BASIC ELECTRICAL ENGINEERING

Course Code: EE100

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Module 1: DC Circuits

Theorems

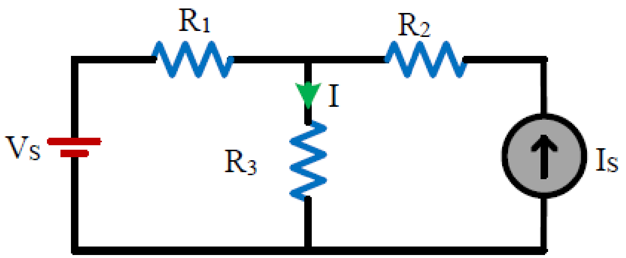
- ✓ Superposition Theorem
- ✓ Thevenin's Theorem
- ✓ Norton's Theorem
- ✓ Maximum Power transfer Theorem

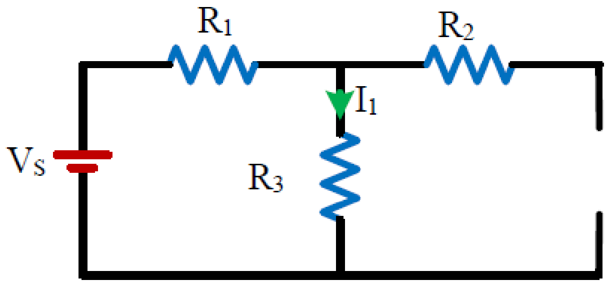
Superposition Theorem

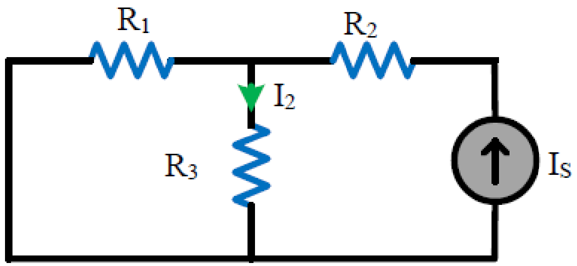
In a linear, bilateral d.c. network containing more than one energy source, the resultant potential difference across or current through any element is equal to the algebraic sum of potential differences or currents for that element produced by each source acting alone with all voltage sources replaced by short circuits and current sources replaced by open circuits.

Procedure for Superposition Theorem

1. Select one source in the circuit and replace all other voltage sources by short circuits and current sources by open circuits.
2. Determine the voltage across or current through the desired element/branch due to single source selected in step 1.
3. Repeat the above two steps for each of the remaining sources.
4. Algebraically add all the voltages across or currents through the element/branch under consideration. The sum is the actual voltage across or current through that element/branch when all the sources are acting simultaneously.







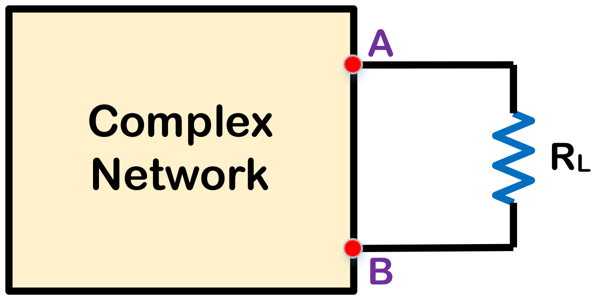
$$I = I_1 + I_2$$

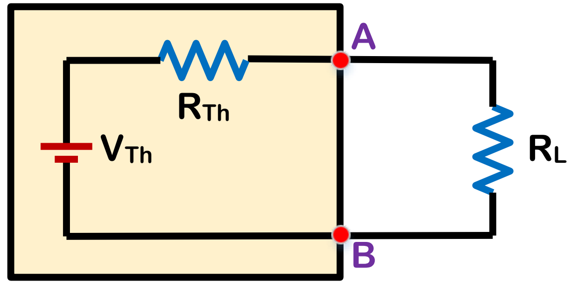
Thevenin's Theorem

Any linear, bilateral network having terminals A and B can be replaced by a single source of *e.m.f.* V_{Th} in series with a single resistance R_{Th}.

(i) The e.m.f. V_{Th} is the voltage obtained across terminals A and B with load, if any removed i.e. it is open-circuited voltage between terminals A and B.

(ii) The resistance R_{Th} is the resistance of the network measured between terminals A and B with load removed and sources of e.m.f. replaced by their internal resistances. Voltage sources are replaced with short circuits and current sources are replaced with open circuits.



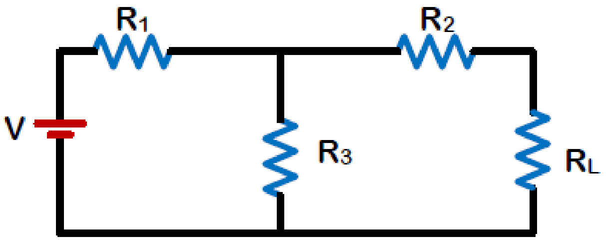


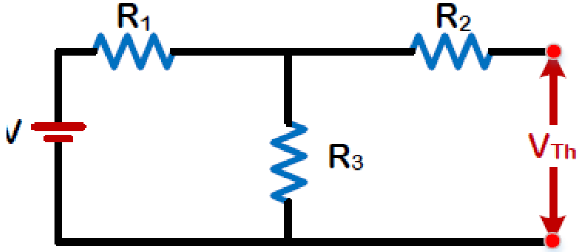
Thevenin s Equivalent Circuit

Thevenin's Theorem

Procedure for Finding Thevenin Equivalent Circuit

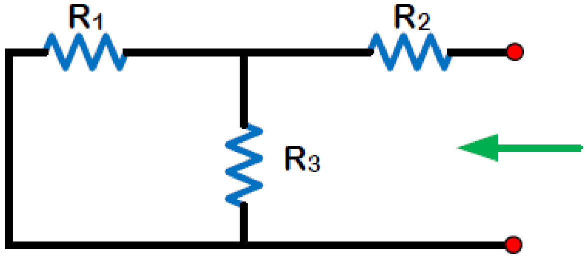
1. Open the two terminals (*i.e.*, remove any load) between which you want to find Thevenin equivalent circuit.
2. Find the open-circuit voltage between the two open terminals. It is called Thevenin voltage V_{Th}.
3. Determine the resistance between the two open terminals with all voltage sources shorted and all current sources opened. It is called Thevenin resistance R_{Th}.
4. Connect V_{Th} and R_{Th} in series to produce Thevenin equivalent circuit between the two terminals under consideration.
5. Place the load resistor removed in step (1) across the terminals of the Thevenin equivalent circuit. The load current can now be calculated using only Ohm's law and it has the same value as the load current in the original circuit.



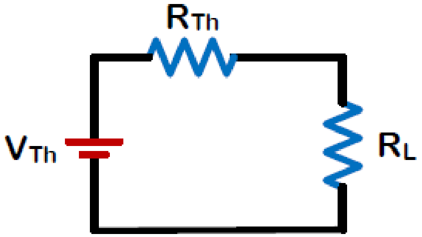


$$V_{Th} = Volatge\ across\ R_3$$

$$V_{Th} = \frac{V}{R_1 + R_3} R_3$$



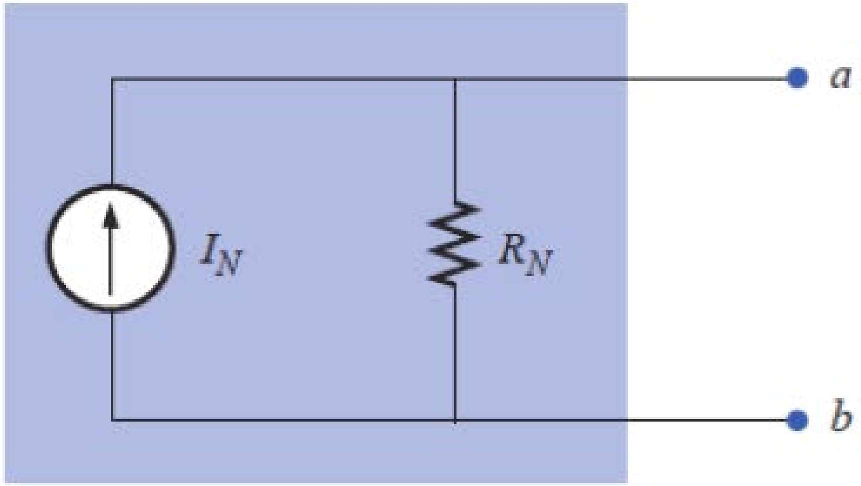
RTh $R_{Th} = R_2 + \dfrac{R_1 R_3}{R_1 + R_3}$



$$I_L = \frac{V_{Th}}{R_{Th} + R_L}$$

Nortons Theorem

Any two-terminal linear bilateral dc network can be replaced by an equivalent circuit consisting of a current source and a parallel resistor, as shown in Fig.



Nortons Theorem

1. *Remove the portion of the network across which the Norton equivalent circuit is to be found.*
2. *Mark the terminals of the remaining two-terminal network.*

R_N:

3. *Calculate R_N by first setting all sources to zero (voltage sources are replaced by short circuits, and current sources by open circuits) and then finding the resultant resistance between the two marked terminals. (If the internal resistance of the voltage and/or current sources is included in the original network, it must remain when the sources are set to zero.) Since $R_N = R_{Th}$, the procedure and value obtained using the approach described for Thévenin's theorem will determine the proper value of R_N.*

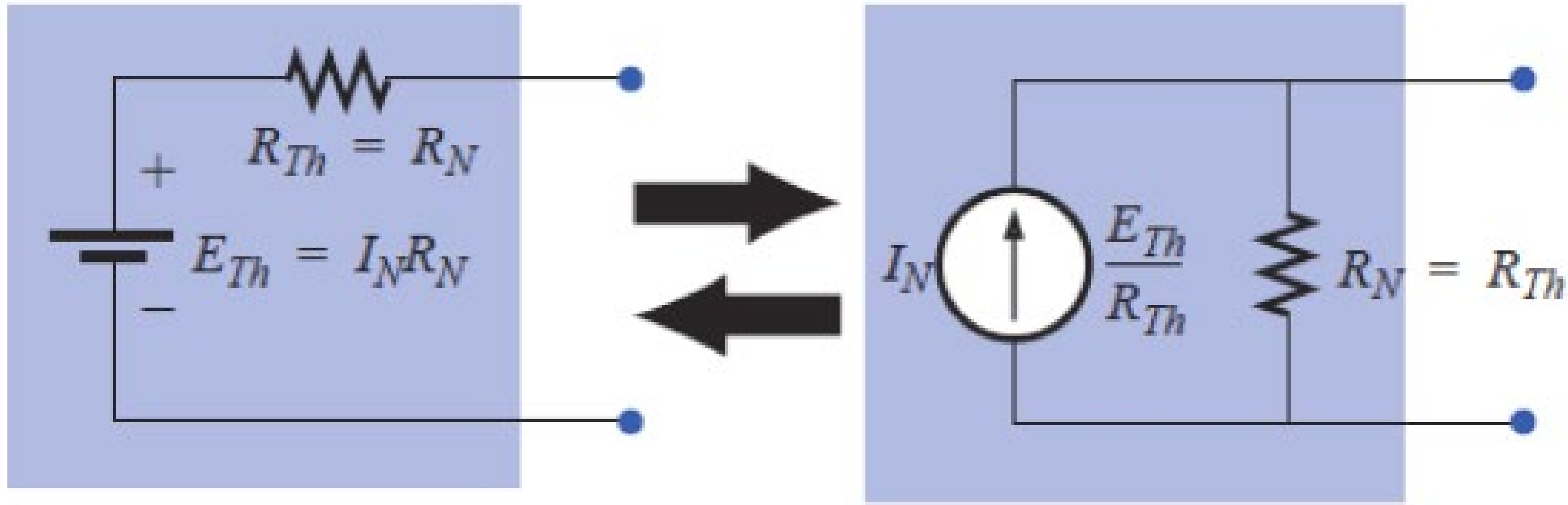
I_N:

4. *Calculate I_N by first returning all sources to their original position and finding the short-circuit current between the marked terminals.*

Conclusion:

5. *Draw the Norton equivalent circuit with the portion of the circuit previously removed replaced between the terminals of the equivalent circuit.*

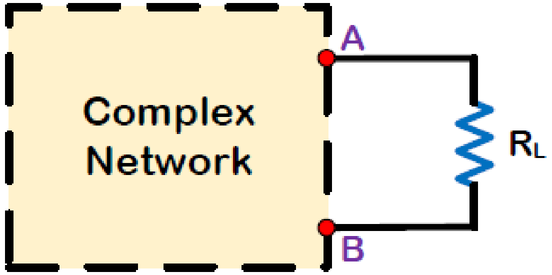
Nortons Theorem

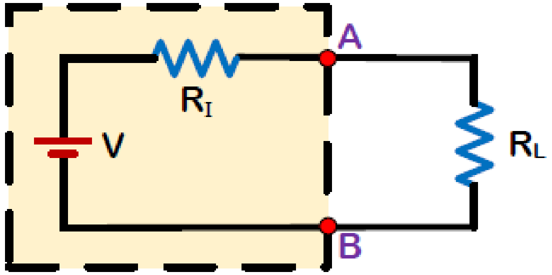


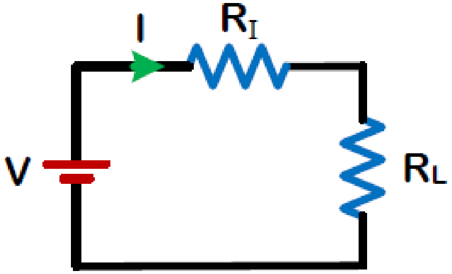
Converting between Thévenin and Norton equivalent circuits.

Maximum Power Transfer Theorem

In d.c. circuits, maximum power is transferred from a source to load when the load resistance is made equal to the internal resistance of the source as viewed from the load terminals with load removed and all e.m.f. sources replaced by their internal resistances.



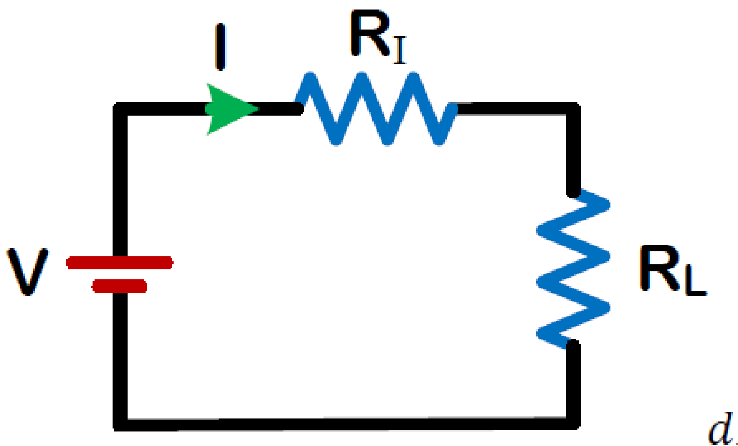




V = 12V $\quad$ $R_l = 3\ \Omega$

R_L	$I = \dfrac{V}{R_I + R_L}$	Power Delivered to Load $P_L = I^2 * R_L$
1Ω	I=3 A	$P_L = 9$ W
2Ω	I=2.4 A	$P_L = 11.52$ W
3Ω	I=2 A	$P_L = 12$ W
4Ω	I=1.71 A	$P_L = 11.69$ W
5Ω	I=1.5 A	$P_L = 11.25$ W
6Ω	I=1.33 A	$P_L = 10.61$ W

Proof of Maximum Power Transfer Theorem



$$I = \frac{V}{R_L + R_I}$$

$$P_L = I^2 R_L = \left(\frac{V}{R_L + R_I}\right)^2 R_L$$

$$\frac{dP_L}{dR_L} = V^2 \left[\frac{(R_L + R_I)^2 - 2R_L(R_L + R_I)}{(R_L + R_I)^4}\right] = 0$$

$$(R_L + R_I)^2 - 2R_L(R_L + R_I) = 0$$

$$(R_L + R_I)(R_L + R_I - 2R_L) = 0$$

$$(R_L + R_I)(R_I - R_L) = 0$$

$$(R_L + R_I) \neq 0$$

$$R_I - R_L = 0$$

$$R_L = R_I$$

Load resistance = Internal resistance

Maximum Power Transfer Theorem

Important Points

- ✓ The circuit efficiency at maximum power transfer is only 50% as one-half of the total power generated is dissipated in the internal resistance R_i of the source.

$$\eta = \frac{Output\ Power}{Input\ Power} = \frac{I^2 R_L}{I^2 (R_L + R_I)} = \frac{R_L}{2R_L} = \frac{1}{2} = 50\%$$

- ✓ Under the conditions of maximum power transfer, the load voltage is one-half of the open circuited voltage at the load terminals.

$$V_L = IR_L = \frac{V}{R_L + R_I} R_L = \frac{V}{2}$$

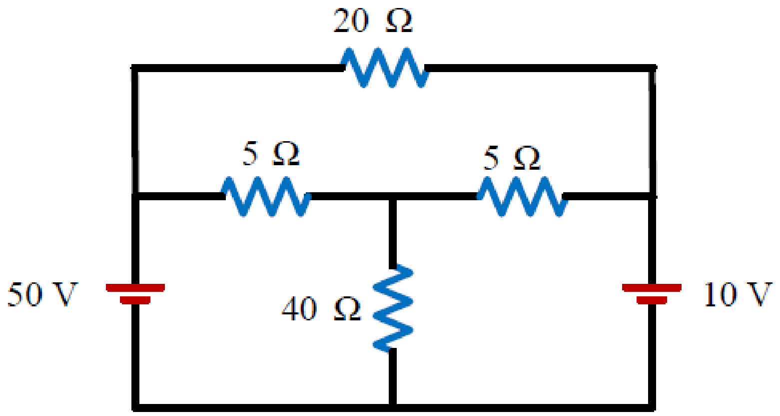
- ✓ Value of maximum power transferred

$$P_{L,max} = \left(\frac{V}{R_L + R_I}\right)^2 R_L = \frac{V^2}{4R_L}$$

Superposition Theorem

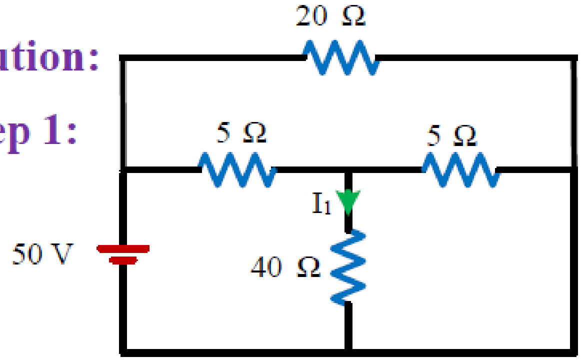
Example

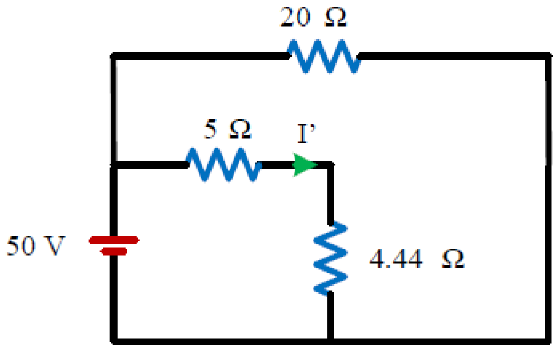
Using superposition theorem, find the current through the 40 Ω resistor in the circuit shown



Solution:

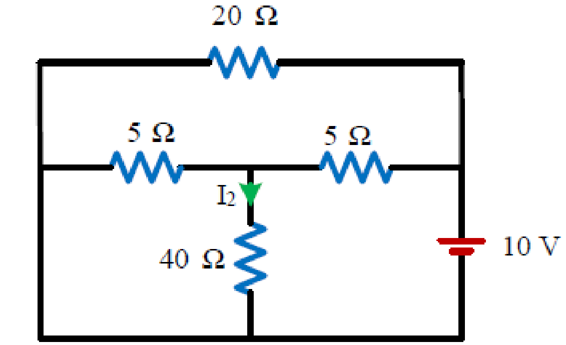
Step 1:

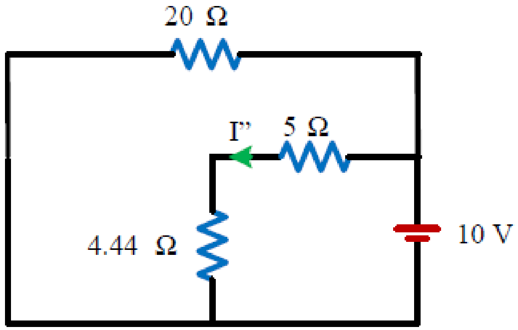




$$I' = \frac{50}{5+4.44} = 5.296A \qquad I_1 = I' \frac{5}{5+40} = 0.589A$$

Step 2:



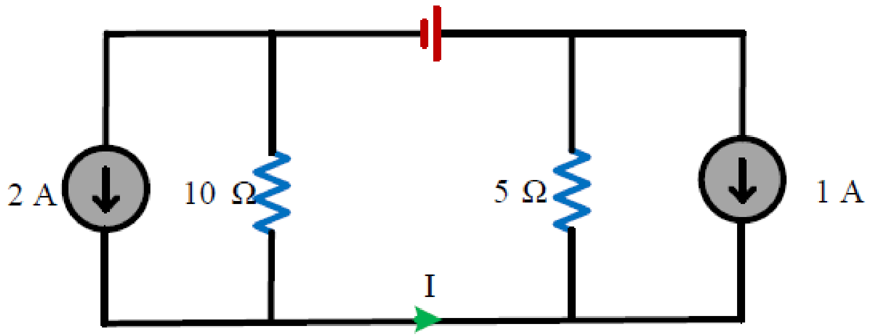


$$I'' = \frac{10}{5+4.44} = 1.059A \qquad I_2 = 1.059 \frac{5}{5+40} = 0.118A$$

$$I = I_1 + I_2 = 0.589 + 0.118 = 0.707A$$

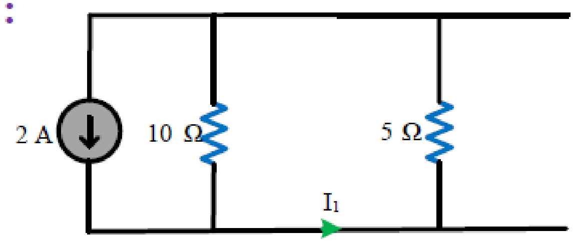
Superposition Theorem

Example



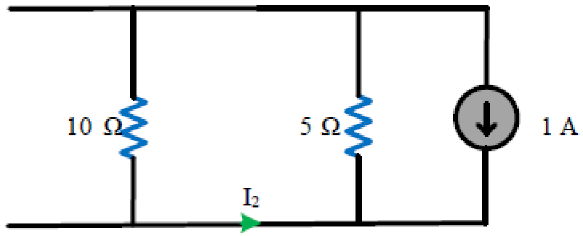
Solution:

Step 1:



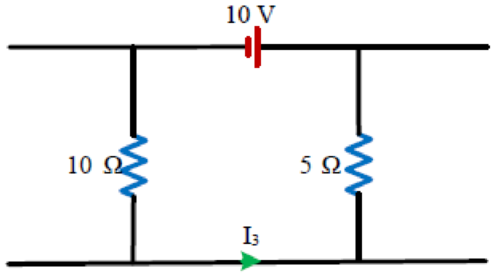
$$I_1 = 2\ \frac{10}{5+10} = 1.33A$$

Step 2:



$$I_2 = -1\ \frac{5}{5+10} = -0.33A$$

Step 3:



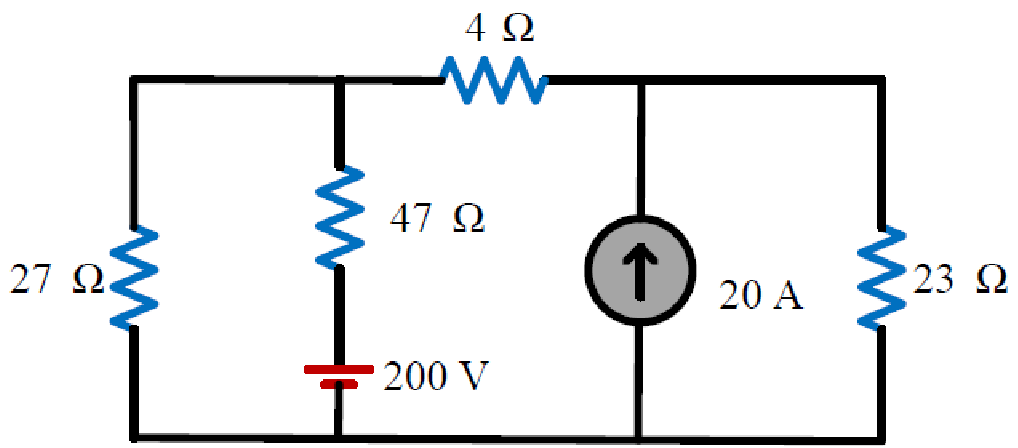
$$I_3 = -\ \frac{10}{5+10} = -0.667A$$

$$I = I_1 + I_2 + I_3 = 0.33A$$

Superposition Theorem

Tutorial

Using superposition theorem, find the current in 23 Ω resistor in the circuit shown



Solution:

200 V source acting alone $I_1 = 1.65A$

20 current source acting alone. $I_2 = 9.58A$

$$I = I_1 + I_2 = 11.23A$$