2 \times 3$

$= 10.546875\mathrm{W}$

$\therefore$ **i = 1.875A**
$\therefore$ **P = 10.546875W**

SIMULATED RESULTS:

The given circuit is simulated in LTspice and the results obtained are as follows:

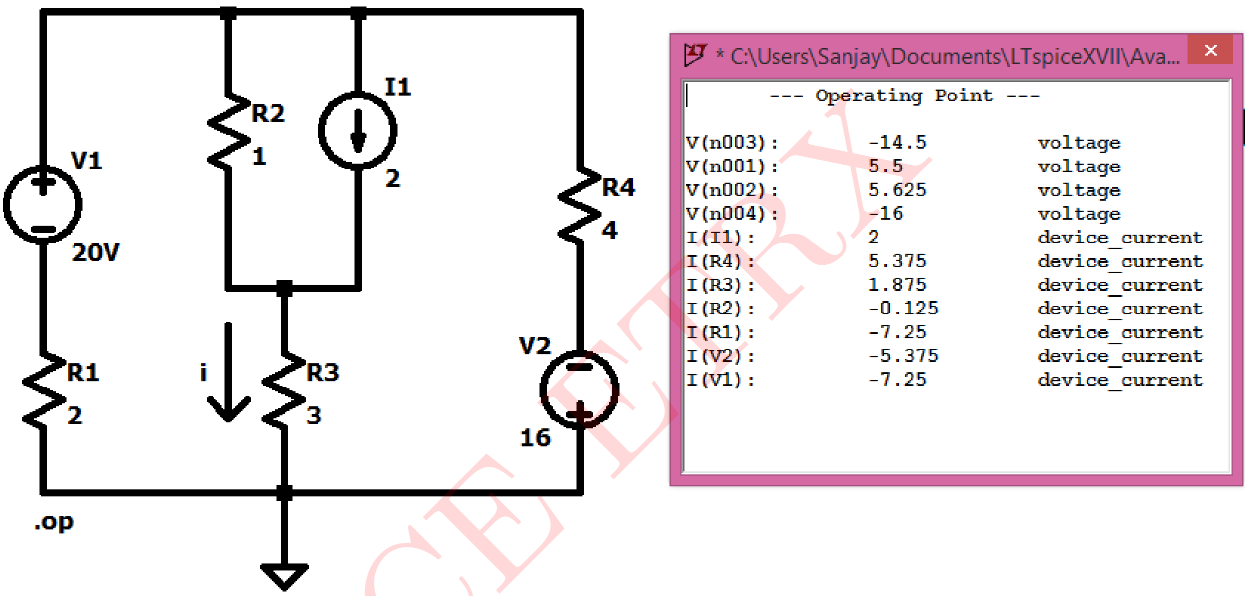

Figure 25: Circuit Schematic and Simulated Results

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
i	1.875A	1.8750A
P	10.546875W	10.546875W

Table 4: Numerical 3

Numerical 4: For the given circuit shown in figure 26, use superposition theorem to find i_o.

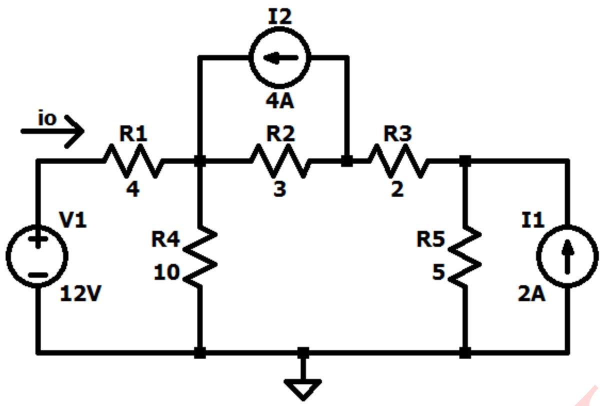

Figure 26: Circuit 4

Solution:

We will use Superposition theorem to find i_o.

Case 1: We will first consider the 12V source alone and replace the other sources by their internal resistances

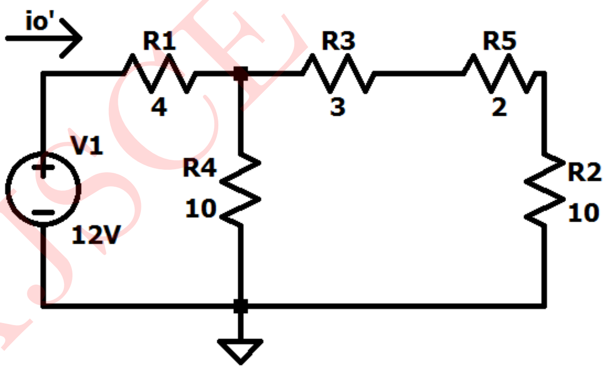

Figure 27: Case 1 - Considering only 12V source acting alone

The resistors 3Ω, 2Ω and 5Ω are connected in series.

$\therefore R_s = 3 + 2 + 5 = 10\Omega$

$\therefore$ The circuit is simplified as shown in figure 28:

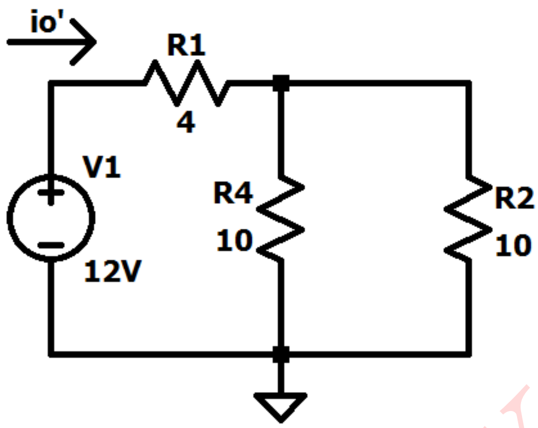

Figure 28: Simplified Circuit 4a for figure 27

The resistors 10Ω and 10Ω are connected in parallel.

$$\begin{aligned}\therefore R_{\text{p}} &= 10 \,||\, 10 \\ &= \frac{10 \times 10}{10 + 10} \\ &= 5\Omega\end{aligned}$$

$\therefore$ The circuit is further simplified as shown in figure 29:

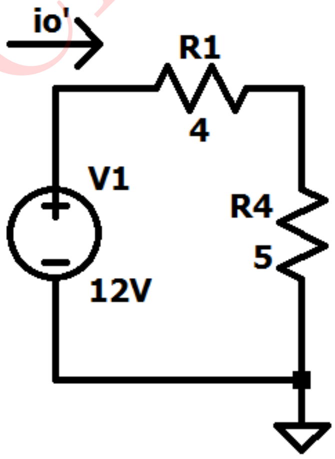

Figure 29: Simplified Circuit 4b for figure 28

$$\therefore \mathrm{i_o}' = \frac{12}{4 + 5} = 1.3333\text{A}$$

$\therefore \mathbf{i_o' = 1.3333A} \rightarrow$

Case 2: We will now consider the 4A source alone and replace the other sources by their internal resistances

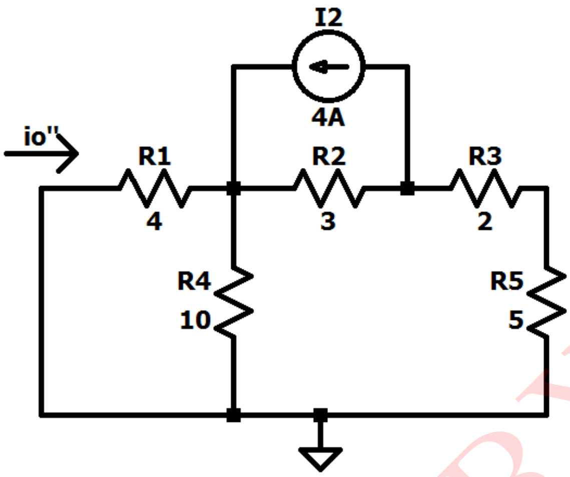

Figure 30: Case 2 - Considering only 4A source acting alone

The resistors 2Ω and 5Ω are connected in series.

$\therefore R_s = 2 + 5 = 7\Omega$

$\therefore$ The circuit is simplified as sjown in figure 31:

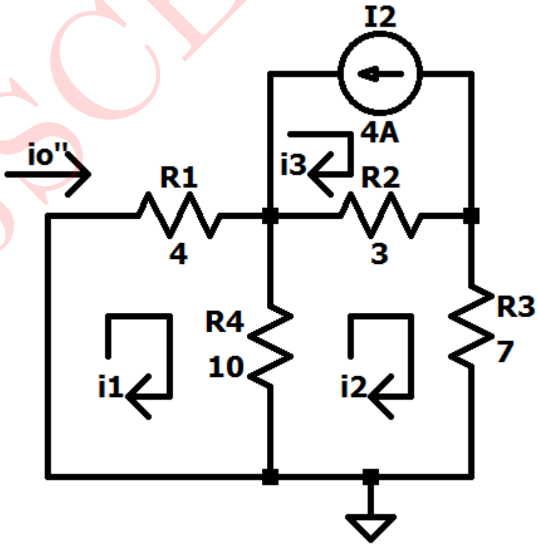

Figure 31: Simplified Circuit 4c for figure 30

We will now use Mesh Analysis to find i_o''

Assume mesh currents i_1, i_2 and i_3 flowing through loops 1, 2 and 3 in clockwise direction

From the figure, $i_3 = -4A$ ......(i)

Applying KVL to loop 1, we get:

$-4i_1 - 10(i_1 - i_2) = 0$

$\therefore -14i_1 + 10i_2 = 0$ ......(ii)

Applying KVL to loop 2, we get:

$-10(i_2 - i_1) - 3(i_2 - i_3) - 7i_2 = 0$

$\therefore 10i_1 - 20i_2 = 12$ ......(iii)

Solving (i), (ii) and (iii) we get

$i_1 = -0.6667A$ and $i_2 = -0.9333A$

$\therefore \mathbf{i_o'' = i_1 = -0.6667A} \rightarrow$

Case 3: We will now consider the 2A source alone and replace the other sources by their internal resistances

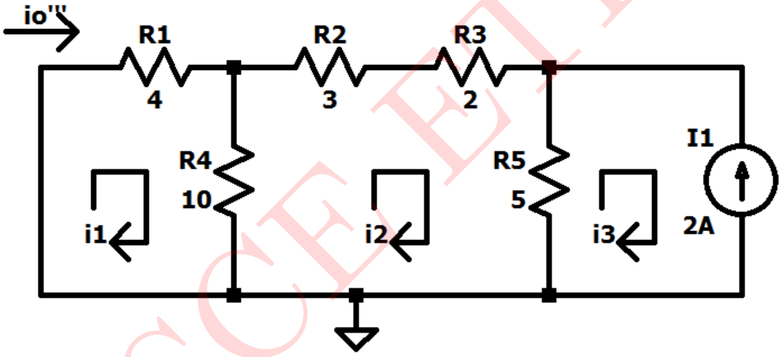

Figure 32: Case 3 - Considering only 2A source acting alone

We will now use Mesh Analysis to find i_o'''

Assume mesh currents i_1, i_2 and i_3 flowing through loops 1, 2 and 3 in clockwise direction

From the figure, $i_3 = -2A$ ......(i)

Applying KVL to loop 1, we get:

$-4i_1 - 10(i_1 - i_2) = 0$

$\therefore -14i_1 + 10i_2 = 0$ ......(ii)

Applying KVL to loop 2, we get:

$-10(i_2 - i_1) - 3i_2 - 2i_2 - 5(i_2 - i_3) = 0$

$\therefore 10i_1 - 20i_2 = 10$ ......(iii)

Solving (i), (ii) and (iii) we get

$i_1 = -0.5556A$ and $i_2 = -0.7778A$

$\therefore \mathbf{i_o''' = i_1 = -0.5556A} \rightarrow$

$$\therefore \mathrm{i_o} = \mathrm{i_o}' + \mathrm{i_o}'' + \mathrm{i_o}'''$$
$$= 1.3333\rightarrow + (-0.6667)\rightarrow + (-0.5556)\rightarrow$$
$$= 0.1111\mathrm{A}\rightarrow$$

$$\therefore \ \mathbf{i_o = 0.1111A}$$

SIMULATED RESULTS:

The given circuit is simulated in LTspice and the results obtained are as follows:

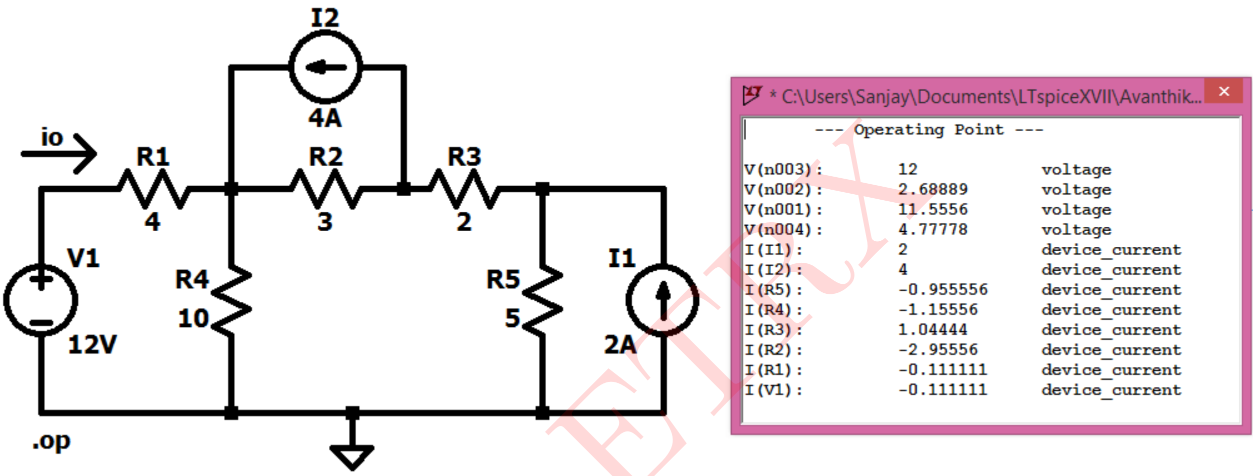

Figure 33: Circuit Schematic and Simulated Results

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
$\mathrm{i_o}$	0.1111A	0.1111A

Table 5: Numerical 4

Numerical 5: Obtain the Thevenin's Equivalent at terminals a-b for the circuit shown in figure 34

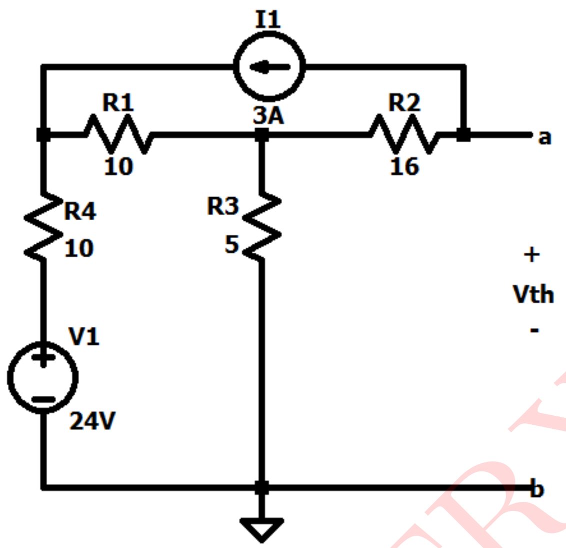

Figure 34: Circuit 5

Solution:

I. Calculation of V_{th}

We will consider open-circuit voltage $V_{ab} = V_{th}$ across terminals a-b.

We will use mesh analysis to find the currents through the loops of the circuit.

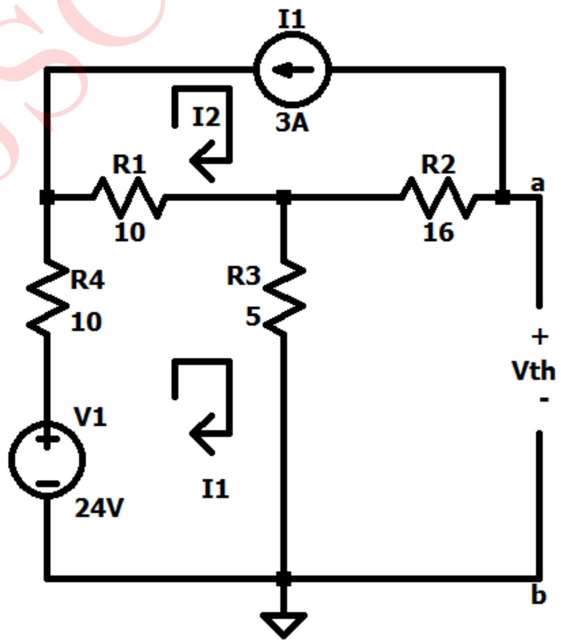

Figure 35: Circuit for calculation of V_{th}

Assume mesh currents I_1 and I_2 flowing through loops 1 and 2 in clockwise direction

From the figure 2, we can see that:

$I_2 = -3\text{A}$ ......(i)

Applying KVL to loop 1, we get:

$24 - 10I_1 - 10(I_1 - I_2) - 5I_1 = 0$

$\therefore -25I_1 + 10I_2 = -24$ ......(ii)

Solving (i) and (ii) we get

$\text{I}_1 = -\ 0.24\text{A}$ ......(iii)

Equation of V_{th}:

$5I_1 + 16I_2 = \text{V}_{\text{th}}$

Using (i) and (iii) we get

$\therefore \mathbf{V_{th} = -49.2V}$

II. Calculation of $\mathbf{R_{th}}$

Replacing all voltage and current sources by short and open circuit respectively we get,

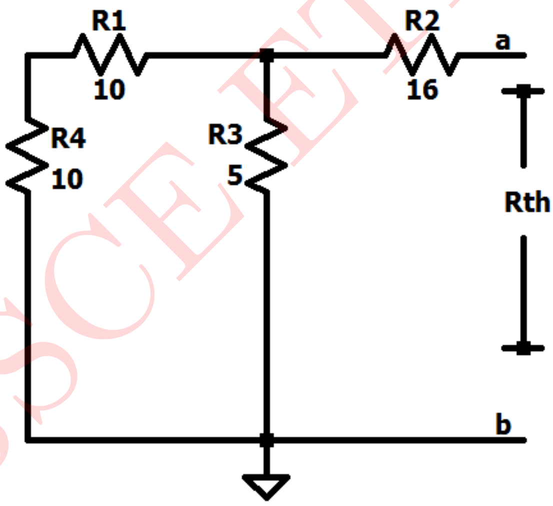

Figure 36: Circuit for calculation of R_{th}

10Ω and 10Ω resistors are connected in series

$\therefore R_s = 10\ +\ 10 = 20\Omega$

$\therefore$The circuit is simplified as shown in figure 37:

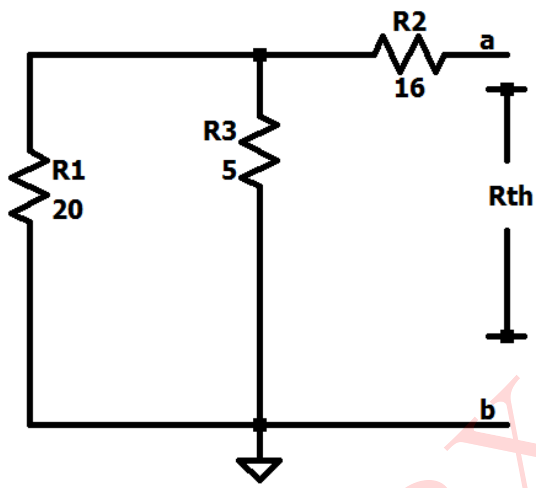

Figure 37: Simplified Circuit 5a for figure 36

The resistors 20Ω and 5Ω are connected in parallel.

$$\begin{aligned}\therefore R_\text{p} &= 20 \mid\mid 5 \\ &= \frac{20 \times 5}{20 + 5} \\ &= 4\Omega\end{aligned}$$

$\therefore$The circuit is simplified as shown in figure 38:

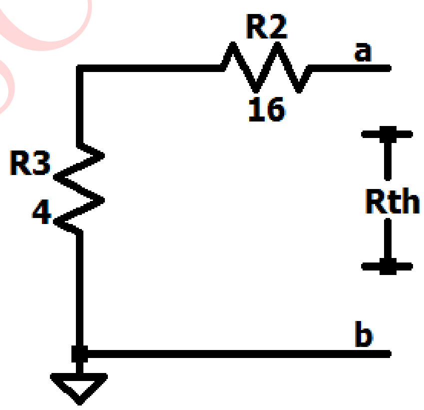

Figure 38: Simplified Circuit 5b for figure 37

The resistors 4Ω and 16Ω are connected in series.

$\therefore$ $\text{R}_\text{ab} = 4\Omega + 16\Omega = 20\Omega$

$\therefore \mathbf{R_{th} = 20\Omega}$

∴ The Thevenin's Equivalent circuit is as shown in figure 39:

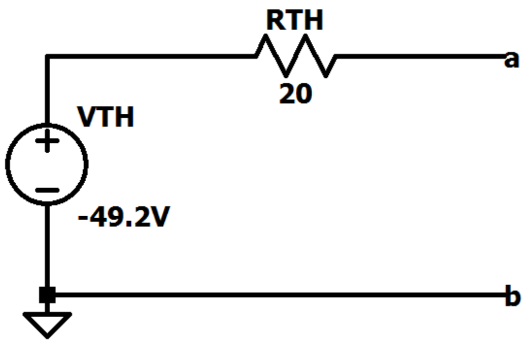

Figure 39: Thevenin's Equivalent Circuit

SIMULATED RESULTS:

The given circuit is simulated in LTspice and the results obtained are as follows:

I. Simulation of circuit to find V_{th}

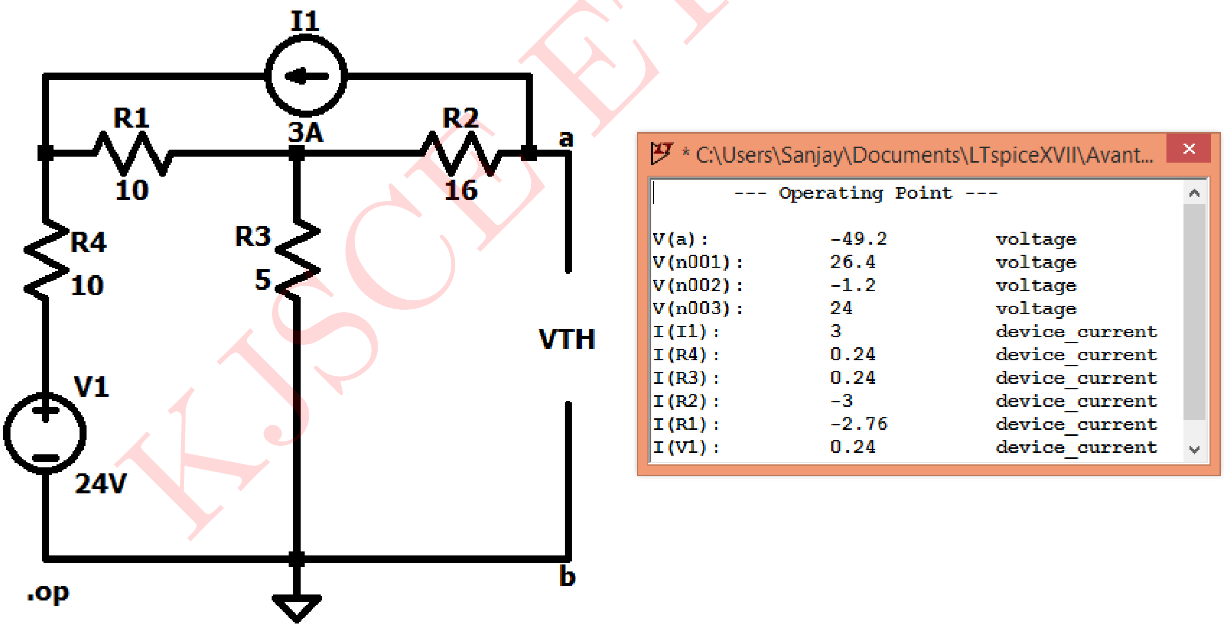

Figure 40: Circuit Schematic for V_{th} and Simulated Results

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
V_{th}	-49.2V	-49.2V

Table 6: Numerical 5:- Calculation of V_{th}

II. Simulation of circuit to find R_{th}

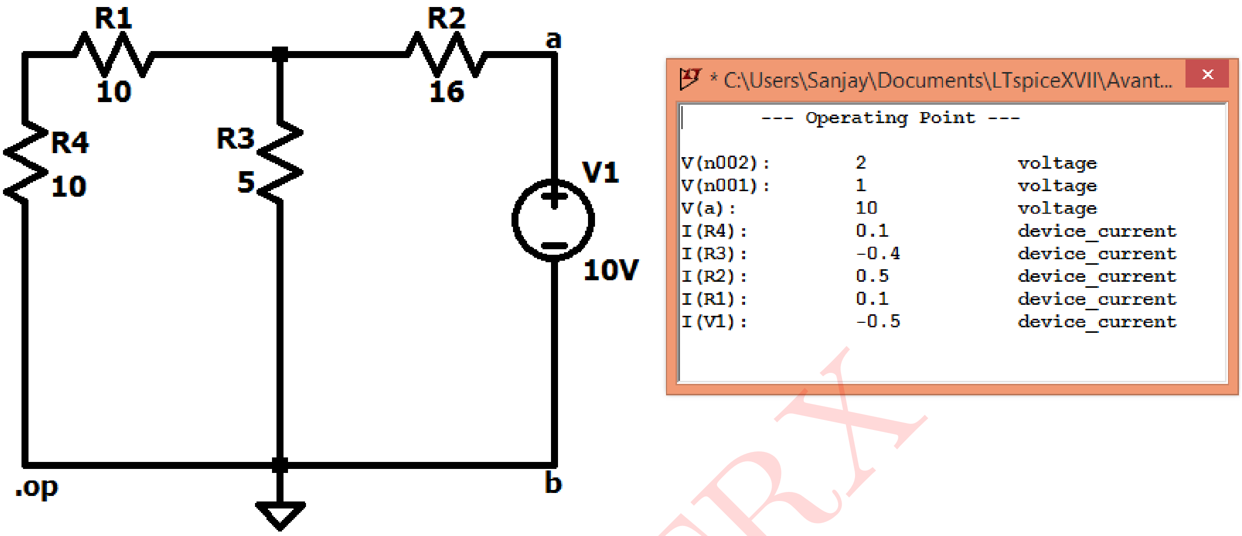

Figure 41: Circuit Schematic for R_{th} and Simulated Results

$$R_{th} = \frac{V1}{I(V1)} = \frac{10}{0.5} = 20\Omega$$

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
R_{th}	20Ω	20Ω

Table 7: Numerical 5:- Calculation of R_{th}

Numerical 6: Obtain the Thevenin's Equivalent at terminals a-b for the circuit shown in figure 42

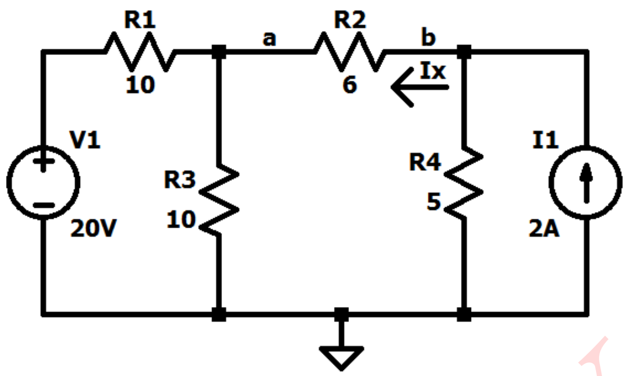

Figure 42: Circuit 6

Solution:

I. Calculation of V_{th}

We will remove the 6Ω resistor and consider open-circuit voltage $V_{ab} = V_{th}$ across terminals a-b.

We will use mesh analysis to find the currents through the loops of the circuit.

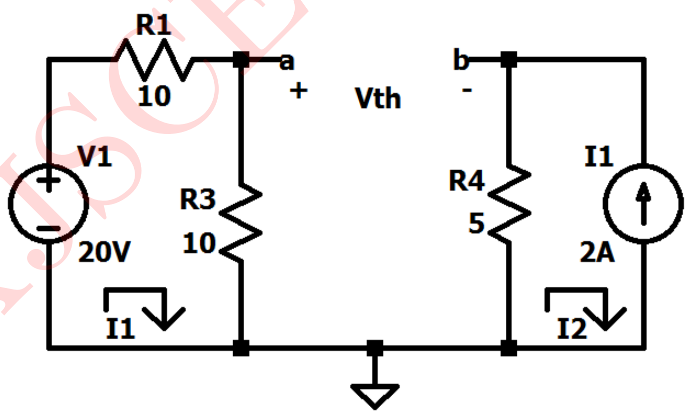

Figure 43: Circuit for calculation of V_{th}

Assume mesh currents I_1 and I_2 flowing through loops 1 and 2 in clockwise direction

From the figure 2, we can see that:

$I_2 = -2\text{A}$ ......(i)

Applying KVL to loop 1, we get:

$20 - 10I_1 - 10I_1 = 0$

$\therefore 20I_1 = 20$

$\therefore I_1 = 1\text{A}$ ......(ii)

Equation of V_{th}:

$-5I_2 - 10I_1 = V_{th}$

Using (i) and (ii) we get

$\therefore \mathbf{V_{th} = 0V}$

II. Calculation of R_{th}

Replacing all voltage and current sources by short and open circuit respectively we get,

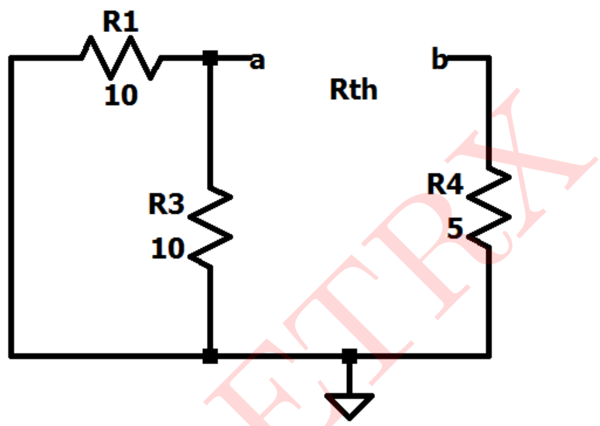

Figure 44: Circuit for calculation of R_{th}

The resistors 10Ω and 10Ω are connected in parallel.

$$\therefore R_p = 10 \,||\, 10 = \frac{10 \times 10}{10 + 10} = 5\Omega$$

$\therefore$The circuit is simplified as shown in figure 45

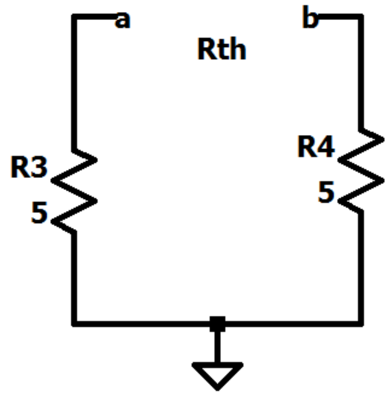

Figure 45: Simplified Circuit 6a for figure 44

The resistors 5Ω and 5Ω are connected in series.

$\therefore$ $R_{ab} = 5\Omega + 5\Omega = 10\Omega$

$\therefore$ $\mathbf{R_{th} = 10\Omega}$

$\therefore$ The Thevenin's Equivalent circuit is as shown in figure 13:

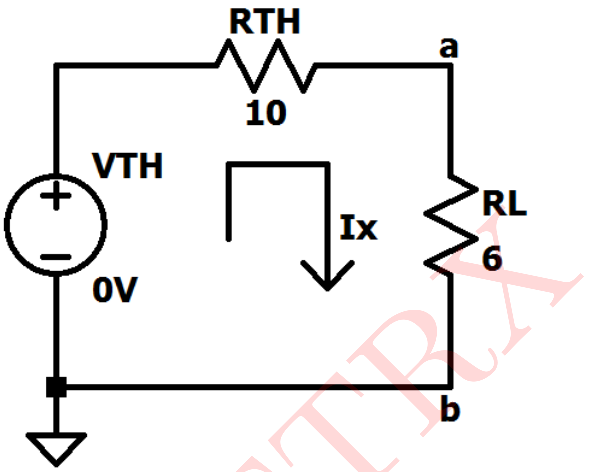

Figure 46: Thevenin's Equivalent Circuit

$$i_x = \frac{V_{th}}{R_{th} + R_L} = \frac{0}{10 + 6} = 0\text{A}$$

$\therefore$ $\mathbf{i_x = 0A}$

SIMULATED RESULTS:

The given circuit is simulated in LTspice and the results obtained are as follows:

I. Simulation of circuit to find $\mathbf{V_{th}}$

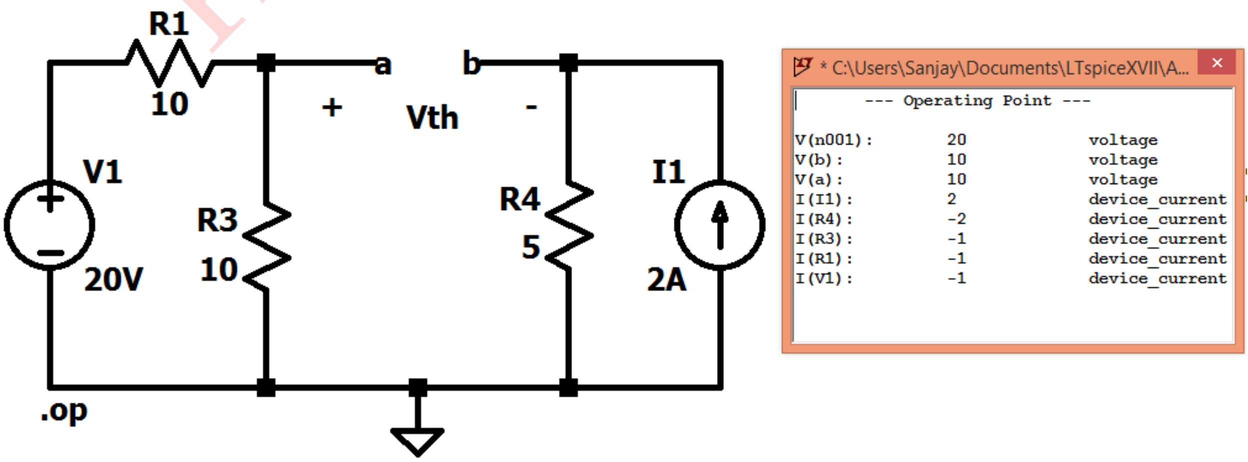

Figure 47: Circuit Schematic for V_{th} and Simulated Results

$V_{th} = V_a - V_b = 10 - 10 = 0V$

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
V_{th}	0V	0V

Table 8: Numerical 6:- Calculation of V_{th}

II. Simulation of circuit to find R_{th}

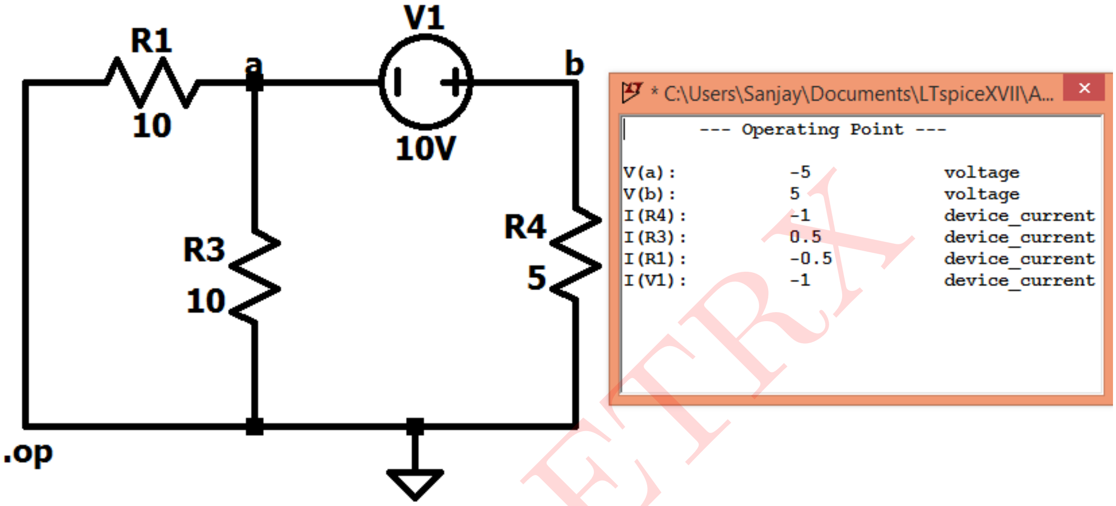

Figure 48: Circuit Schematic for R_{th} and Simulated Results

$$R_{th} = \frac{V1}{I(V1)} = \frac{10}{1} = 10\Omega$$

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
R_{th}	10Ω	10Ω

Table 9: Numerical 6:- Calculation of R_{th}

III. Simulation of circuit to find i_x

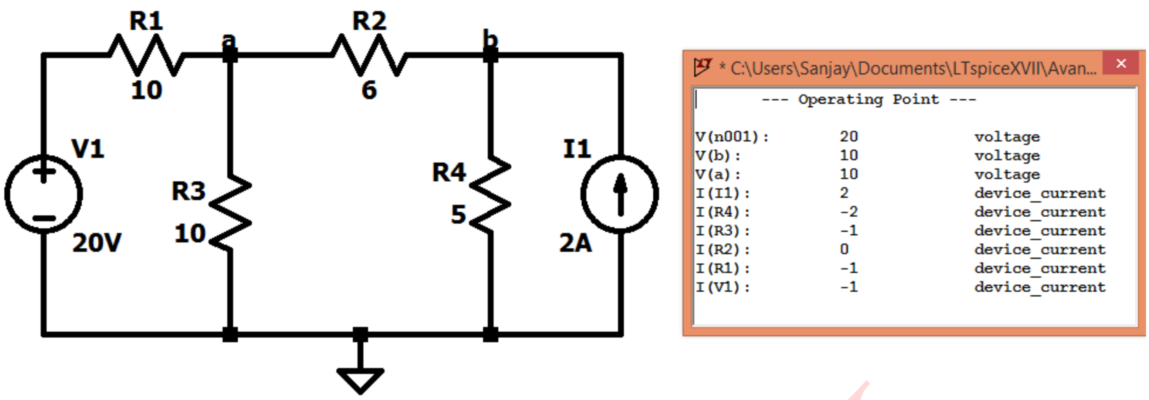

Figure 49: Circuit Schematic for i_x and Simulated Results

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
i_x	0A	0A

Table 10: Numerical 6:- Calculation of i_x

Numerical 7: With the help of Norton's Theorem, find V_o in the circuit shown in figure 50

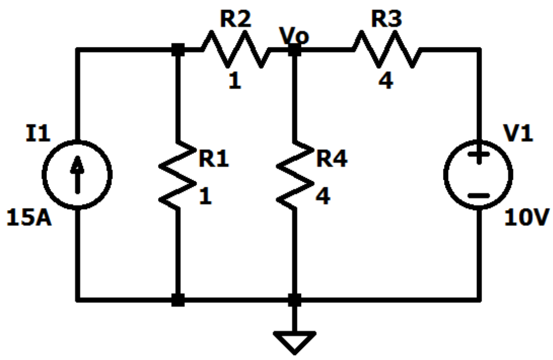

Figure 50: Circuit 7

Solution:

I. Calculation of I_{sc}

We will remove the 4Ω resistor and consider short-circuit current $I_N = I_{sc}$.

We will use mesh analysis to find the currents through the loops of the circuit.

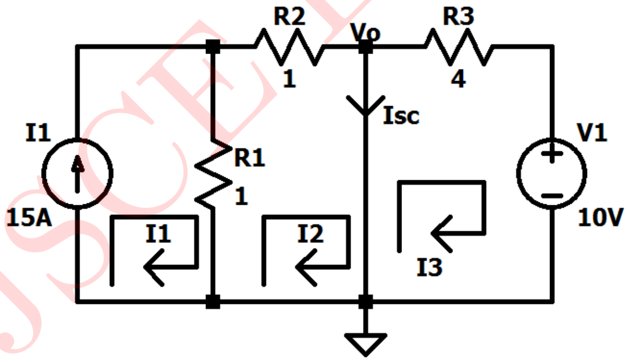

Figure 51: Circuit for calculation of I_{sc}

Assume mesh currents I_1 and I_2 flowing through loops 1 and 2 in clockwise direction

From the figure 2, we can see that:

$I_1 = 15A$ ......(i)

Applying KVL to loop 2, we get:

$-1(I_2 - I_1) - I_2 = 0$

$\therefore I_1 - 2I_2 = 0$ ......(ii)

Solving (i) and (ii) we get

$I_2 = 7.5A$ ......(iii)

Applying KVL to loop 3, we get:

$-4I_3 - 10 = 0$

$\therefore I_3 = -2.5A$ ......(iv)

Using (i) and (iv) we get

$I_{sc} = I_2 - I_3$

$= 7.5 - (-2.5)$

$\therefore \mathbf{I_{sc} = 10A}$

II. Calculation of R_N

Replacing all voltage and current sources by short and open circuit respectively we get,

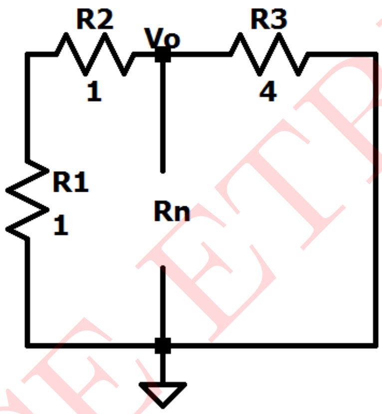

Figure 52: Circuit for calculation of R_N

1Ω and 1Ω resistors are connected in series

$\therefore R_s = 1 + 1 = 2\Omega$

$\therefore$The circuit is simplified as shown in figure 53:

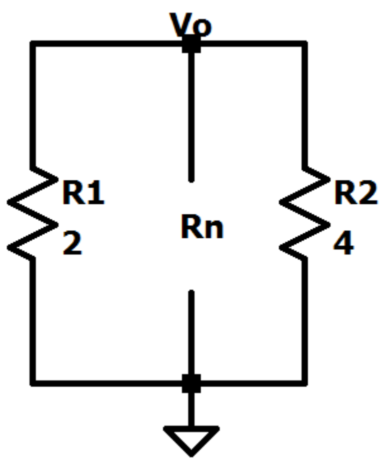

Figure 53: Simplified Circuit 7a for figure 52

The resistors 2Ω and 4Ω are connected in parallel.

$$\therefore R_p = 2 \parallel 4$$

$$= \frac{2 \times 4}{2+4}$$

$$= 1.3333\Omega$$

$\therefore \mathbf{R_N = 1.3333\Omega}$

$\therefore$ The Norton's Equivalent circuit is as shown in figure 54:

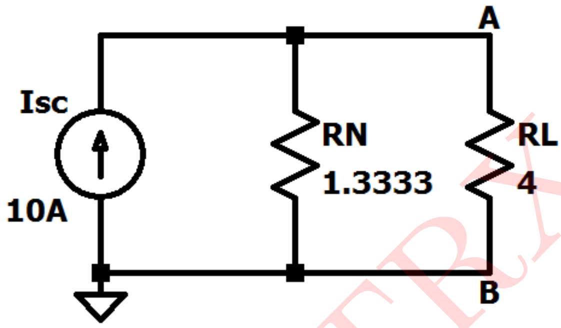

Figure 54: Norton's Equivalent Circuit

$\therefore$ By current division rule, we have

$$I_{(RL)} = \frac{10 \times 1.3333}{1.3333+4} = 2.5A$$

$$\therefore V_o = I_{(RL)} \times R_L$$

$$= 2.5 \times 4$$

$$= 10V$$

$\therefore \mathbf{V_o = 10V}$

SIMULATED RESULTS:

The given circuit is simulated in LTspice and the results obtained are as follows:

I. Simulation of circuit to find I_{sc}

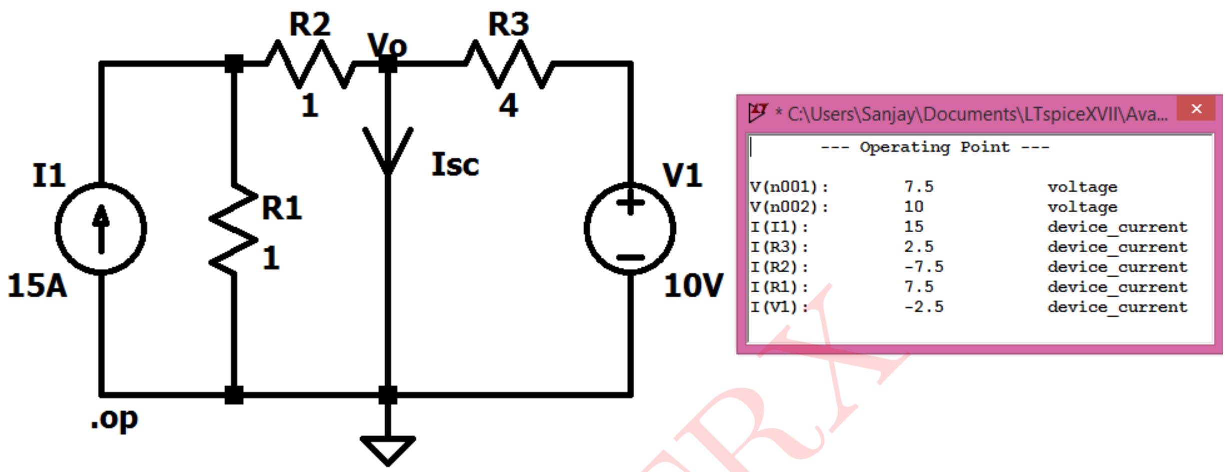

Figure 55: Circuit Schematic for I_{sc} and Simulated Results

$I_{sc} = I_{R3} - I_{R2} = 2.5 - (-7.5) = 10A$

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
I_{sc}	10A	10A

Table 11: Numerical 7:- Calculation of I_{sc}

II. Simulation of circuit to find R_N

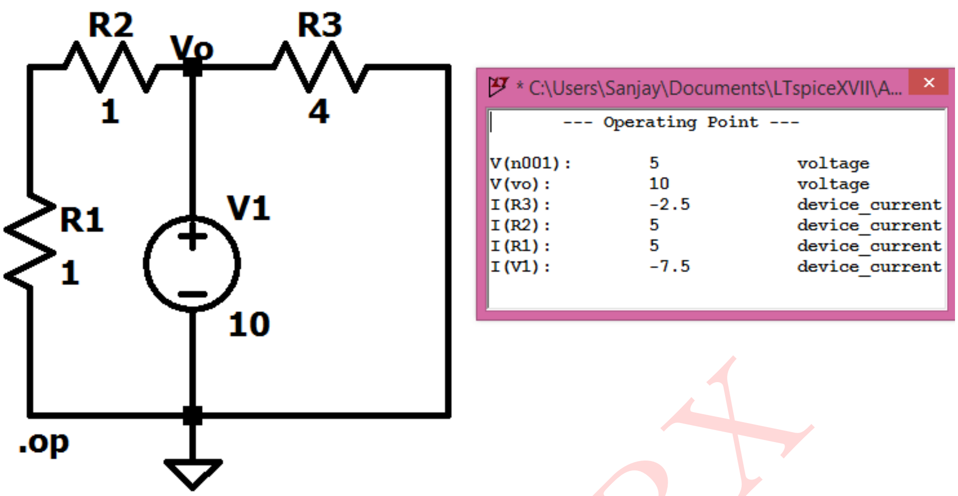

Figure 56: Circuit Schematic for R_N and Simulated Results

$$R_{th} = \frac{V1}{I(V1)} = \frac{10}{7.5} = 1.3333\Omega$$

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
R_N	1.3333Ω	1.3333Ω

Table 12: Numerical 7:- Calculation of R_N

III. Simulation of circuit to find V_o

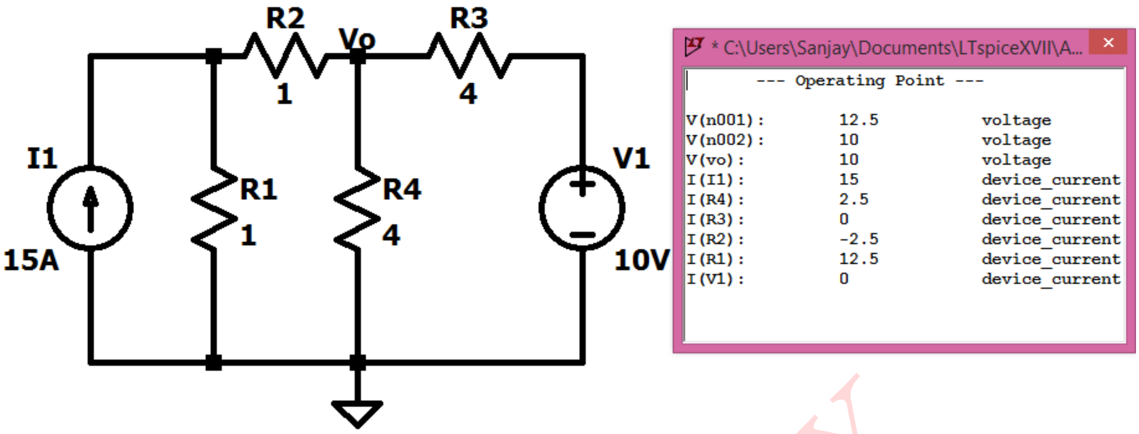

Figure 57: Circuit Schematic for V_o and Simulated Results

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
V_o	10V	10V

Table 13: Numerical 7:- Calculation of V_o

Numerical 8: For the circuit given in figure 58, calculate the current in the 6Ω resistor using Norton's theorem

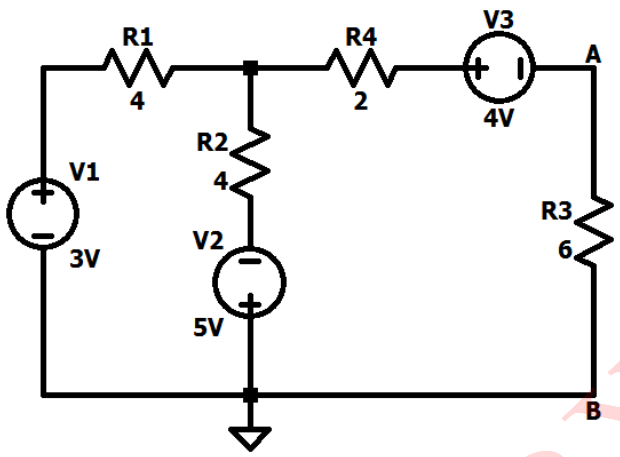

Figure 58: Circuit 8

Solution:

I. Calculation of I_{sc}

We will remove the 6Ω resistor and consider short-circuit current $I_N = I_{sc}$ across terminals A and B

We will use mesh analysis to find the currents through the loops of the circuit.

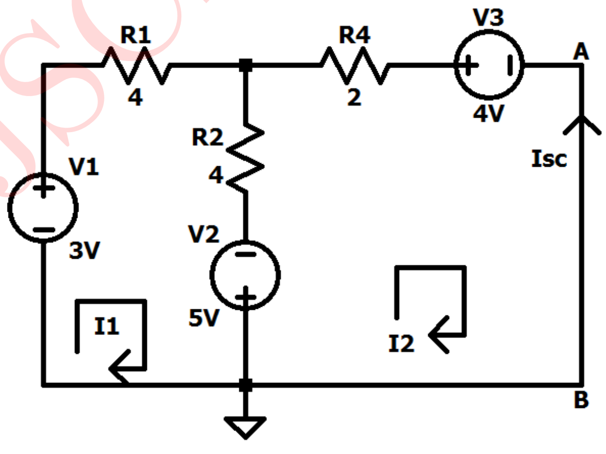

Figure 59: Circuit for calculation of I_{sc}

Assume mesh currents I_1 and I_2 flowing through loops 1 and 2 in clockwise direction

Applying KVL to loop 1, we get:

$3 - 4I_1 - 4(I_1 - I_2) + 5 = 0$

$\therefore -8I_1 + 4I_2 = -8$ ......(i)

Applying KVL to loop 2, we get:

$-2I_2 - 4 - 5 - 4(I_2 - I_1) = 0$

$\therefore 4I_1 - 6I_2 = 9$ ......(ii)

Solving (i) and (ii) we get,

$\mathrm{I_1} = 0.375\mathrm{A}$ and $\mathrm{I_2} = -1.25\mathrm{A}$

From the figure we see that

$\mathrm{I_{sc}} = -\ \mathrm{I_2}$

$\therefore \mathbf{I_{sc} = 1.25A}$

II. Calculation of $\mathbf{R_N}$

Replacing all voltage sources by short circuit we get,

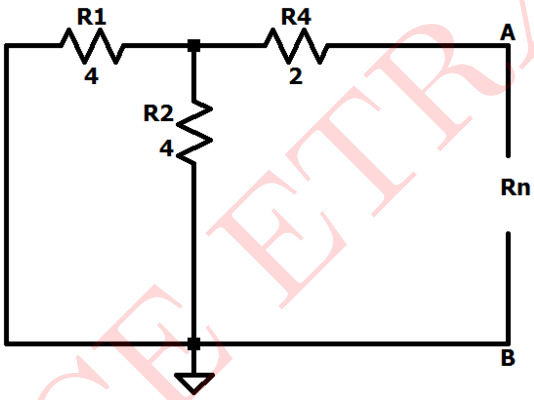

Figure 60: Circuit for calculation of $\mathrm{R_N}$

The resistors 4Ω and 4Ω resistors are connected in parallel and this combination is in series with 2Ω

$$\begin{aligned} \mathrm{R_N} &= (4||4) + 2 \\ &= \frac{4 \times 4}{4+4} + 2 \\ &= 4\Omega \end{aligned}$$

$\therefore \mathbf{R_N = 4\Omega}$

∴ The Norton's Equivalent circuit is as shown in figure 61:

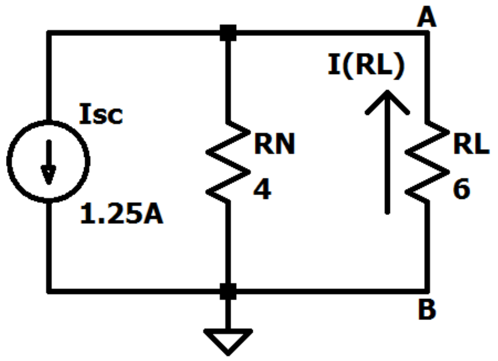

Figure 61: Norton's Equivalent Circuit

∴ By current division rule, we have

$$I_{(RL)} = \frac{1.25 \times 4}{4+6} = 0.5A$$

∴ $\mathbf{I_{(RL)} = 0.5A}$

SIMULATED RESULTS:

The given circuit is simulated in LTspice and the results obtained are as follows:

I. Simulation of circuit to find I_{sc}

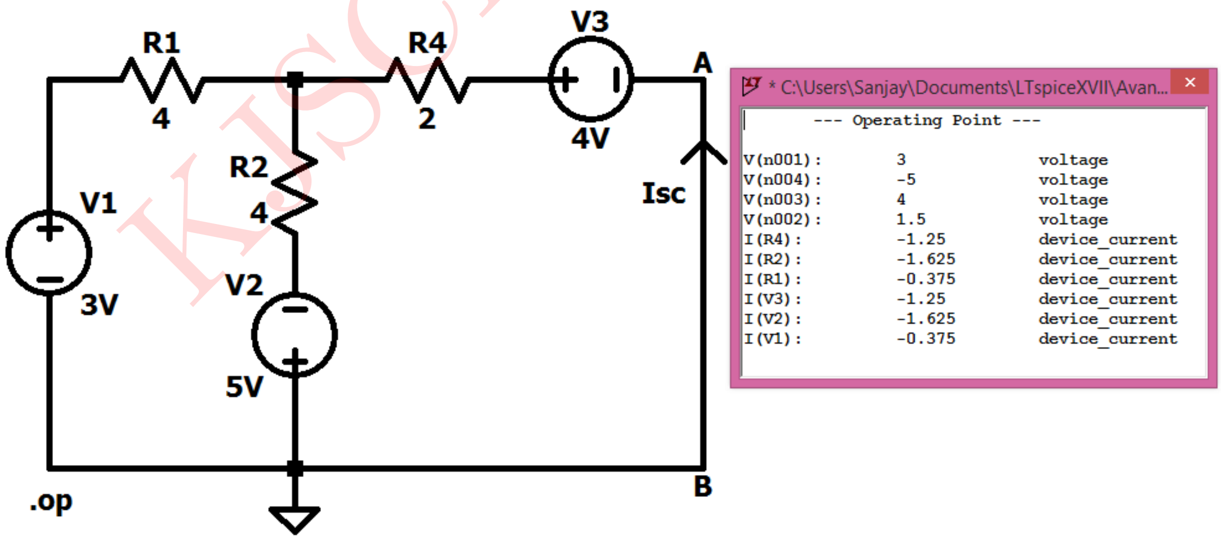

Figure 62: Circuit Schematic for I_{sc} and Simulated Results

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
I_{sc}	1.25A	1.25A

Table 14: Numerical 8:- Calculation of I_{sc}

II. Simulation of circuit to find R_N

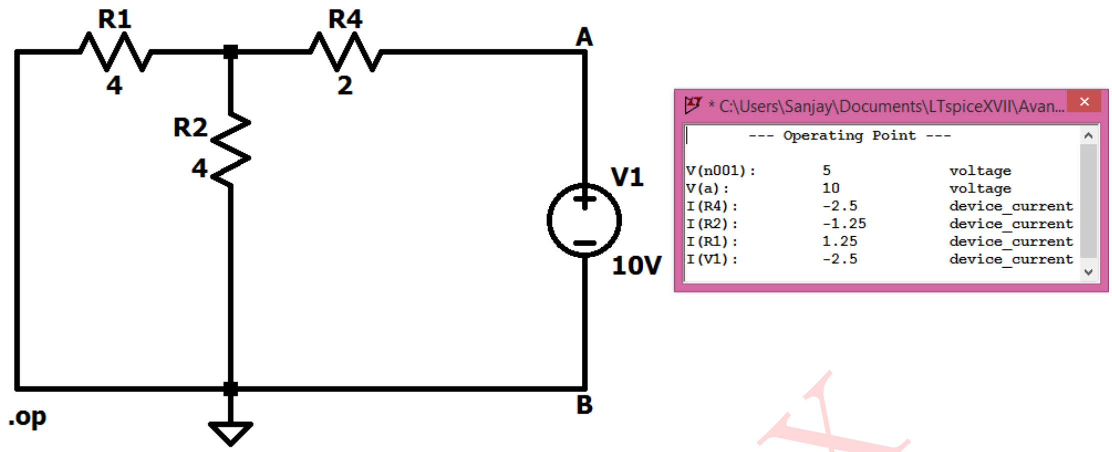

Figure 63: Circuit Schematic for R_N and Simulated Results

$$R_N = \frac{V1}{I(V1)} = \frac{10}{2.5} = 4\Omega$$

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
R_N	4Ω	4Ω

Table 15: Numerical 8:- Calculation of R_N

III. Simulation of circuit to find $I_{(R3)}$

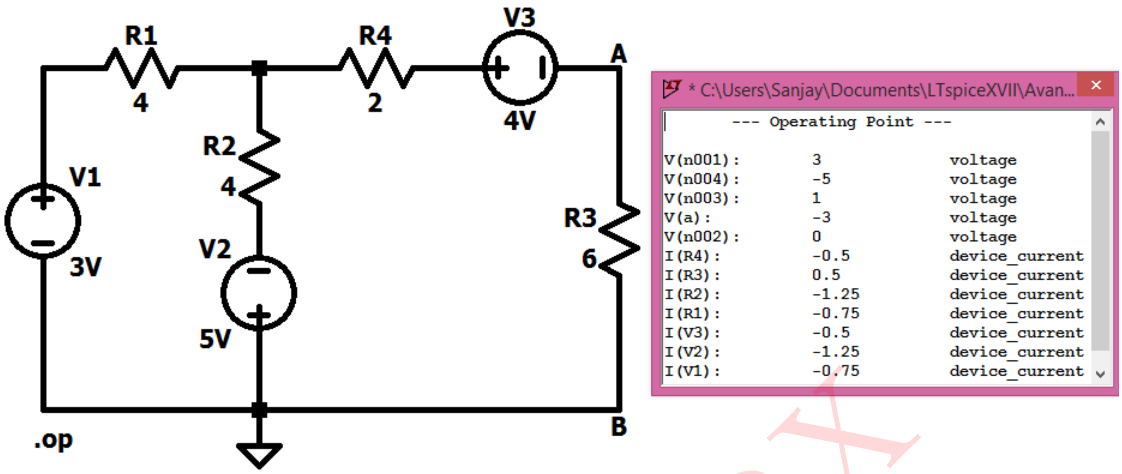

Figure 64: Circuit Schematic for I_{R3} and Simulated Results

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
I_{R3}	0.5A	0.5A

Table 16: Numerical 8:- Calculation of $I_{(R3)}$

Numerical 9: Obtain the Thevenin's and Norton's equivalent circuits at terminals a and b.

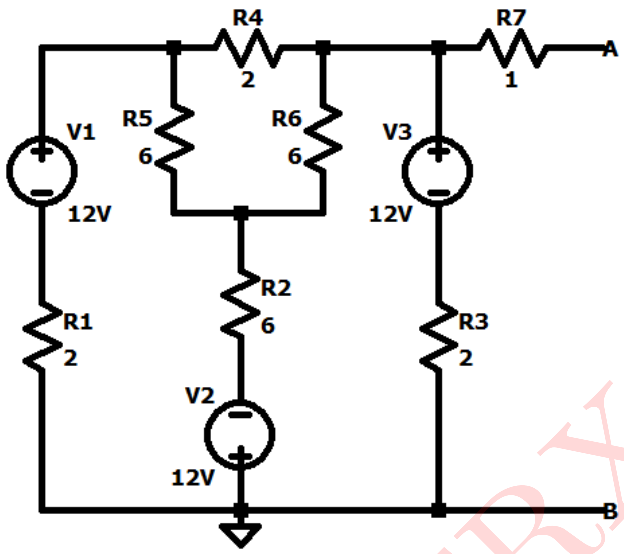

Figure 65: Circuit 9

Solution:

THEVENIN'S EQUIVALENT CIRCUIT:-

I. Calculation of V_{th}

Consider open-circuit voltage $V_{ab} = V_{th}$ across terminals a-b.

We will use mesh analysis to find the currents through the loops of the circuit.

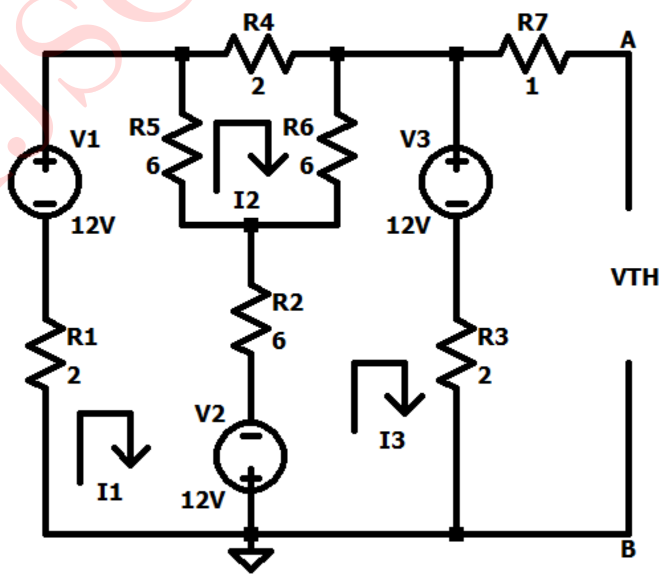

Figure 66: Circuit for calculation of V_{th}

Assume mesh currents I_1, I_2 and I_3 flowing through loops 1, 2 and 3 in clockwise direction

Applying KVL to loop 1, we get:

$-2I_1 + 12 - 6(I_1 - I_2) - 6(I_1 - I_3) + 12 = 0$

$\therefore -14I_1 + 6I_2 + 6I_3 = -24$ ......(i)

Applying KVL to loop 2, we get:

$-2I_2 - 6(I_2 - I_3) - 6(I_2 - I_1) = 0$

$\therefore 6I_1 - 14I_2 + 6I_3 = 0$ ......(ii)

Applying KVL to loop 3, we get:

$-12 - 2I_3 - 12 - 6(I_3 - I_1) - 6(I_3 - I_2) = 0$

$\therefore 6I_1 + 6I_2 - 14I_3 = 24$ ......(iii)

Solving (i), (ii) and (iii) we get,

$\mathrm{I}_1 = 1.2\mathrm{A}$, $\mathrm{I}_2 = 0\mathrm{A}$ and $\mathrm{I}_3 = -1.2\mathrm{A}$

Equation of V_{th}:

$-2I_3 + 12 = \mathrm{V}_{\mathrm{th}}$

$\therefore$ **$\mathbf{V}_{\mathbf{th}} = \mathbf{9.6V}$**

II. Calculation of $\mathbf{R}_{\mathbf{th}}$

Replacing all voltage and current sources by short and open circuit respectively we get,

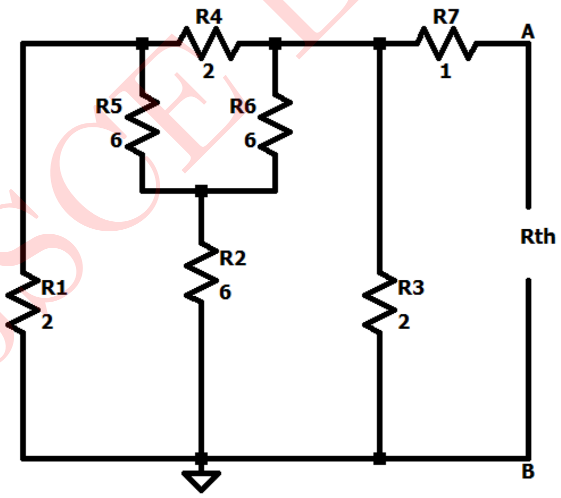

Figure 67: Circuit for calculation of R_{th}

The resistors 6Ω, 6Ω and 2Ω are connected in delta.

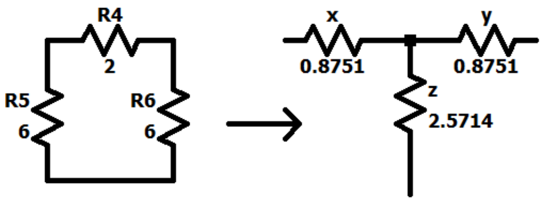

Figure 68: Delta - Star Conversion

Converting delta to star, we have:

$$x = \frac{6 \times 2}{6 + 2 + 6} = 0.8751\Omega$$

$$y = \frac{2 \times 6}{2 + 6 + 6} = 0.8571\Omega$$

$$z = \frac{6 \times 6}{6 + +20} = 2.5714\Omega$$

$\therefore$ The circuit is simplified as shown in figure 69:

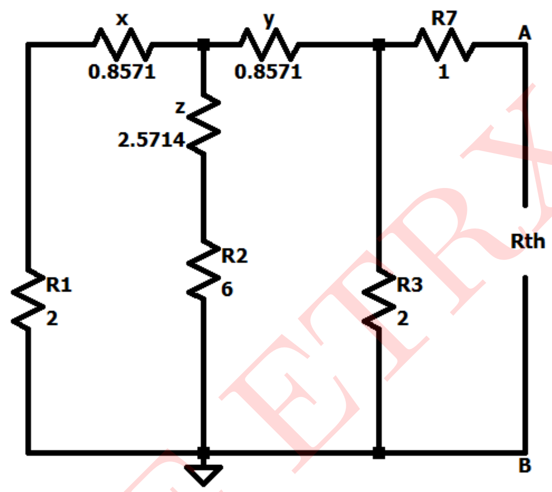

Figure 69: Simplified Circuit 9a for figure 67

The resistors 6Ω and 2.5714Ω are connected in series.

$\therefore R_s = 6 + 2.5714 = 8.5714\Omega$

Similarly,the resistors 2Ω and 0.8571Ω are connected in series.

$\therefore R_s = 2 + 0.8571 = 2.8571\Omega$

$\therefore$ The circuit is simplified as shown in figure 70:

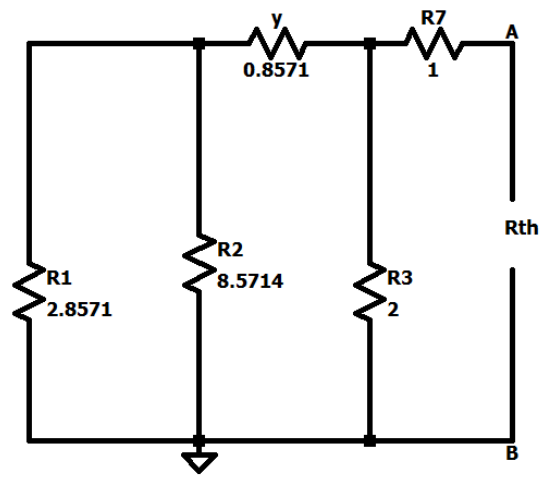

Figure 70: Simplified Circuit 9b for figure 69

The resistors 8.5714Ω and 2.8571Ω are connected in parallel.

$$\therefore R_{\mathrm{p}} = 8.5714 \,||\, 2.8571$$
$$= \frac{8.5714 \times 2.8571}{8.5714 + 2.8571}$$
$$= 2.1428\ \Omega$$

∴ The circuit is simplified as shown in figure 71:

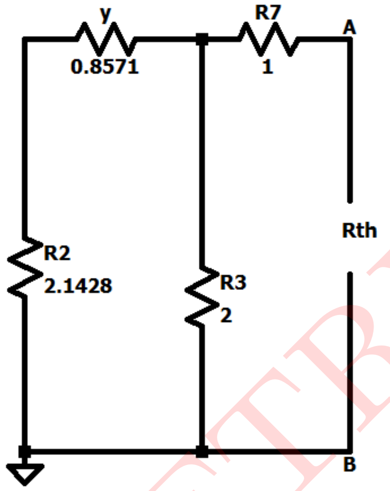

Figure 71: Simplified Circuit 9c for figure 70

The resistors 2.1428Ω and 0.8571Ω are connected in series.

$\therefore R_{\mathrm{s}} = 0.8571 + 2.1428 = 3\Omega$

∴ The circuit is simplified as shown in figure 72:

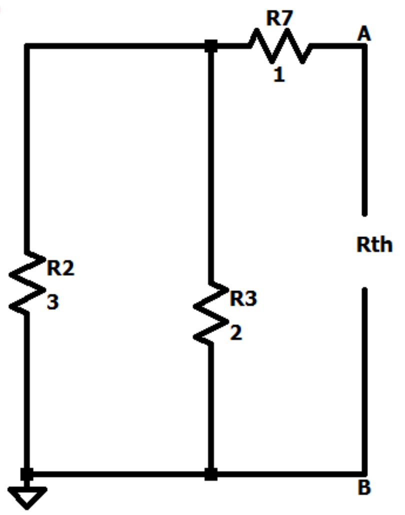

Figure 72: Simplified Circuit 9d for figure 71

The resistors 3Ω and 2Ω are connected in parallel.

$$\begin{aligned}\therefore R_{\mathrm{p}} &= 3 \,||\, 2 \\ &= \frac{3\times 2}{3+2} \\ &= 1.2\Omega\end{aligned}$$

$\therefore$ The circuit is simplified as shown in figure 73:

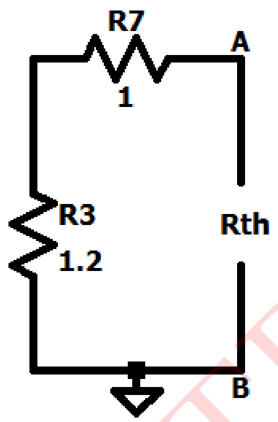

Figure 73: Simplified Circuit 9e for figure 72

The resistors 1Ω and 1.2Ω are connected in series.

$\therefore R_{\mathrm{s}} = 1 + 1.2 = 2.2\Omega$

$\therefore \mathbf{R_{th}} = \mathbf{2.2}\Omega$

$\therefore$ The Thevenin's Equivalent circuit is as shown in figure 74:

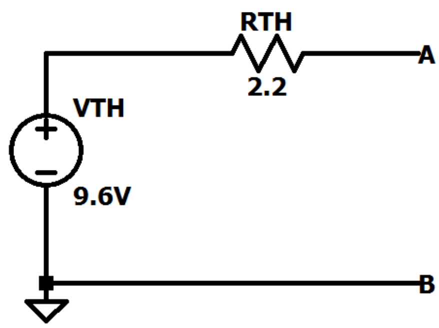

Figure 74: Thevenin's Equivalent Circuit

NORTON'S EQUIVALENT CIRCUIT :-

I. Calculation of I_{sc}

Consider short-circuit current $I_N = I_{sc}$ between terminals a and b.

We will use mesh analysis to find the currents through the loops of the circuit.

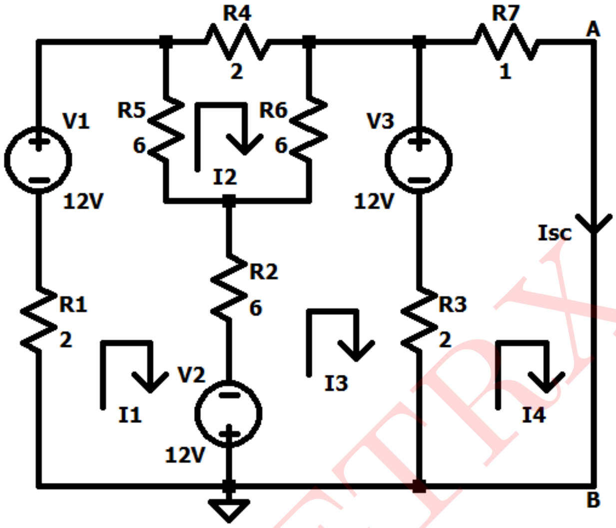

Figure 75: Circuit for calculation of I_{sc}

Assume mesh currents I_1, I_2, I_3 and I_4 flowing through loops 1, 2, 3 and 4 in clockwise direction

Applying KVL to loop 1, we get:

$$-2I_1 + 12 - 6(I_1 - I_2) - 6(I_1 - I_3 + 12) = 0$$
$$\therefore -14I_1 - 6I_2 + 6I_3 = -24 \qquad \text{......(i)}$$

Applying KVL to loop 2, we get:

$$-2I_2 - 6(I_2 - I_3) - 6(I_2 - I_1) = 0$$
$$\therefore 6I_1 - 14I_2 + 6I_3 = 0 \qquad \text{......(ii)}$$

Applying KVL to loop 3, we get:

$$-12 - 2(I_3 - I_4) - 12 - 6(I_3 - I_1) - 6(I_3 - I_2) = 0$$
$$\therefore 6I_1 + 6I_2 - 14I_3 + 2I_4 = 24 \qquad \text{......(iii)}$$

Applying KVL to loop 4, we get:

$$-I_4 - 2(I_4 - I_3) + 12 = 0$$
$$\therefore 2I_3 - 3I_4 = 24 \qquad \text{......(iv)}$$

Solving (i), (ii), (iii) and (iv) we get,

$I_1 = 2.5090A$, $I_2 = 1.3090A$, $I_3 = 0.5454A$ and $I_4 = 4.3636A$

$\therefore \mathbf{I_{sc} = I_4 = \ 4.3636A}$

II. Calculation of R_N

The value of R_{th} and R_N will be same.

$\therefore \mathbf{R_N = R_{th} = 2.2\Omega}$

∴ The Norton's Equivalent circuit is as shown in figure 76:

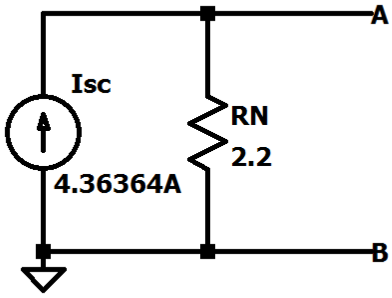

Figure 76: Norton's Equivalent Circuit

SIMULATED RESULTS:

The given circuit is simulated in LTspice and the results obtained are as follows:

I. Simulation of circuit to find V_{th}

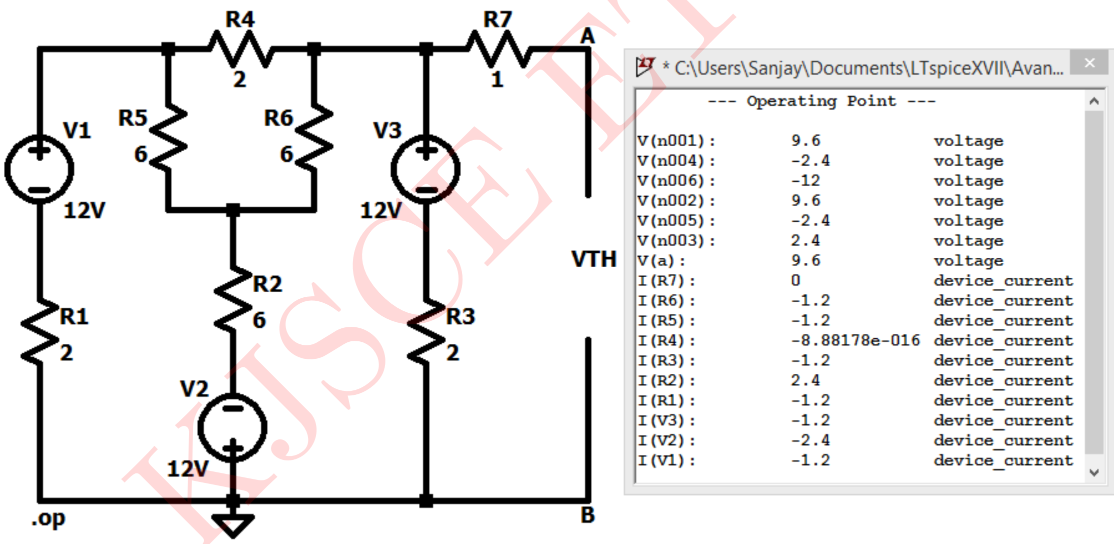

Figure 77: Circuit Schematic for V_{th} and Simulated Results

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
V_{th}	9.6V	9.6V

Table 17: Numerical 9:- Calculation of V_{th}

II. Simulation of circuit to find R_{th}

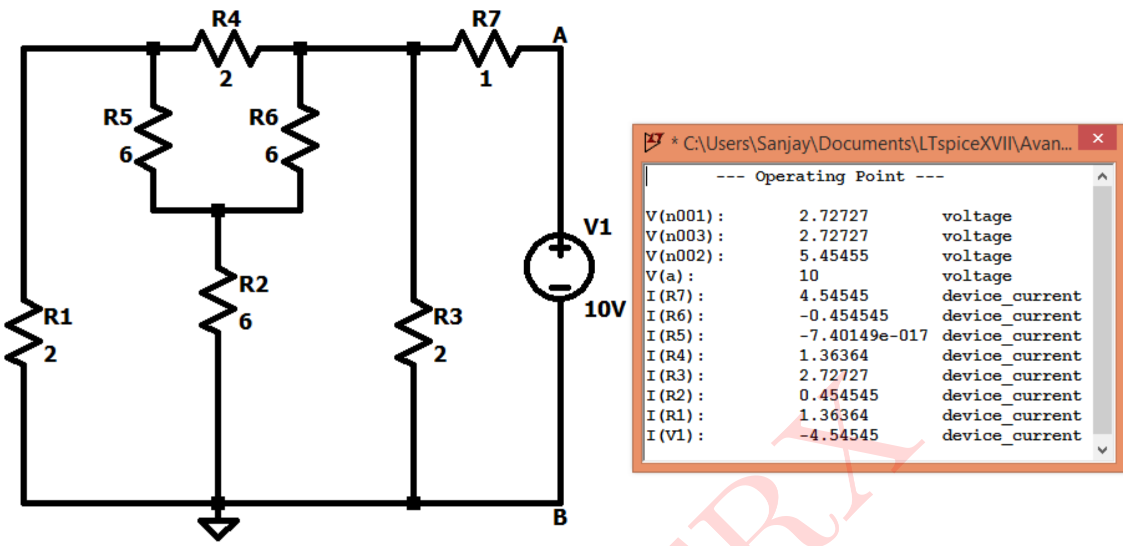

Figure 78: Circuit Schematic for R_{th} and Simulated Results

$$R_{th} = \frac{V1}{I(V1)} = \frac{10}{4.5454} = 2.2\Omega$$

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
R_{th}	10Ω	10Ω

Table 18: Numerical 9:- Calculation of R_{th}

III. Simulation of circuit to find I_{sc}

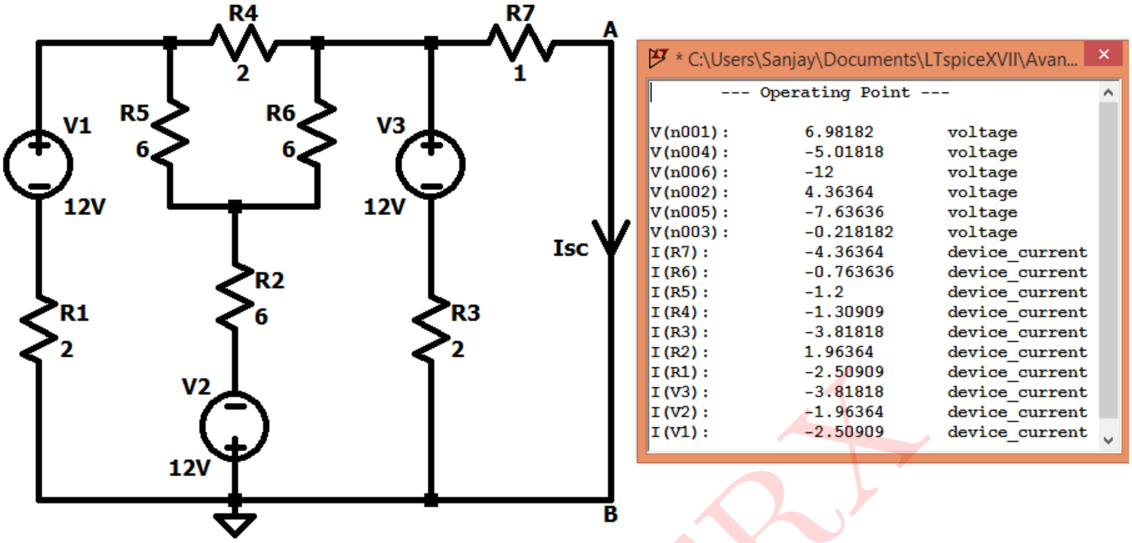

Figure 79: Circuit Schematic for I_{sc} and Simulated Results

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
I_{sc}	4.3636A	4.3636A

Table 19: Numerical 9:- Calculation of I_{sc}

Numerical 10: For the circuit given in figure 80, find the maximum value of R_L

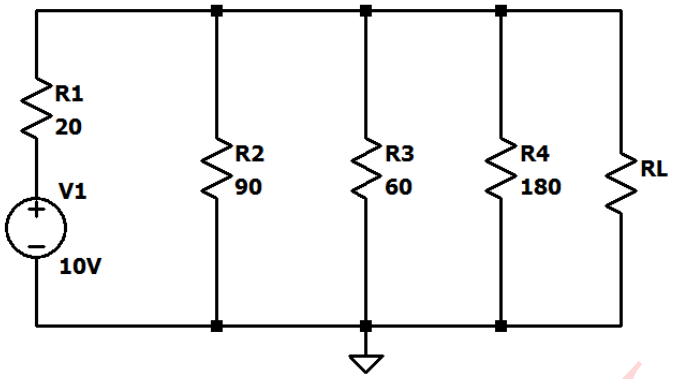

Figure 80: Circuit 10

Solution:

We will use Thevenin's Theorem to calculate V_{th} and R_{th}

I. Calculation of V_{th}

We will remove R_L and consider open-circuit voltage V_{th} across terminals.

We will use mesh analysis to find the currents through the loops of the circuit.

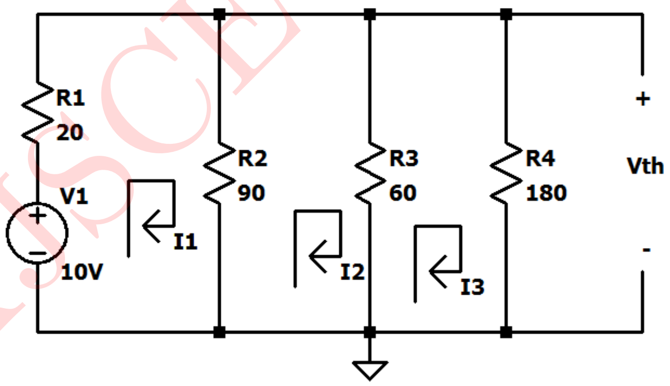

Figure 81: Circuit for calculation of V_{th}

Assume mesh currents I_1, I_2 and I_3 flowing through loops 1, 2 and 3 in clockwise direction

Applying KVL to loop 1, we get:

$10 - 20I_1 - 90(I_1 - I_2) = 0$

$\therefore -110I_1 + 90I_2 = -10$ ......(i)

Applying KVL to loop 2, we get:

$-90(I_2 - I_1) - 60(I_2 - I_3) = 0$

$\therefore 90I_1 - 150I_2 + 60I_3 = 0$ ......(ii)

Applying KVL to loop 3 , we get:

$-60(I_3 - I_2) - 180I_3 = 0$

$\therefore 60I_2 - 240I_3 = -0$ ......(iii)

Solving (i), (ii) and (iii) we get

$I_1 = 0.2A$, $I_2 = 1.3333A$ and $I_3 = 0.3333A$

Equation of V_{th}:

$10 - 20I_1 = V_{th}$

Using (i) we get

$\therefore \mathbf{V_{th} = 6V}$

II. Calculation of R_{th}

Replacing all voltage and current sources by short and open circuit respectively we get,

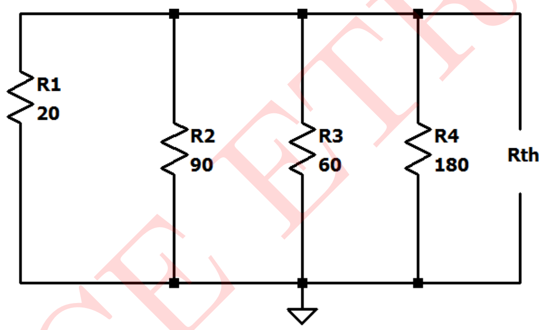

Figure 82: Circuit for calculation of R_{th}

The resistors 20Ω and 90Ω are connected in parallel.

$$\therefore R_p = 20 \mid\mid 90 = \frac{20 \times 90}{20 + 90} = 16.3636\Omega$$

$\therefore$The circuit is simplified as shown in figure 83:

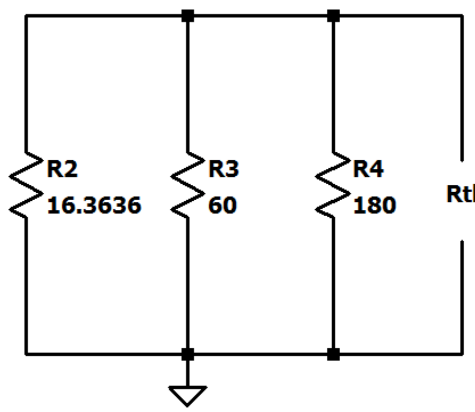

Figure 83: Simplified Circuit 10a for figure 82

The resistors 16.3636Ω and 60Ω are connected in parallel.

$$\therefore R_{\text{p}} = 16.3636 \,||\, 60$$
$$= \frac{16.3636 \times 60}{16.3636 + 60}$$
$$= 12.8571\Omega$$

∴The circuit is simplified as shown in figure 84:

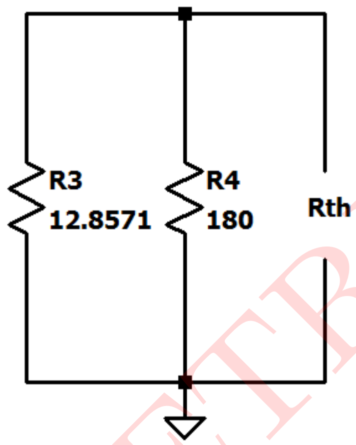

Figure 84: Simplified Circuit 10b for figure 83

The resistors 12.8571Ω and 180Ω are connected in parallel.

$$\therefore R_{\text{p}} = 12.8571 \,||\, 180$$
$$= \frac{12.8571 \times 180}{12.8571 + 180}$$
$$= 12\Omega$$

$\therefore \mathbf{R_{th} = 12\Omega}$

According to Maximum Power Transfer Theorem, for maximum power transfer, $R_{th} = R_L$

$\therefore \mathbf{R_L = 12\Omega}$

∴ The Thevenin's Equivalent circuit is as shown in figure 85:

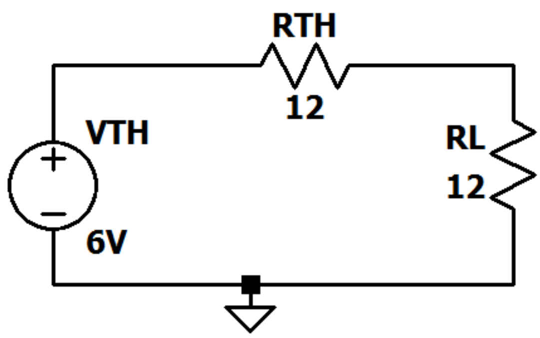

Figure 85: Thevenin's Equivalent Circuit

$$\therefore \mathrm{P}_{\max} = \frac{{V_{\mathrm{th}}}^2}{4 \times R_{\mathrm{L}}}$$
$$= \frac{6^2}{4 \times 12}$$
$$= 0.75\mathrm{W}$$
$$= 750\mathrm{mW}$$

SIMULATED RESULTS:

The given circuit is simulated in LTspice and the results obtained are as follows:

I. Simulation of circuit to find $\mathbf{V_{th}}$

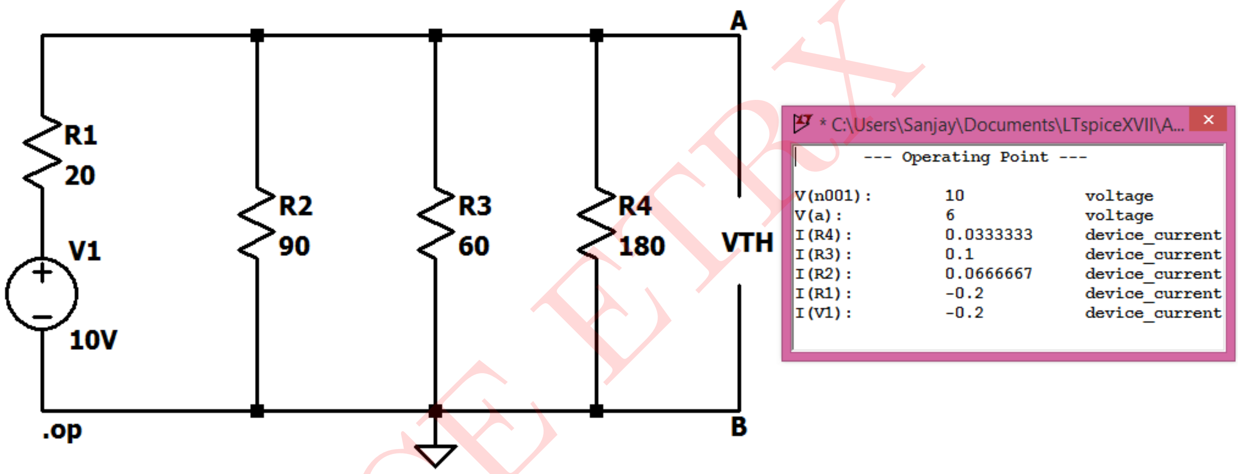

Figure 86: Circuit Schematic for V_{th} and Simulated Results

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
V_{th}	6V	6V

Table 20: Numerical 10 :- Calculation of V_{th}

II. Simulation of circuit to find R_{th}

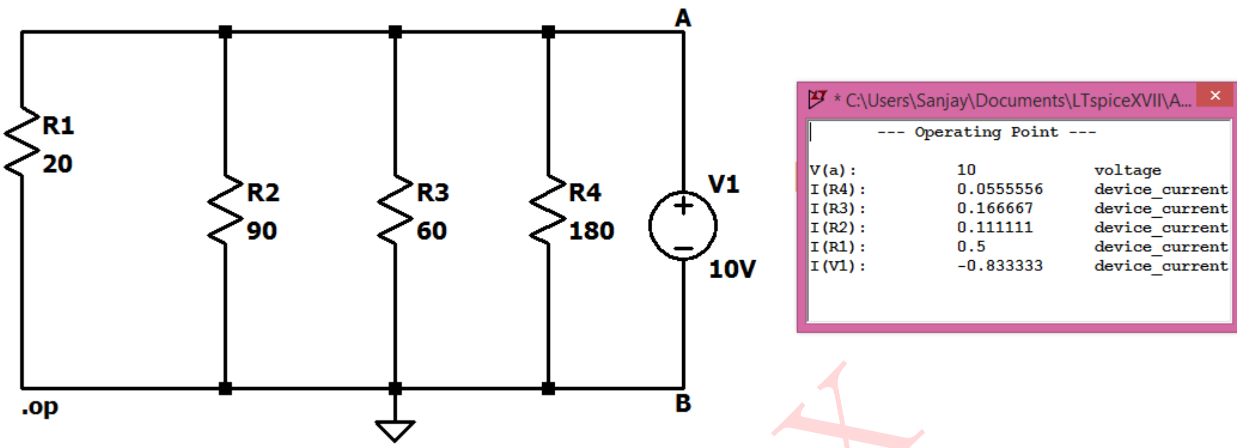

Figure 87: Circuit Schematic for R_{th} and Simulated Results

$$R_{th} = \frac{V1}{I(V1)} = \frac{10}{0.83333} = 12\Omega$$

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
R_{th}	12Ω	12Ω

Table 21: Numerical 10 :- Calculation of R_{th}

II. Simulation of circuit to find P_{max}

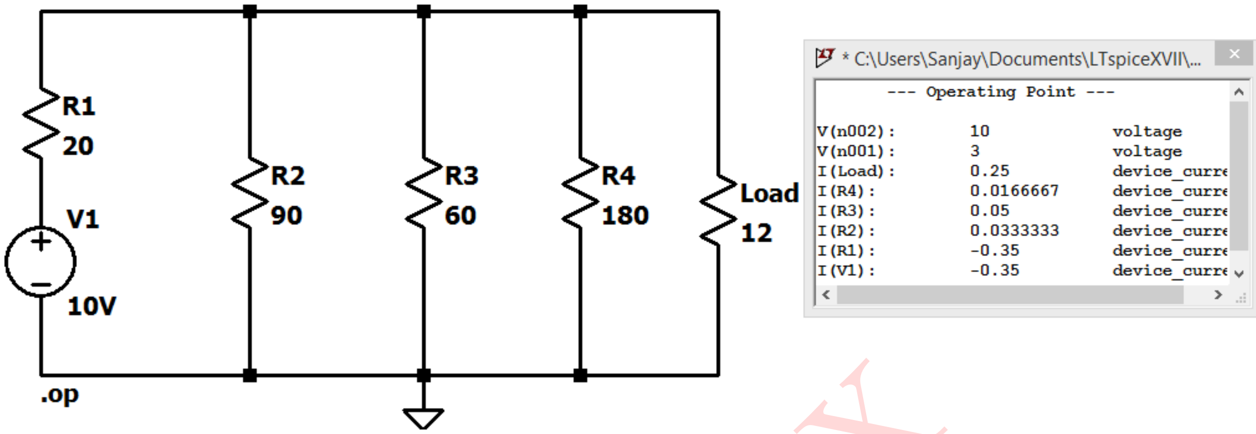

Figure 88: Circuit Schematic for P_{max} and Simulated Results

$P_{max} = I^2 \times R = 0.25^2 \times 12 = 750\text{mW}$

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
P_{max}	750mW	750mW

Table 22: Numerical 10 :- Calculation P_{max}

Numerical 11: a) For the circuit given in figure 89, obtain the Thevenin equivalent at terminals a-b.
b) Calculate the current for $R_L = 8\Omega$
c) Find R_L for maximum power deliverable to R_L
d) Determine that maximum power

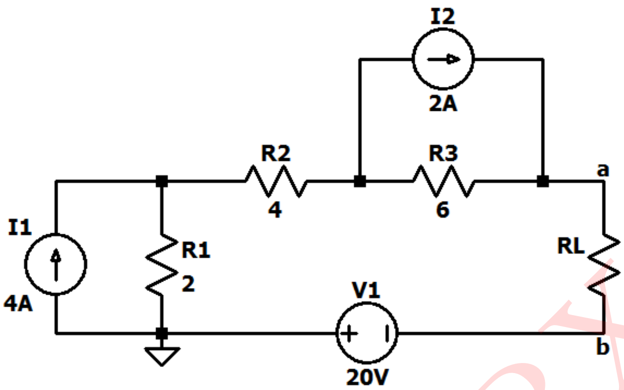

Figure 89: Circuit 11

Solution:

a) I. Calculation of $\mathbf{V_{th}}$

We will remove the R_L and consider open-circuit voltage V_{th} across terminals a-b.

We will use mesh analysis to find the currents through the loops of the circuit.

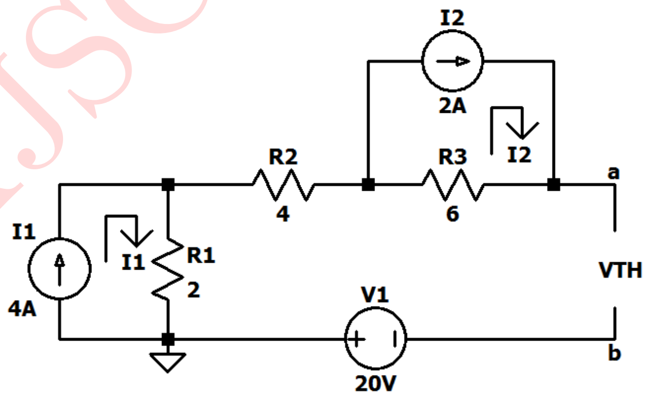

Figure 90: Circuit for calculation of V_{th}

Assume mesh currents I_1 and I_2 flowing through loops 1 and 2 in clockwise direction

From the figure, we can see that $I_1 = 4A$ and $I_2 = 2A$

Equation of V_{th}:

$2I_1 + 10I_1 + 20 = V_{th}$

Substituting values of I_1 and I_2 we get

$\therefore \mathbf{V_{th} = 40V}$

II. Calculation of R_{th}

Replacing all current sources by open circuit we get,

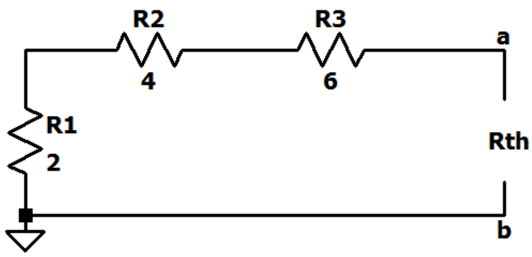

Figure 91: Circuit for calculation of R_{th}

The resistors 2Ω, 4Ω and 6Ω are connected in series.

$\therefore R_{ab} = 2\Omega + 4\Omega + 6\Omega = 12\Omega$

$\therefore \mathbf{R_{th} = 12\Omega}$

$\therefore$ The Thevenin's Equivalent circuit is as shown in figure 92:

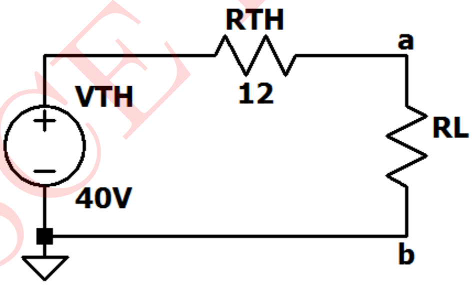

Figure 92: Thevenin's Equivalent Circuit

b) The value of R_L is to be taken as 8Ω

$\therefore$ The Thevenin's Equivalent circuit for $R_L = 8\Omega$ is as shown in figure 92:

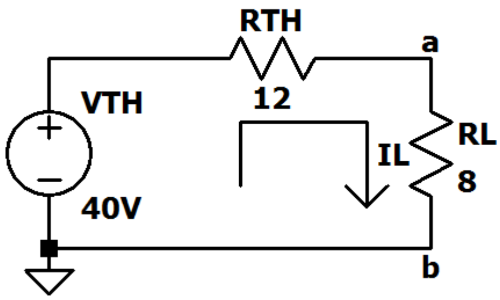

Figure 93: Thevenin's Equivalent Circuit for $R_L = 8\Omega$

$$I_L = \frac{V_{th}}{R_{th} + R_L} = \frac{40}{12+8} = 2A$$

$\therefore \mathbf{I_L = 2A}$

c) According to Maximum Power Transfer Theorem, for maximum power to be delivered, $R_{th} = R_L$

$\therefore \mathbf{R_L = 12\Omega}$

$\therefore$ The Thevenin's Equivalent circuit for $R_L = 12\Omega$ is as shown in figure 94:

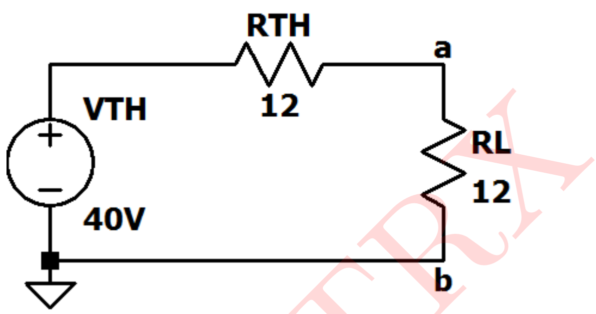

Figure 94: Thevenin's Equivalent Circuit for $R_L = 12\Omega$

$$\therefore P_{max} = \frac{{V_{th}}^2}{4 \times R_L}$$
$$= \frac{40^2}{4 \times 12}$$
$$= 33.33W$$

SIMULATED RESULTS:

The given circuit is simulated in LTspice and the results obtained are as follows:

I. Simulation of circuit to find V_{th}

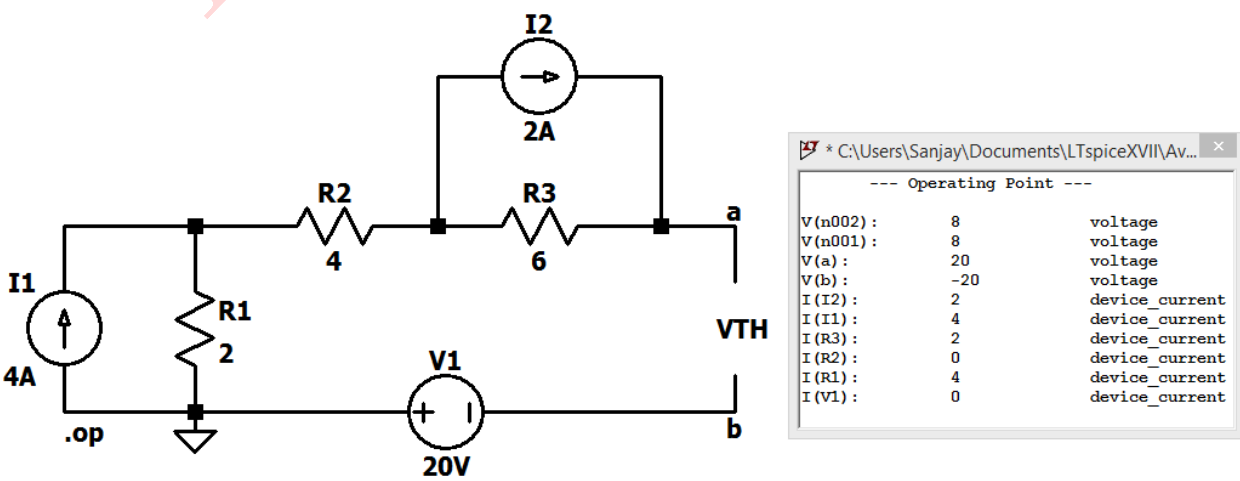

Figure 95: Circuit Schematic for V_{th} and Simulated Results

$\therefore \mathrm{V_{th}} = \mathrm{V_a} - \mathrm{V_b} = 20 - (-20) = 40\mathrm{V}$

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
$\mathrm{V_{th}}$	40V	40V

Table 23: Numerical 11:- Calculation of $\mathrm{V_{th}}$

II. Simulation of circuit to find $\mathbf{R_{th}}$

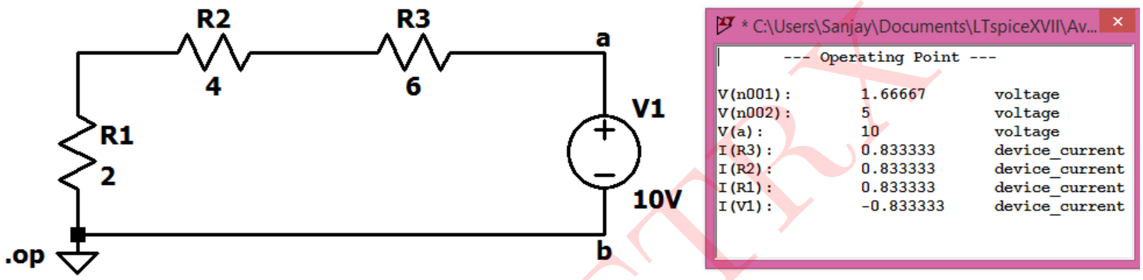

Figure 96: Circuit Schematic for $\mathrm{R_{th}}$ and Simulated Results

$$\mathrm{R_{th}} = \frac{V1}{I(V1)} = \frac{10}{0.83333} = 12\Omega$$

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
$\mathrm{R_{th}}$	12Ω	12Ω

Table 24: Numerical 11:- Calculation of $\mathrm{R_{th}}$

III. Simulation of circuit to find P_{max}

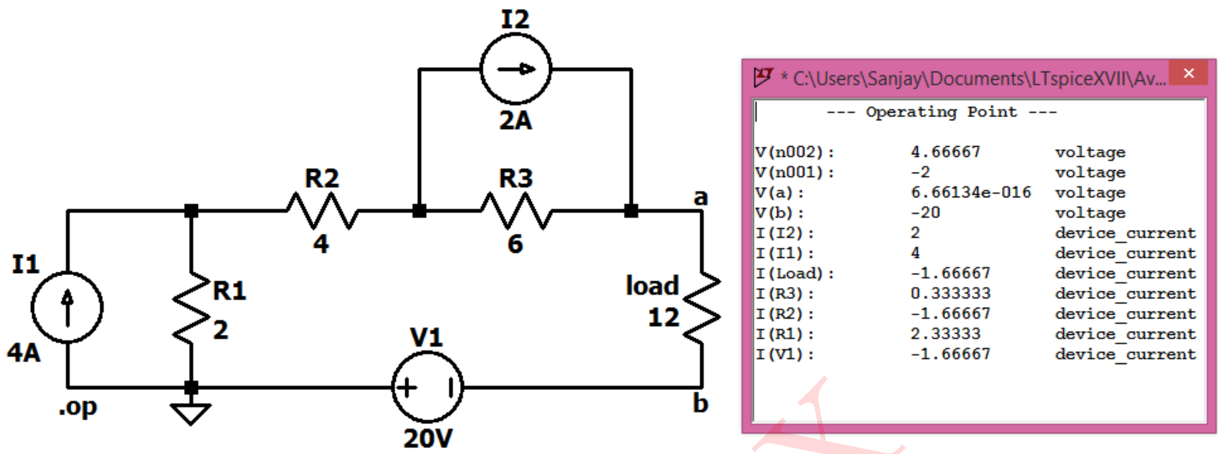

Figure 97: Circuit Schematic for P_{max} and Simulated Results

$P_{max} = I^2 \times R = 1.6667^2 \times 12 = 33.33W$

Comparison of Theoretical and Simulated values:-

Parameters	Theoretical values	Simulated values
P_{max}	33.33W	33.33W

Table 25: Numerical 11:- Calculation P_{max}