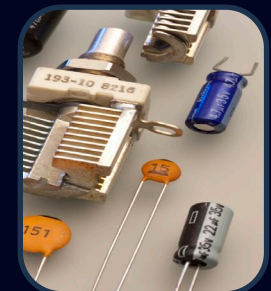


ELECTRICAL TECHNOLOGY

NIK NORHASANAH BINTI NIK HASSAN
FADZLIDA BINTI SHAMSUDIN

POLITEKNIK PORT DICKSON



ELECTRICAL TECHNOLOGY

**VOLUME 1:
INTRODUCTION TO ELECTRIC CIRCUIT
DC EQUIVALENT CIRCUIT AND NETWORK THEOREMS**

**NIK NORHASANAH BINTI NIK HASSAN
FADZLIDA BINTI SHAMSUDIN**



First Edition

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PREFACE

This e-book is written to provide basic knowledge of electrical technology, focusing on DC circuit theory for electrical and electronic engineering students, especially in polytechnics and other technical institutes.

It is written in an easy-to-understand manner with concept used is interactive in form of infographic elements are included to facilitate all levels of society to understand electrical technology. This e-book contains two topic related to Electrical circuit principles. Topic 1 focuses on the general features and the understanding of cells and batteries. It also cover on Ohm's law, as well as the characteristics of current, voltage and resistance in series and parallel circuits. Network analysis involving Kirchhoff's law, mesh and nodal analysis, Thevenin's Theorem, Norton's Theorem, Superposition Theorem and Maximum Power Transfer Theorem are all included in Topic 2.

At the end of each chapter, Review Questions which cover two topics are also available at the end of the e-book by scan QR code given. Model examination questions, which cover all chapters, are also available at the end of the book.

We hope that this e-book will be very useful to the readers, students as well as lecturers in all respects.



ABSTARCT

This e book is written to provide basic knowledge of electrical technology, focusing on DC circuit theory for electrical and electronic engineering students, especially in polytechnics and other technical institutes.

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- ✓ Standard Symbols For Electrical Components.
- ✓ General Features Of Cells And Batteries
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- ✓ Electrical Power And Energy

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TOPIC 1.0 : INTRODUCTION TO ELECTRIC CIRCUIT



Standard Symbols For Electrical Components.



General Features Of Cells And Batteries



Electric Current And Quantity Of Electricity.



Main Effects Of Electric Current



Resistance And Resistivity



Ohm's Law



Series, Parallel And Series-parallel Connections



Series, Parallel And Series-parallel Connections To Dc Circuit.



Delta-star Transformation



Electrical Power And Energy

TOPIC 1.0 : INTRODUCTION TO ELECTRIC CIRCUIT

STANDARD ELECTRICAL UNIT OF MEASURE

Electrical Parameter	Parameter Symbol	Unit	Unit symbol
Voltage	V or E	Volt	V
Current	I or i	Ampere	A
Resistance	R or Ω	Ohm	Ω
Capacitance	C	Farad	F
Inductance	L	Henry	H
Power	P	Watt	W
Energy	E	Joule	J
Time	T	second	s

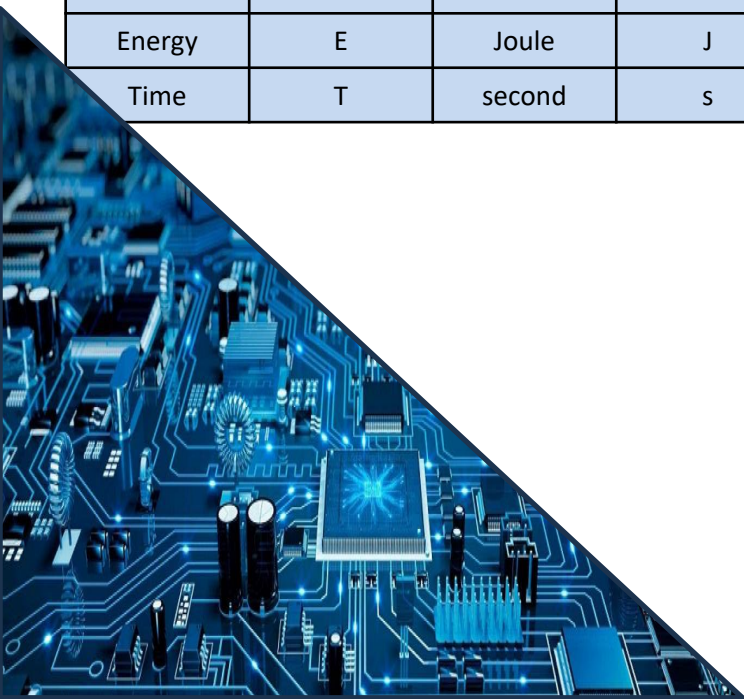
LIST OF COMMON SI PREFIXES

Prefix	Prefix Symbol	Value	
centi	c	10^{-2}	0.01
milli	M	10^{-3}	0.001
micro	μ	10^{-6}	0.000 001
nano	N	10^{-9}	0.000 000 001
pico	P	10^{-12}	0.000 000 000 001
kilo	K	10^3	1000
Mega	M	10^6	1 000 000
Giga	G	10^9	1 000 000 000
tera	T	10^{12}	1 000 000 000 000

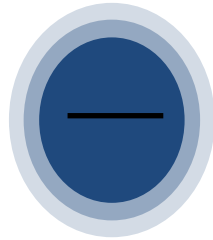


LIST OF SI UNIT

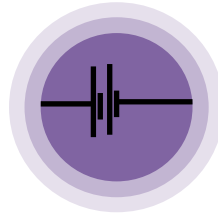
PARAMATER	UNIT	SYMBOL
Length	Metre	m
Mass	Kilogram	kg
Time	Second	s
Electric current	Ampere	A
Temperature	Kelvin	K
Luminous intensity	Candela	Cd
Amaount of substance	Mole	mol



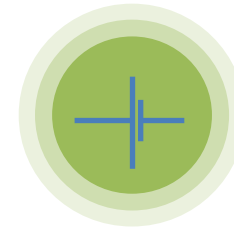
STANDARD SYMBOL FOR ELECTRICAL COMPONENT



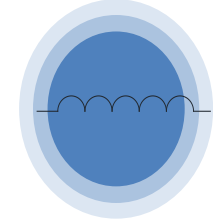
Wire



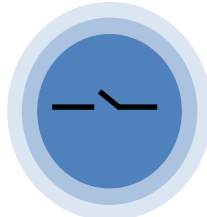
Battery (dc supply)



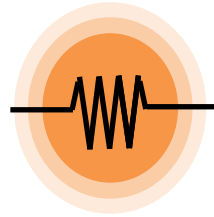
Cell (dc supply)



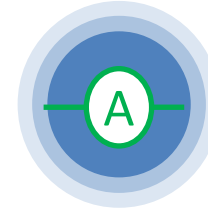
Inductor



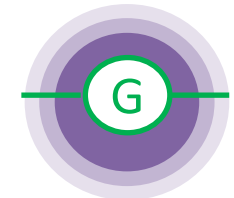
Switch



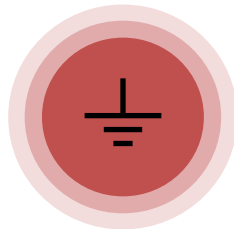
Resistor



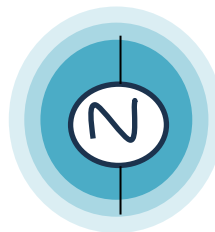
Ammeter



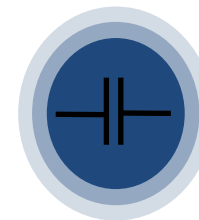
Galvanometer



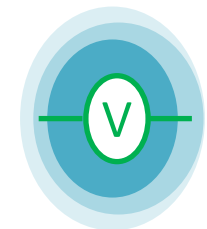
Ground/ earth



Ac supply



Capacitor

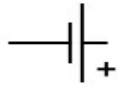


Voltmeter

1. DEFINITION

A cell is an active circuit element that converts chemical energy to produce electrical energy.

2. SYMBOL



3. TYPES

Cells are of two types
– primary cell and secondary cell.

4. Service time period

Cell supplies electrical power for a short period of time.

5. Energy Supplied

Cell can supply only small amount of energy for short time.



1. DEFINITION

A battery is a collection of two or more cells connected together in a single unit and produces electrical energy by performing a chemical reaction.

2. SYMBOL



3. TYPES

Types of battery are primary battery and secondary battery.

4. Service time period

Battery supplies electrical power to the circuit for a long duration.

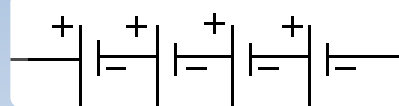
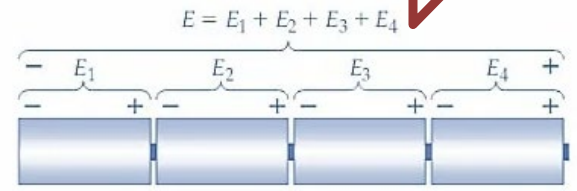
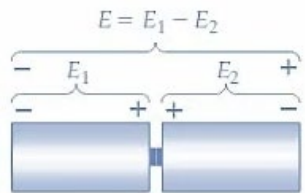
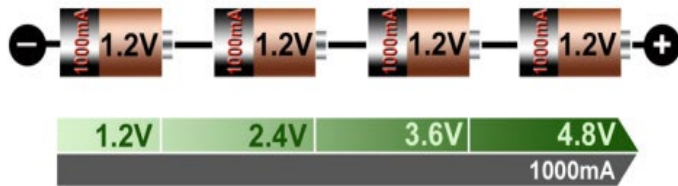
5. Energy Supplied

Battery can provide more amount of energy than a cell, because it consists of many cells in a single unit.



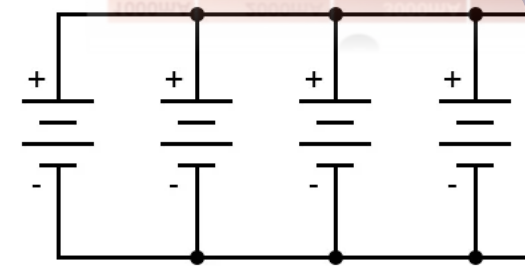
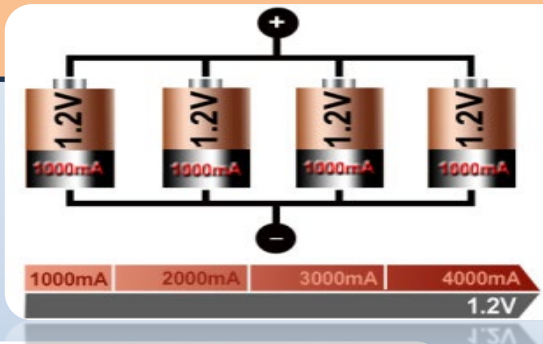
SERIES CONNECTION

The cells are said to be connected in series if the positive terminal of the first cell is connected to the negative terminal of the second cell, and the negative terminal of the second cell is connected to the positive terminal of the third cell. The same current flows through each cell



PARALLEL CONNECTION

In a parallel combination of cells, all the positive terminals of the cells are connected together, and the negative terminals of the cells are connected together



Resistance is property of a component which restricts the flow of electric current

The value of resistance depends upon 4 factors:

- ✓ Length, l
- ✓ Cross-sectional area, A
- ✓ Resistivity, ρ
- ✓ Temperature

Equation:

$$R = \frac{\rho l}{A} \quad [\text{Unit} = \Omega]$$

R = resistance [Ω]
 l = Length [m]
 A = Cross-sectional area [m^2]
 ρ = resistivity [$\Omega \cdot \text{m}$]

Resistivity is difference for different material

EXAMPLE 1.3

Calculate resistance of a 5m long conductor if it has cross sectional area 10mm^2 and resistivity $0.3 \times 10^{-5} \Omega \cdot \text{m}$

SOLUTION :

$$\begin{aligned} \text{Resistance, } R &= \frac{\rho l}{A} = \frac{0.3 \times 10^{-5} \times 5}{10 \times 10^{-6}} \\ &= 1.5\Omega \end{aligned}$$

MAIN EFFECT OF ELECTRIC CIRCUIT

1

Heat Effect

Example: soldering iron, water heater, fuse, bulb, cookers, electric fires, furnaces, kettles, iron

2

Magnetic Effect

Example: bells, relays, motors, generators, transformers, telephones, lifting magnets, car ignition

3

Chemical Effect

Example: cell and battery, electroplating



RESISTOR

Resistance is property of a component which restricts the flow of electric current

1. A device that is manufactured to have specific resistance
2. Used to limit current flow and reduce voltage applied to other components
3. Basic unit is ohm (Ω)

4. 

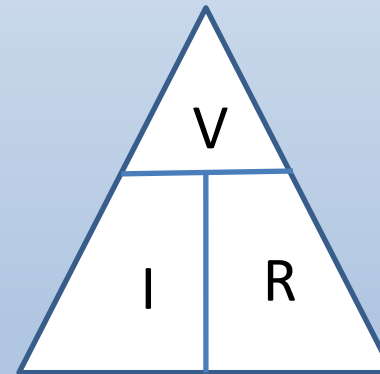
5. TYPES OF RESISTOR



OHM'S LAW

Ohm's Law states that the current (I) through a conductor between two points is directly proportional to the potential difference or voltage (V) across the two points, and inversely proportional to the resistance (R) between them

$$I = \frac{V}{R}$$



$$V = IR$$

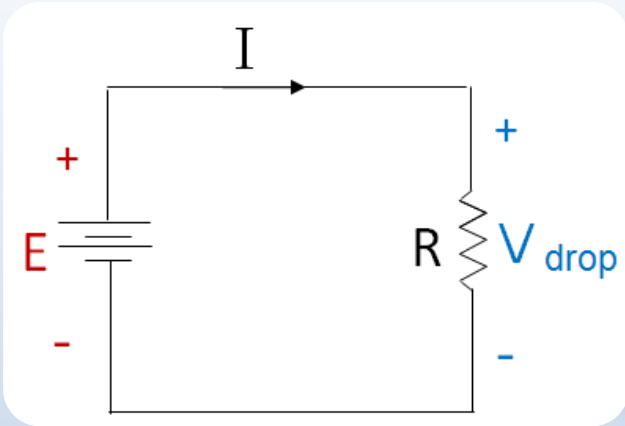


$$I = \frac{V}{R}$$



$$R = \frac{V}{I}$$

SIMPLE CIRCUIT - OHM'S LAW



E = E.M.F. (Electromotive force)

- Generates from voltage source
- Example: cells / batteries

From Ohm's Law:

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

$$I = \frac{E}{R}$$

V_drop = Voltage drop

- Appears when current, I flows through resistor, R.
- Inverse polarity from E

From Ohm's Law:

Voltage = Current x Resistance

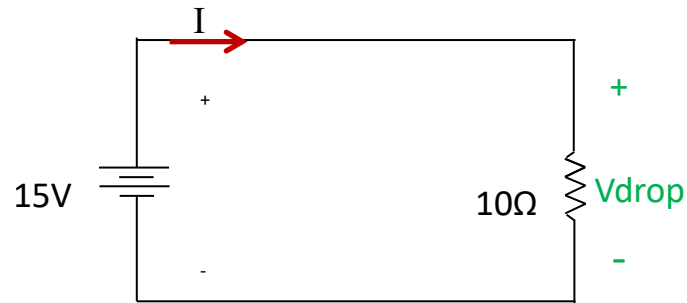
$$V_{\text{drop}} = IR$$



Example 1.4

By referring to the circuit below, calculate:

- i) Current, I
- ii) Voltage drop across resistor 10Ω , V_{drop}



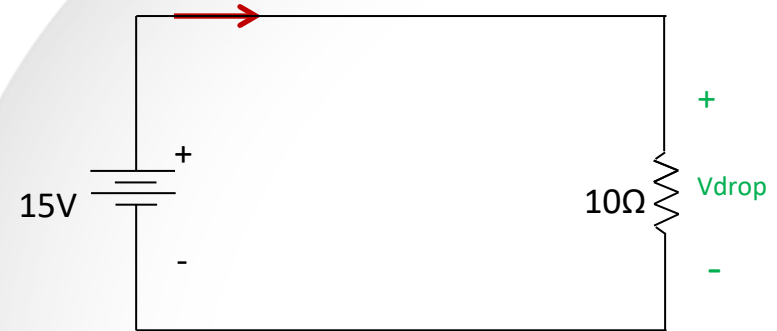
Solution :

i) Current, $I = \frac{V}{R} = \frac{15}{10} = 1.5A$

ii) Voltage drop, $V_{drop} = IR = 1.5 \times 10 = 15V$

Example 1.5

A 100 V battery is connected across a resistor and causes a current of 5 mA to flow. Determine the resistance of the resistor. If the voltage is now reduced to 25 V, what will be the new value of the current flowing?



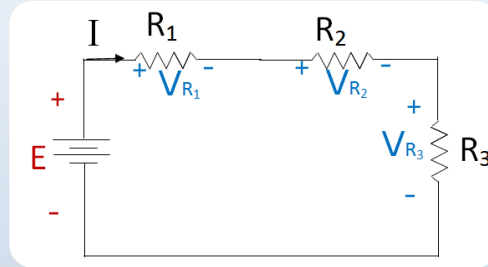
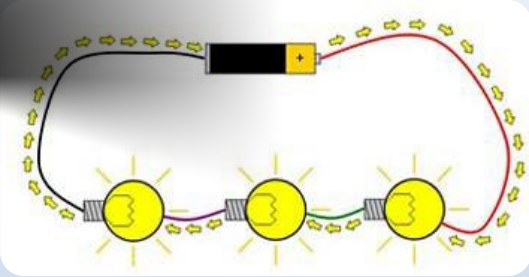
Solution :

i) Current, $I = \frac{V}{R} = \frac{15}{10} = 1.5A$

ii) Voltage drop, $V_{drop} = IR = 1.5 \times 10 = 15V$

SERIES CIRCUIT

Is formed when any number of devices are connected end-to-end so that there is only one path for current to flow.



01

Resistances are additive
 $R_T = R_1 + R_2 + R_3$

02

The current flows throughout the circuit is same.
 $I = I_{R1} = I_{R2} = I_{R3}$

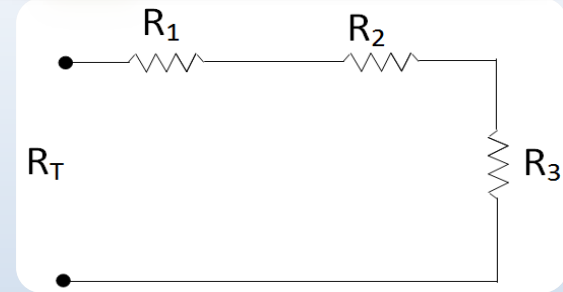
03

Different resistors have their individual voltage drop
 $V_{R1} \neq V_{R2} \neq V_{R3}$

04

Total e.m.f equals to the sum of voltage drops across each resistor
 $E = V_{R1} + V_{R2} + V_{R3}$

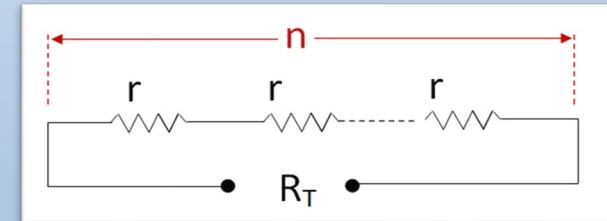
Equivalent resistance in series



$$R_T = R_1 + R_2 + R_3$$

Equ. 1

Applicable to any means of resistors.
 Standard equation of series connection resistors.

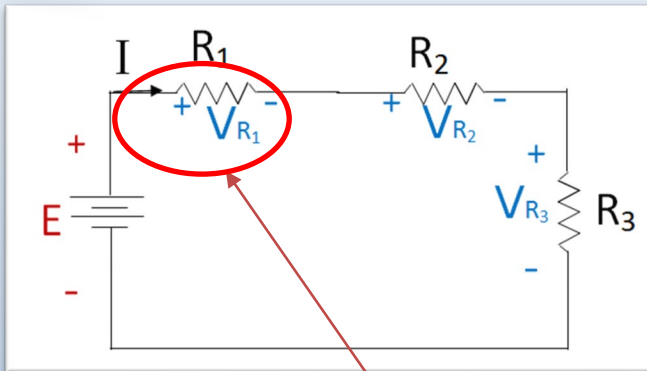


$$R_T = r \times n$$

Equ. 2

Applicable for any means of resistors with same value.

VOLTAGE DIVIDER RULE (VDR)



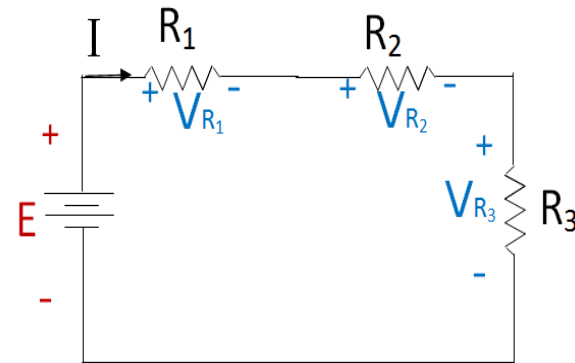
$$V_{R1} = \frac{R_1}{R_1 + R_2 + R_3} \times E$$



EXAMPLE 1.6

By referring to the circuit above, calculate:

- Total resistance of the circuit, R_{total}
- Current, I
- Voltage drop across resistor 6Ω , V_{R2}



SOLUTION :

- $R_{total} = 4 + 6 + 8 = 18\Omega$
- $I = \frac{E}{R} = \frac{15}{18} = 0.833A$
- $V_{R2} = IR_2 = 0.833 \times 6 = 5V$

Use VDR

$$V_{R2} = \frac{R_2}{R_1 + R_2 + R_3} \times E = \frac{6}{4 + 6 + 8} \times 15 = 5V$$



Total resistance can be determined from:

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$



Different resistors have their individual current.

$$I_{R1} \neq I_{R2} \neq I_{R3}$$



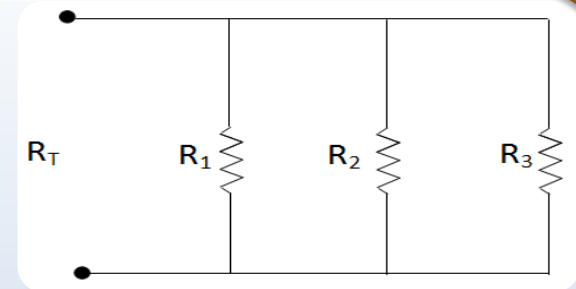
Same voltage acts across all parts of the circuit

$$E = V_{R1} = V_{R2} = V_{R3}$$



Supplied current equals to the sum of different current flows through each resistor.

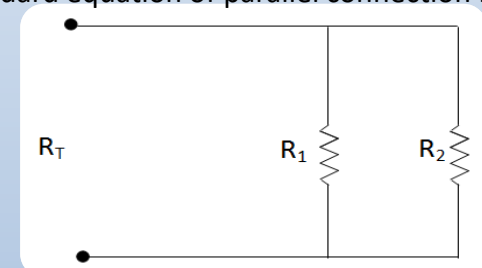
$$I = I_{R1} + I_{R2} + I_{R3}$$



$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

Equ. 1

- Applicable to any means of resistors.
- Standard equation of parallel connection resistors.



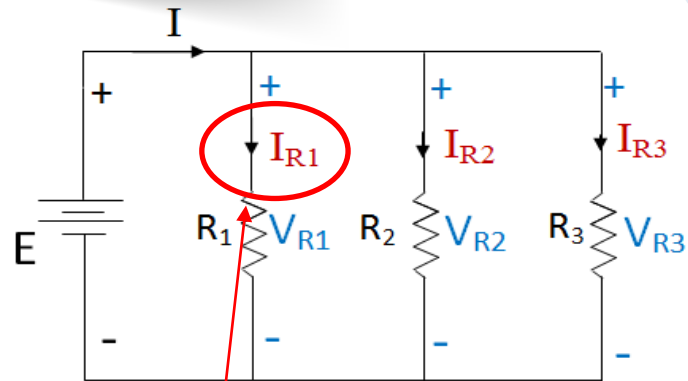
$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

Equ. 1

- Applicable for 2 resistors connection only

PARALLEL CIRCUIT CHARACTERISTICS

CURRENT DIVIDER RULE (CDR)

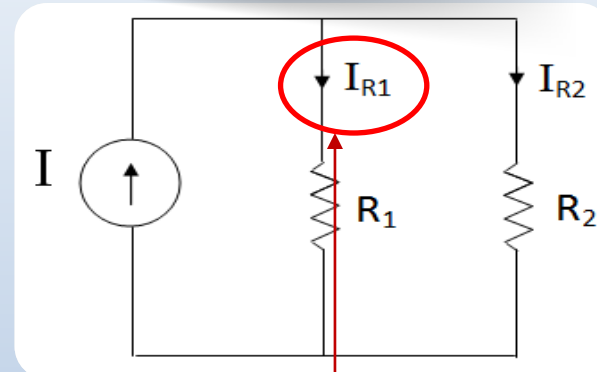


$$I_{R1} = \frac{\frac{1}{R_1}}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} \times I$$

Equ. 1

- Applicable to any means of resistors.
- Standard equation of current divider rule

CURRENT DIVIDER RULE (CDR) 2 RESISTOR CASE



$$I_{R1} = \frac{R_2}{R_1 + R_2} \times I$$

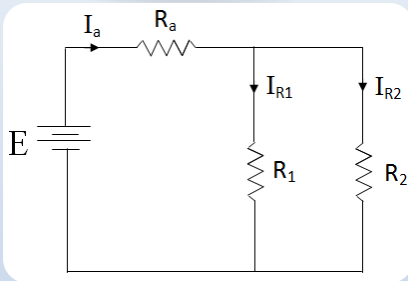
Equ. 2

- Applicable for 2 resistors connection only.

SERIES CIRCUIT CHARACTERISTICS

SERIES-PARALLEL CIRCUIT

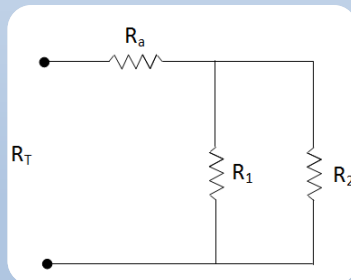
Is formed when any number of devices are connected end-to-end so that there is only one path for current to flow.



For this diagram:

- R1 is parallel with R2.
- Ra is series with equivalent resistance of R1 and R2.

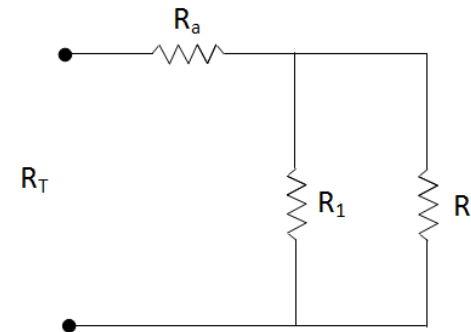
Reference Point



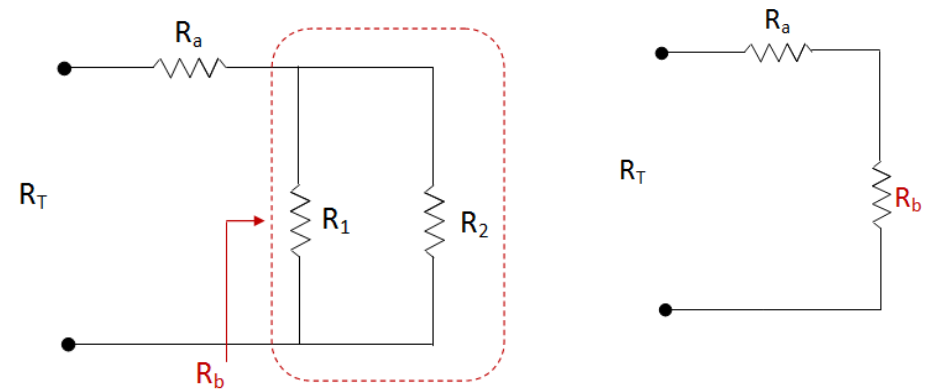
- R_T is the equivalent resistance of R_a , R_1 and R_2
- Start solving by calculating the total resistance of parts located farthest away from the reference point.

EXAMPLE 1.7 :

Calculate equivalent resistance, R_T of the circuit below



SOLUTION :

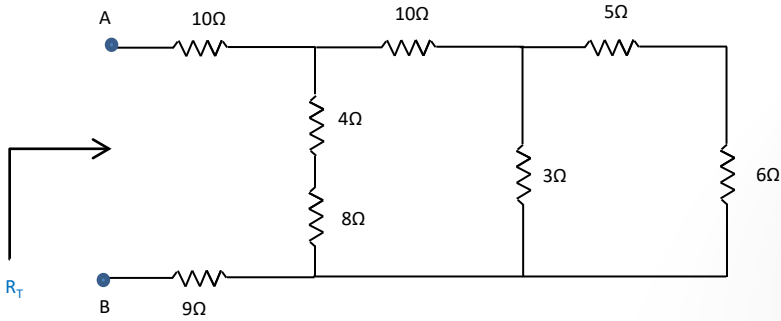


$$\therefore R_T = R_a + R_b$$

$$R_b = \frac{R_1 \times R_2}{R_1 + R_2}$$

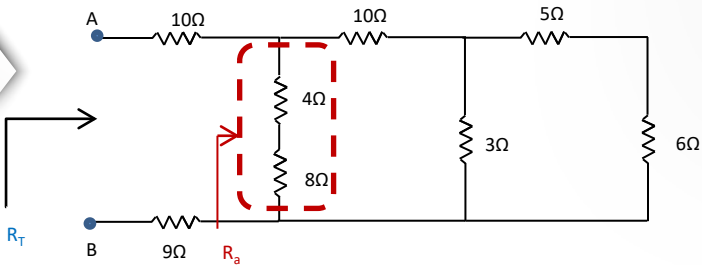
EXAMPLE 1.8

Calculate the total resistance, R_T of the circuit below.

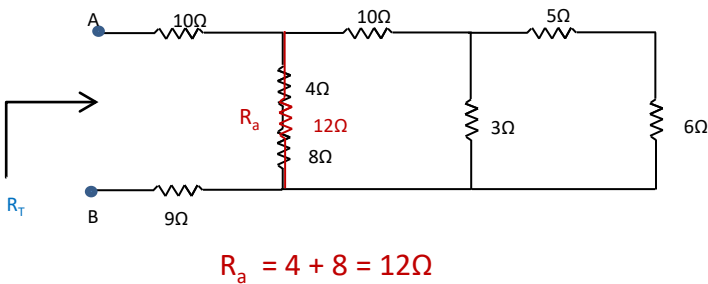


SOLUTION :

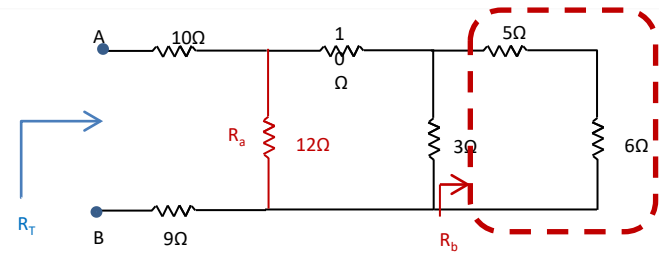
STEP 1



Identify any series/parallel connection (in between) and calculate the total resistance.

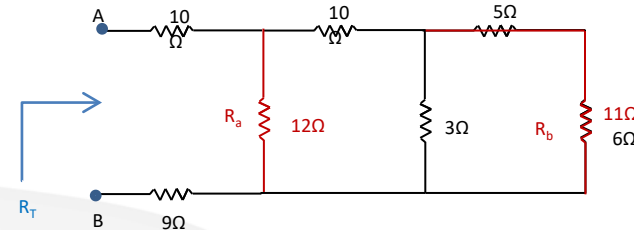


STEP 2

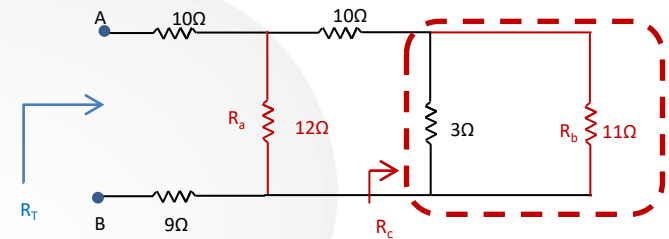


Identify the farthest part from ref. point and calculate the total resistance.

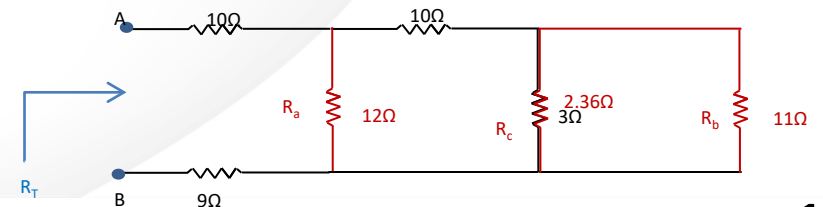
$$R_b = 5 + 6 = 11\Omega$$



STEP 3

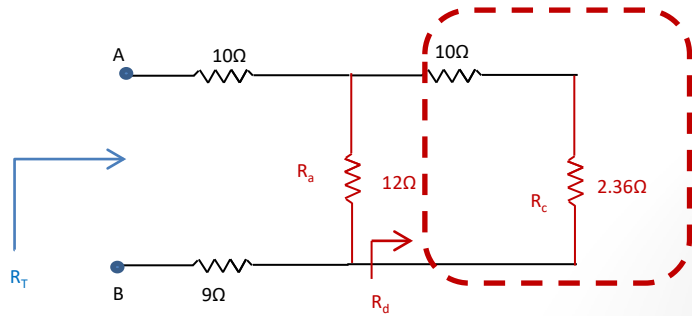


Calculate The Total Resistance Of Next Portion Until Reach Ref. Point.



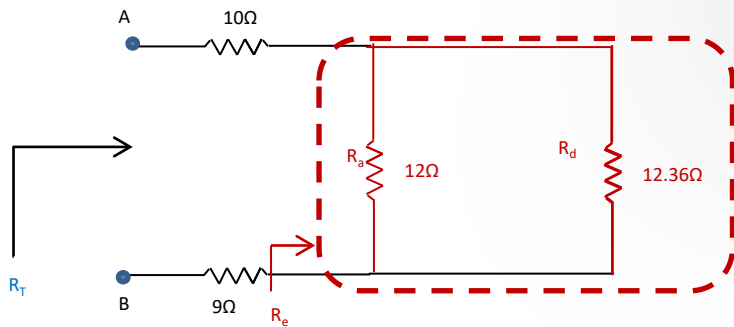
$$R_c = \frac{3 \times 11}{3 + 11} = 2.36\Omega$$

STEP 4

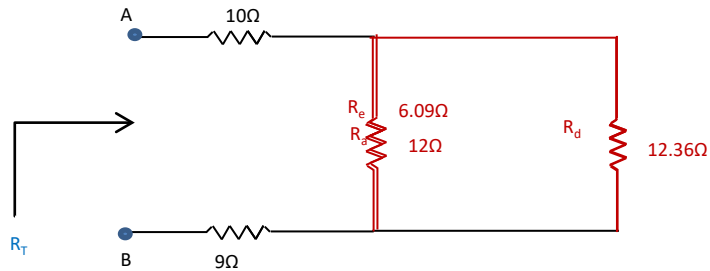


$$R_d = 10 + 2.36 = 12.36\Omega$$

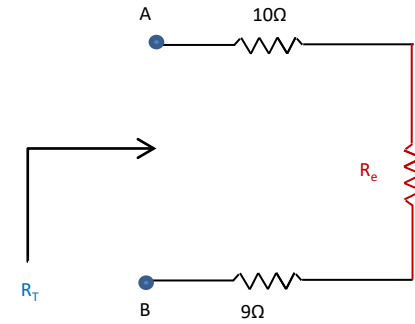
STEP 5



$$R_e = \frac{12 \times 12.36}{12 + 12.36} = 6.09\Omega$$



STEP 6

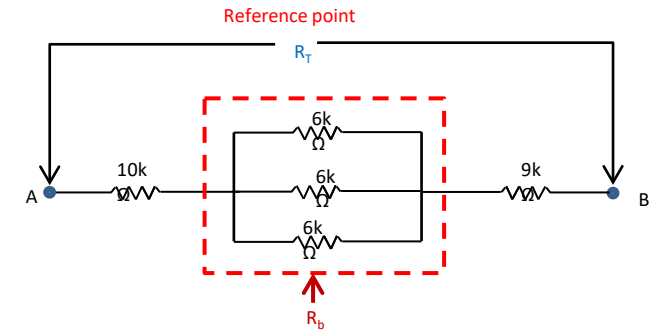
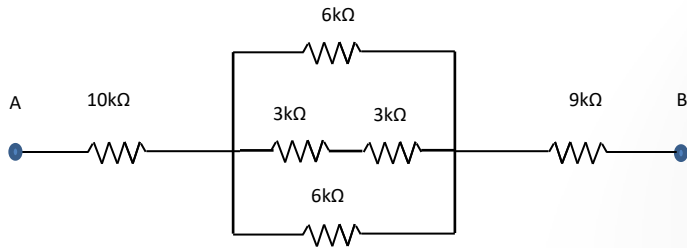


Finally, calculate the total resistance, R_T of the circuit.

$$R_T = 10 + 6.09 + 9 = 25.09\Omega$$

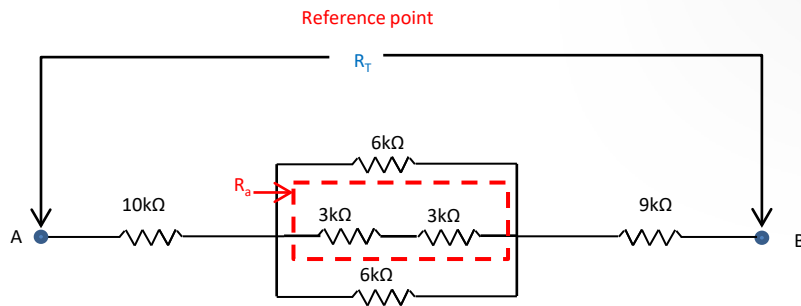
EXAMPLE 1.9

Calculate the total resistance across point A - B

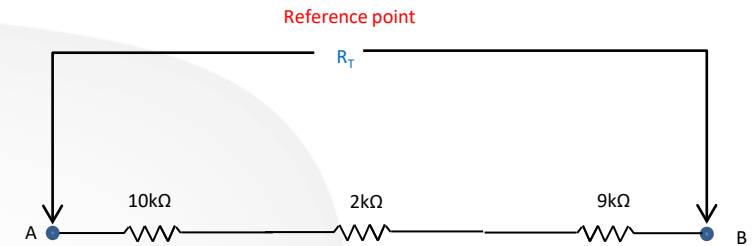


$$R_b = \frac{6k}{3} = 2k\Omega$$

SOLUTION :



$$R_a = 3k + 3k = 6k\Omega$$

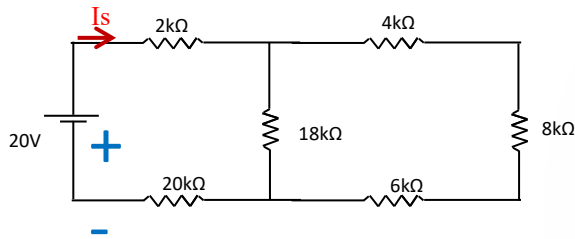


$$R_T = 10k + 2k + 9k = 21k\Omega$$

EXAMPLE 1.10

By referring to the circuit above, **calculate**:

- i) Equivalent resistance of the circuit, **R_{total}**
- ii) Current from supply, **I_s**
- iii) Current through resistor **18kΩ**
- iv) Voltage drop across resistor **8kΩ**,

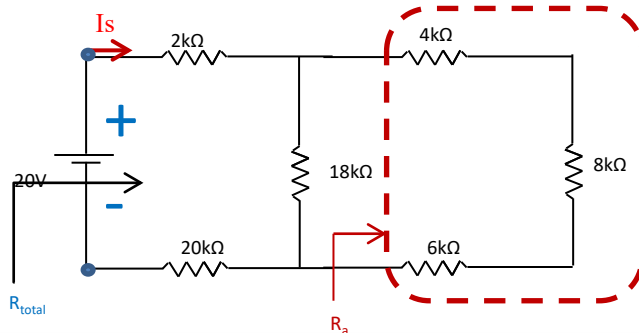


SOLUTION :

1

R_{total} Calculation

- Temporarily, remove voltage source from the circuit.
- The open nodes leaved by your voltage source would be your reference point

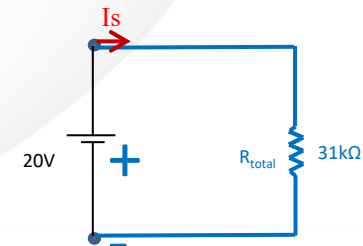


$$R_a = 4k + 8k + 6k = 18k\Omega$$

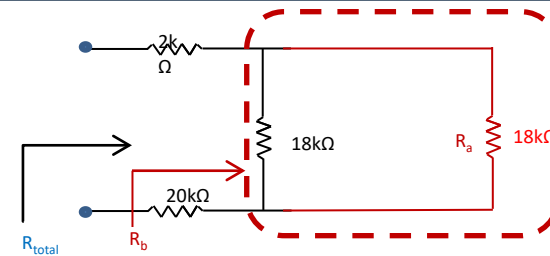
2

I_s Calculation

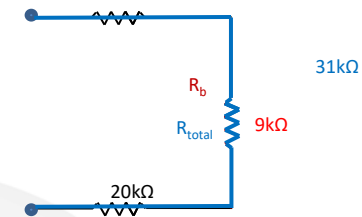
- Place voltage source back to the circuit.
- Your current from source is calculated using Ohm's Law



$$I_s = \frac{E}{R} = \frac{20}{31k} = 645.16 \mu A$$



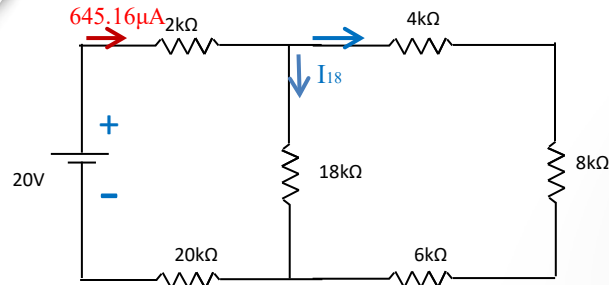
$$R_b = \frac{18k}{2} = 9k\Omega$$



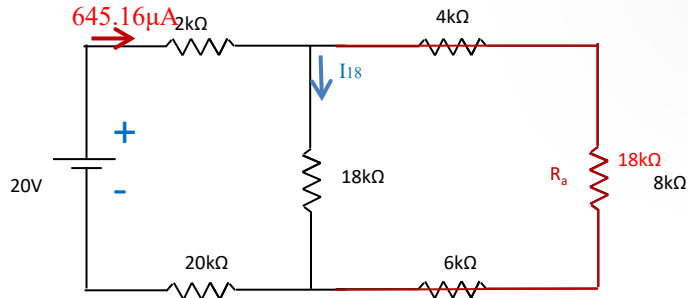
$$R_{total} = 2k + 9k + 20k = 31k\Omega$$

3

I₁₈ Calculation



- Use current divider rules (CDR) or any other relevant methods



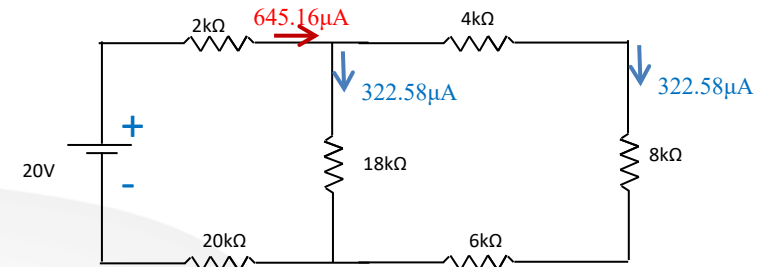
If Use CDR: $I_{18} = \frac{18k}{18k+18k} \times 645.16\mu = 322.58 \mu A$

Other method: $I_{18} = \frac{645.16\mu}{2} = 322.58 \mu A$

4

V₈ Calculation

- Calculate the current flows through 8kΩ resistor first
- Use Ohm's Law to calculate the Voltage drop
- Other method as Voltage Divider Rule (VDR) also could be used here if you understand well the technique



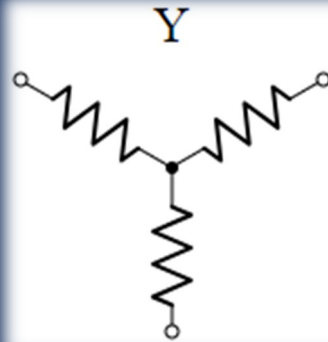
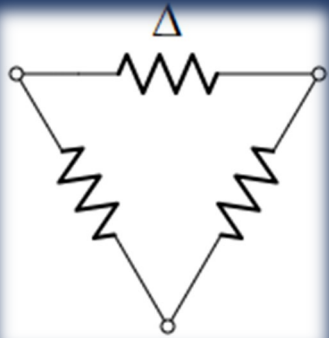
$$I_8 = 645.16\mu - 322.58\mu = 322.58 \mu A$$

$$V_8 = IR = 322.58\mu \times 8k = 2.58V$$

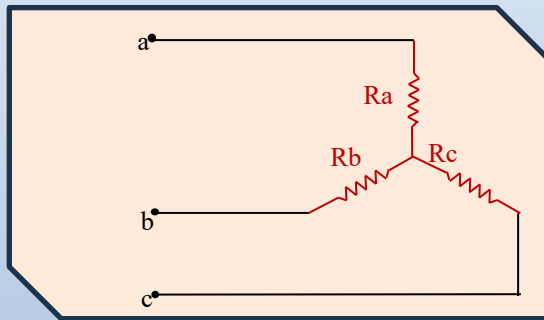
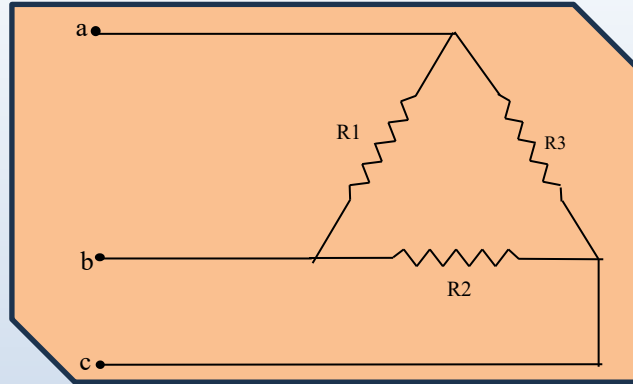


DELTA-STAR TRANSFORMATION

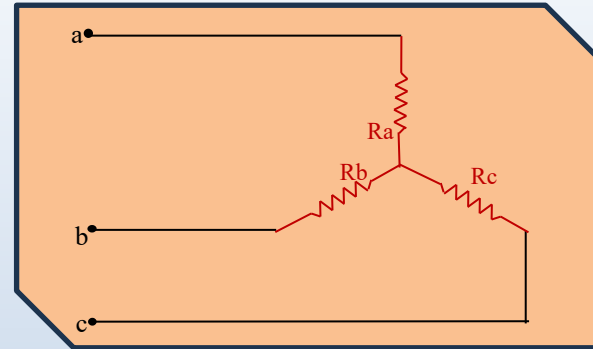
Standard 3-phase circuits or networks take on two major forms with names that represent the way in which the resistances are connected, a **Star** connected network which has the symbol of the letter, Y (wye) and a **Delta** connected network which has the symbol of a triangle, Δ (delta)



DELTA-STAR TRANSFORMATION



STAR-DELTA TRANSFORMATION



Ra $\frac{R1 \times R3}{R1 + R2 + R3}$

Rb $\frac{R1 \times R2}{R1 + R2 + R3}$

Rc $\frac{R2 \times R3}{R1 + R2 + R3}$

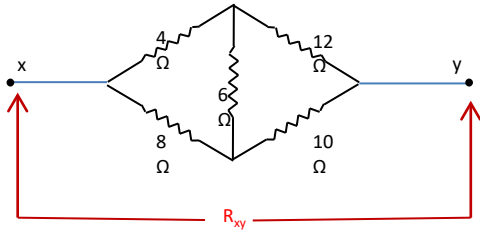
R1 $\frac{(Ra \times Rb) + (Rb \times Rc) + (Ra \times Rc)}{Rc}$

R2 $\frac{(Ra \times Rb) + (Rb \times Rc) + (Ra \times Rc)}{Ra}$

R3 $\frac{(Ra \times Rb) + (Rb \times Rc) + (Ra \times Rc)}{Rb}$

EXAMPLE 1.11

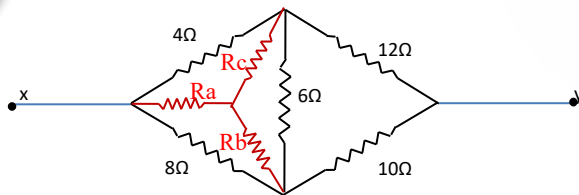
Calculate the total resistance, R_{xy} of the circuit below



SOLUTION :

1

Convert Δ --- Y

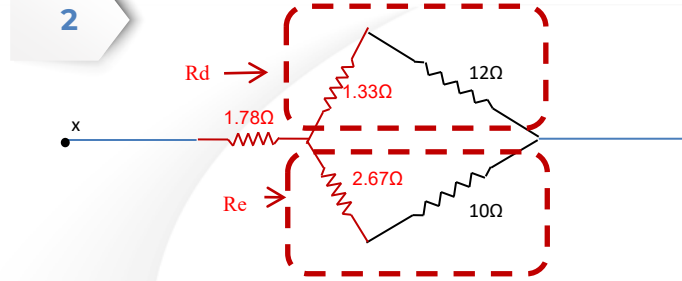


$$R_a = \frac{4 \times 8}{4+8+6} = 1.78\Omega$$

$$R_c = \frac{4 \times 6}{4+8+6} = 1.33\Omega$$

$$R_b = \frac{8 \times 6}{4+8+6} = 2.67\Omega$$

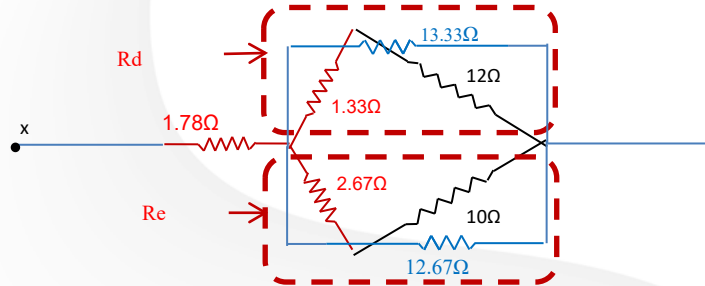
2



$$R_d = 1.33 + 12 = 13.33\Omega$$

$$R_e = 2.67 + 10 = 12.67\Omega$$

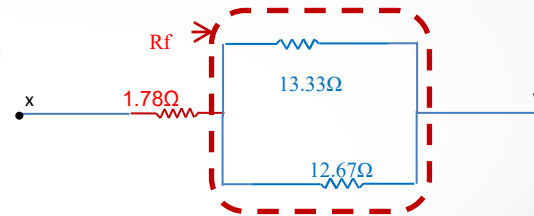
3



$$R_f = \frac{13.33 \times 12.67}{13.33+12.67} = 6.5\Omega$$

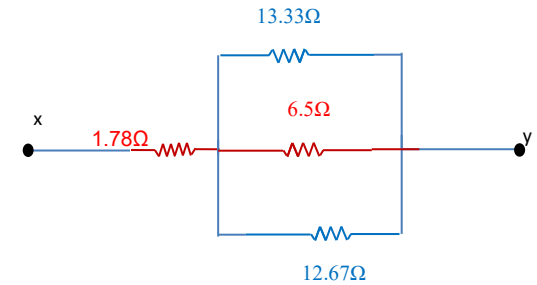
$$R_{xy} = 1.78 + 6.5 = 8.28\Omega$$

4



$$R_{xy} = 1.78 + 6.5 = 8.28\Omega$$

4



$$R_f = \frac{13.33 \times 12.67}{13.33+12.67} = 6.5\Omega$$

$$R_{xy} = 1.78 + 6.5 = 8.28\Omega$$



ELECTRICAL POWER is defined as the rate at which electrical energy is transferred by an electric circuit.

The SI unit of power is Watt.

Equation:

Power,

$$P = VI$$

V – voltage measured in Volts (V)

I – current measured in Ampere (A)

From Ohm's Law;

$$I = V/R \text{ and } V = I \times R$$

Hence Power, $P = \frac{V^2}{R}$ Equ.2

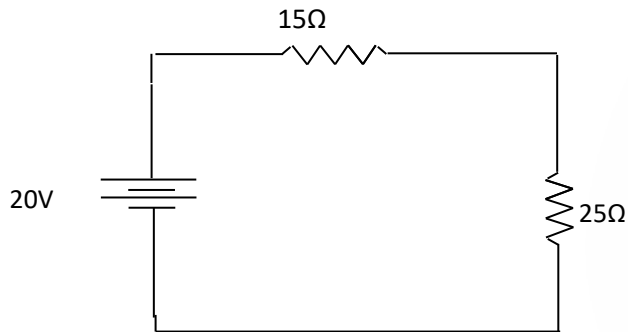
$$P = I^2R \quad \text{Equ.3}$$



EXAMPLE 1.12

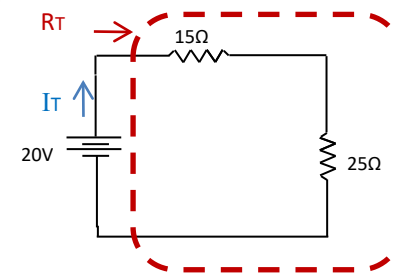
By referring to the circuit below, calculate:

- Power that's supplied by the battery
- Power that's absorbed by 25Ω resistor
- Energy supplied by the battery after 30s
- Energy absorbed by the 15Ω resistor after 2 hours



SOLUTION :

- i) Power that's supplied by the battery, P_s



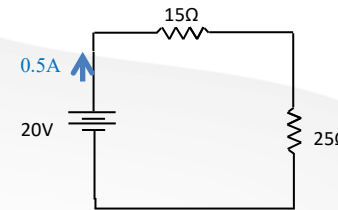
$$R_T = 15 + 25 = 40\Omega$$

$$I_T = \frac{E}{R} = \frac{20}{40} = 0.5A$$

Use Equ. 1:

$$\text{Power, } P_s = V \times I = 20 \times 0.5 = 10W$$

- ii) Power that's absorbed by 25Ω resistor P_L



Use Equ. 3:

$$\text{Power, } P_L = I^2 \times R = 0.5^2 \times 25 = 6.25W$$

- iii) Energy supplied by the battery after 30s

$$\text{Energy, } W = P \times t = 10 \times 30 = 300 J$$

- iv) Energy absorbed by the 15Ω resistor after 2 hours

Energy,

$$W = P \times t = I^2 \times R \times t = 0.5^2 \times 15 \times 2 \times 60 \times 60 = 27 kJ$$



TOPIC 2.0 : DC EQUIVALENT CIRCUIT & NETWORK THEOREM



Differentiate between nodes and mesh.



Nodal analysis



Mesh analysis



Kirchoff's Current Law and Kirchoff's Voltage Law in a DC circuit.



Thevenin's Theorem



Norton's Theorem.



Thevenin's Equivalent Circuit to Norton's Equivalent Circuit and vice versa

What is NETWORK THEOREM



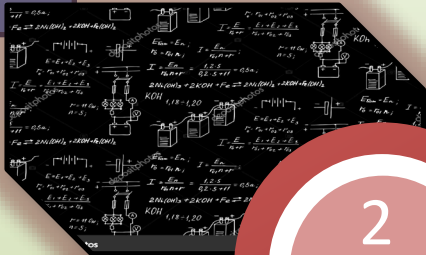
Network theorems use to determine the unknown values of current, resistance and voltage in electrical network



There are certain theorems which can applied to the solution electric network



1
NODAL ANALYSIS



2
MESH ANALYSIS



4
THEVENIN'S THEOREM



3
KIRCHOFF'S CURRENT LAW & KIRCHOFF'S VOLTAGE LAW

5
NORTON'S THEOREM

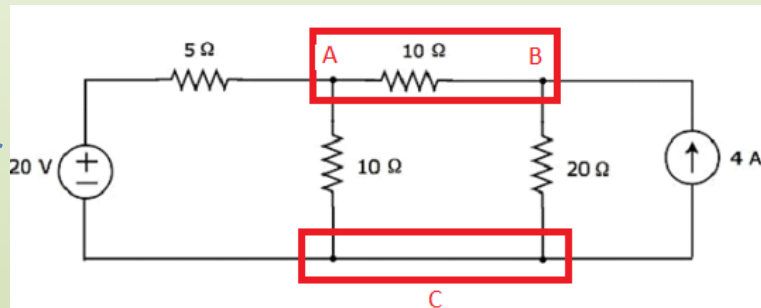


6
THEVENIN'S EQU. CIRCUIT TO NORTON'S EQU.

1 NODE

The intersection of two or more branches is known as a node

The circuit in figure given has three nodes *a, b, c*



In electrical circuit, Node refers to a point of connection between two or more branches.

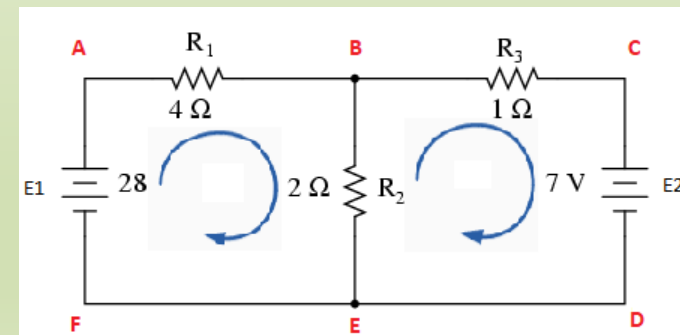
A Node is usually indicated by a dot in a circuit

2 MESH

A mesh is a simplest possible closed path

In figure given, path **abefa** and **bcdeb** are meshes, but path **abcdefa** is not a mesh

The current through a mesh is known as *mesh current*



EXAMPLE 2.1 :

Referring to figure 2.1 find the unknown currents

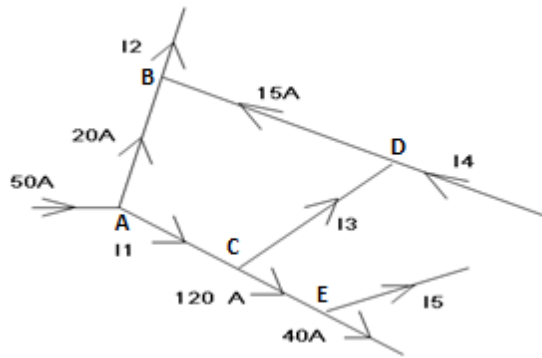


Figure 2.1

SOLUTION:

For Node A

$$\sum I_{in} = \sum I_{out}$$

$$50 = I_1 + 20$$

$$I_1 = 50 - 20$$

$$I_1 = 30A$$

For Node B

$$\sum I_{in} = \sum I_{out}$$

$$20 + 15 = I_2$$

$$I_2 = 35A$$

For Node C

$$\sum I_{in} = \sum I_{out}$$

$$I_1 = 120 + I_3$$

$$30 = 120 + I_3$$

$$I_3 = 30 - 120$$

$$I_3 = -90A$$

For Node D

$$\sum I_{in} = \sum I_{out}$$

$$I_3 + I_4 = 15$$

$$-90 + I_4 = 15$$

$$I_4 = 15 + 90$$

$$I_4 = 105A$$

For Node E

$$\sum I_{in} = \sum I_{out}$$

$$120 = 40 + I_5$$

$$I_5 = 120 - 40$$

$$I_5 = 80A$$

Remember, total current flowing towards a node is equal to the total current flowing away from the node



EXAMPLE 2.2 :

Referring to figure 2.2 determine the value of E

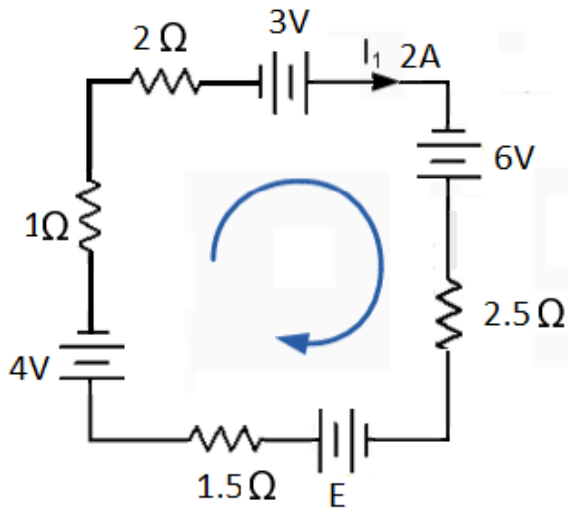


Figure 2.2

SOLUTION:

$$\sum V_{\text{close loop}} = 0$$

$$-6 + 2.5 I_1 - E + 1.5 I_1 + 4 + 1 I_1 + 2 I_1 - 3 = 0$$

$$7 I_1 - 5 - E = 0$$

$$7 I_1 - 5 = E$$

$$7 (2) - 5 = E$$

$$14 - 5 = E$$

$$9 \text{ V} = E$$

Remember, the algebraic sum of the voltage drops taken around the mesh is equal to the resultant e.m.f acting in that mesh



Nodal analysis, also known as the node-voltage method, is a fundamental technique used to analyze electrical circuits. It is a systematic and efficient way to determine the voltage at different nodes in a circuit and can be applied to both DC (direct current) and AC (alternating current) circuits.

The main principle behind nodal analysis is Kirchhoff's Current Law (KCL), which states that the sum of currents entering a node in a circuit is equal to the sum of currents leaving that node. Nodes are points in a circuit where two or more circuit elements are connected together.



STEP 01

Choose one of the main nodes to serve as the reference node.

That reference node will be regarded as the **Ground**.

STEP 02

Label the **node voltages** with respect to Ground from all the principal nodes except the reference node.

STEP 03

Write **nodal equations** at all the principal nodes except the reference node.

Nodal equation is obtained by applying KCL first and then Ohm's law.

STEP 04

Solve the nodal equations obtained in Step 3 in order to get the node voltages.

EXAMPLE 2.3:

Referring to figure 2.3 calculate I₁, I₂ and I₃ by using Nodal Analysis

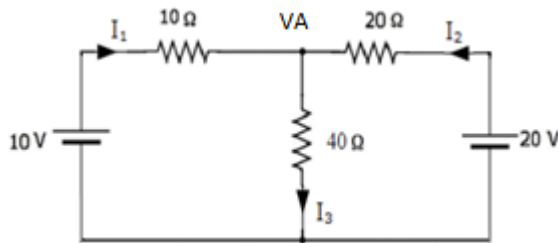


Figure 2.3

SOLUTION:

Step 1: Identify the nodes

Step 2: For the nodes, draw and label current arrow at all branches

Step 3: Write KCL equation at the node:

$$I_1 + I_2 = I_3$$

Step 4: Using the concept that current flows from higher voltage to lower voltage

$$I_1 = \frac{10 - V_A}{10} \quad I_2 = \frac{20 - V_A}{20} \quad I_3 = \frac{V_A}{40}$$

Step 5: Insert the KCL equation from step 3 into the equation in step 4

$$I_1 + I_2 = I_3$$

$$\frac{10 - V_A}{10} + \frac{20 - V_A}{20} = \frac{V_A}{40}$$

$$\frac{(10 - V_A) \times 2}{(10) \times 2} + \frac{20 - V_A}{20} = \frac{V_A}{40}$$

$$\frac{(20 - 2V_A)}{20} + \frac{20 - V_A}{20} = \frac{V_A}{40}$$

$$\frac{(20 - 2V_A + 20 - V_A)}{20} = \frac{V_A}{40}$$

$$\frac{(40 - 3V_A)}{20} = \frac{V_A}{40}$$

$$\frac{40(40 - 3V_A)}{20} = V_A$$

$$80 - 6V_A = V_A$$

$$80 = 7V_A$$

$$V_A = 80/7$$

$$V_A = 11.43V$$

Insert V_A in I₁, I₂, and I₃

$$I_1 = \frac{10 - V_A}{10} = \frac{10 - 11.43}{10} = -0.143A$$

$$I_2 = \frac{20 - V_A}{20} = \frac{20 - 11.43}{20} = 8.57A$$

$$I_3 = \frac{V_A}{40} = \frac{11.43}{40} = 0.286A$$

Example 2.4:

Referring to figure 2.4 calculate I1, I2 and I3 by using Nodal Analysis

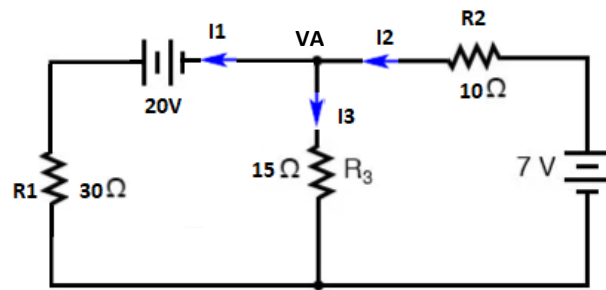


Figure 2.4

SOLUTION :

STEP 1 Identify the nodes

STEP 2 For the nodes, draw and label current arrow at all branches

STEP 3 Write KCL equation at the node: $I_2 = I_1 + I_3$

STEP 4 Using the concept that current flows from higher voltage to lower voltage

$$I_1 = \frac{V_A - (-20)}{30} \quad I_3 = \frac{V_A}{15}$$

$$I_2 = \frac{7 - V_A}{10}$$

STEP 5 Insert the KCL equation from step 3 into the equation in step 4

$$I_1 + I_2 = I_3$$

$$\frac{V_A + 20}{30} + \frac{7 - V_A}{10} = \frac{V_A}{15}$$

$$\frac{(V_A + 20)}{(30)} + \frac{(7 - V_A) \times 3}{(10) \times 3} = \frac{V_A}{15}$$

$$\frac{(V_A + 20)}{30} + \frac{21 - 3V_A}{30} = \frac{V_A}{15}$$

$$\frac{(V_A + 20 + 21 - 3V_A)}{30} = \frac{V_A}{15}$$

$$\frac{(41 - 2V_A)}{30} = \frac{V_A}{15}$$

$$\frac{15(41 - 2V_A)}{30} = V_A$$

$$41 - 2V_A = 2V_A$$

$$41 = 4V_A$$

$$V_A = 41/4$$

$$V_A = 10.25V$$

Insert VA in I1 , I2, and I3

$$I_1 = \frac{V_A + 20}{30} = \frac{10.25 + 20}{30} = 1.008A$$

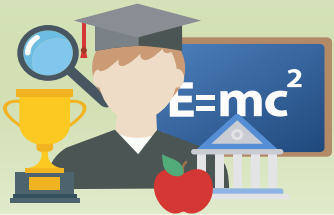
$$I_2 = \frac{7 - V_A}{10} = \frac{7 - 10.25}{10} = -0.325A$$

$$I_3 = \frac{V_A}{15} = \frac{10.25}{15} = 0.683A$$

WHAT IS MESH?

Mesh Analysis is a technique used to find the currents circulating around a loop or mesh with any closed path circuit.

Mesh analysis is the simple method of reducing the amount of mathematically involved



EXAMPLE 2.5 :

Referring to figure 2.5 calculate I_1 , I_2 and I_3 by using Mesh Analysis

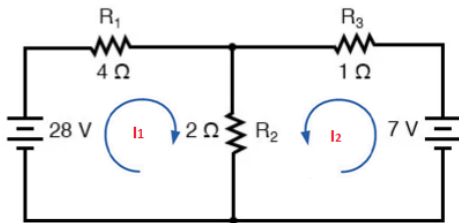


Figure 2.5

SOLUTION :

STEP 1 Assign I_1 and I_2 to the meshes

STEP 2 Apply KVL to each the meshes

mesh 1 :

$$2(I_1 + I_2) - 28 + 4I_1 = 0$$

$$2I_1 + 2I_2 - 28 + 4I_1 = 0$$

$$6I_1 + 2I_2 = 28 \text{ -----Eq. 1}$$

mesh 2 :

$$2(I_1 + I_2) - 7 + 1I_2 = 0$$

$$2I_1 + 2I_2 - 7 + 1I_2 = 0$$

$$2I_1 + 3I_2 = 7 \text{ -----Eq. 2}$$

STEP 3 Solve the equation to get the meshes current

Apply simultaneous equation elimination method:

$$\begin{aligned} 6I_1 + 2I_2 &= 28 \\ (2I_1 + 3I_2 = 7) \times 3 \end{aligned}$$

$$6I_1 + 2I_2 = 28 \text{ -----Eq. 1}$$

$$6I_1 + 9I_2 = 21 \text{ -----Eq. 3}$$

$$\text{Eq. 1} - \text{eq. 3}$$

$$-7I_2 = 7$$

$$I_2 = -7/7$$

$$I_2 = -1 \text{ A}$$

From eq. 1 insert I_2

$$6I_1 + 2(-1) = 28 \text{ -----Eq. 1}$$

$$6I_1 - 2 = 28$$

$$6I_1 = 30$$

$$I_1 = 30/6$$

$$I_1 = 5 \text{ A}$$

$$I_3 = I_{2\Omega} = I_1 + I_2 = 5 + (-1) = 4 \text{ A}$$

EXAMPLE 2.6 :

Referring to figure 2.6 calculate I_1 , I_2 and I_3 by using Mesh Analysis

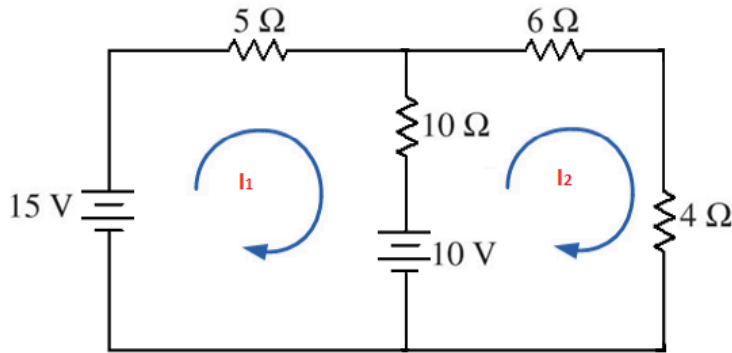


Figure 2.6

Remember, current flowing in opposite direction are subtracted



SOLUTION :

STEP 1

Assign I_1 and I_2 to the meshes

STEP 2

Apply KVL to each the meshes

mesh 1 :

$$10(I_1 - I_2) + 10 - 15 + 5I_1 = 0$$

$$10I_1 - 10I_2 - 5 + 5I_1$$

$$15I_1 - 10I_2 = 5 \text{ -----Eq. 1}$$

mesh 2 :

$$6I_2 + 4I_2 - 10 + 10(I_2 - I_1) = 0$$

$$10I_2 - 10 + 10I_2 - 10I_1 = 0$$

$$-10I_1 + 20I_2 = 10 \text{ -----Eq. 2}$$

STEP 3

Solve the equation to get the meshes current

Apply simultaneous equation elimination method:

$$(15I_1 - 10I_2 = 5) \times 2$$

$$-10I_1 + 20I_2 = 10$$

$$30I_1 - 20I_2 = 10 \text{ -----Eq.3}$$

$$-10I_1 + 20I_2 = 10 \text{ -----Eq. 2}$$

Eq. 3 + eq. 2

$$20I_1 = 20$$

$$I_1 = 20/20$$

$$I_1 = 1A$$

From eq. 1 insert I_1

$$15I_1 - 10I_2 = 5 \text{ -----Eq. 1}$$

$$15(1) - 10I_2 = 5$$

$$-10I_2 = 5 - 15$$

$$-10I_2 = -10$$

$$I_2 = 10/10$$

$$I_2 = 1 A$$

$$I_3 = I_{10\Omega} = I_1 - I_2 = 0A$$

EXAMPLE 2.7 :

Referring to figure 2.7 calculate I_1 , I_2 and I_3 by using Mesh Analysis

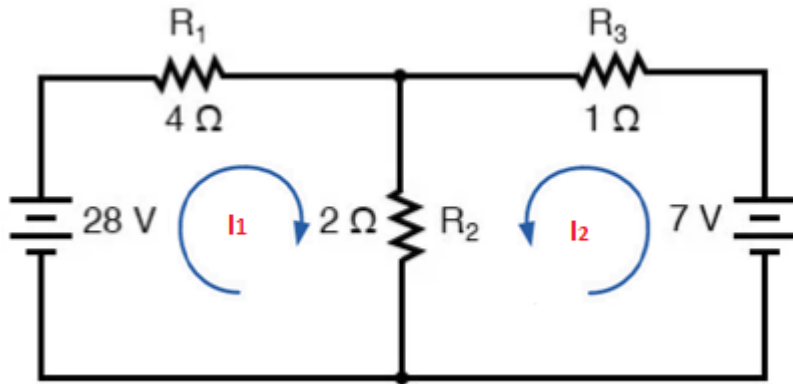


Figure 2.7

SOLUTION :

STEP 1

Assign I_1 and I_2 to the meshes

STEP 2

Apply KVL to each the meshes

mesh 1 :

$$2(I_1 + I_2) - 28 + 4I_1 = 0$$

$$2I_1 + 2I_2 - 28 + 4I_1 = 0$$

$$6I_1 + 2I_2 = 28 \text{ -----Eq. 1}$$

mesh 2 :

$$2(I_1 + I_2) - 7 + 1I_2 = 0$$

$$2I_1 + 2I_2 - 7 + 1I_2 = 0$$

$$2I_1 + 3I_2 = 7 \text{ -----Eq. 2}$$

Step 3: Solve the equation to get the meshes current

Apply simultaneous equation elimination method:

$$6I_1 + 2I_2 = 28$$

$$(2I_1 + 3I_2 = 7) \times 3$$

$$6I_1 + 2I_2 = 28 \text{ -----Eq. 1}$$

$$6I_1 + 9I_2 = 21 \text{ -----Eq. 3}$$

$$\text{Eq. 1} - \text{eq. 3}$$

$$-7I_2 = 7$$

$$I_2 = -7/7$$

$$I_2 = -1 \text{ A}$$

From eq. 1 insert I_2

$$6I_1 + 2(-1) = 28 \text{ -----Eq. 1}$$

$$6I_1 - 2 = 28$$

$$6I_1 = 30$$

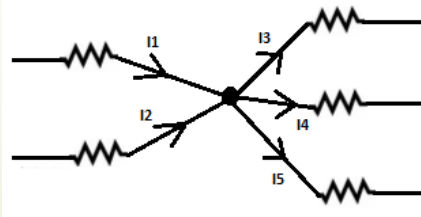
$$I_1 = 30/6$$

$$I_1 = 5 \text{ A}$$

$$I_3 = I_{2\Omega} = I_1 + I_2 = 5 + (-1) = 4 \text{ A}$$

KIRCHOFF' CURRENT LAW

At any junction in an electric circuit the total current 'flowing towards a node is equal to the total current flowing away from the node



$$\sum I_{in} = \sum I_{out}$$

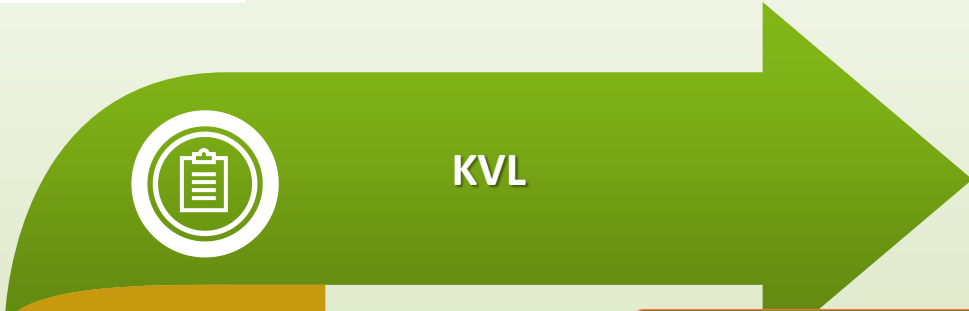
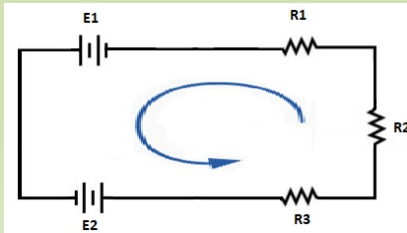
$$I1 + I2 = I3 + I4 + I5$$

$$\sum I_{in} = \sum I_{out}$$



$$\sum e.m.f.s = \sum V_{drops}$$

$$E1 + E2 = VR1 + VR2 + VR3$$



KIRCHOFF'S VOLTAGE LAW

In any mesh in a network, the algebraic sum of the voltage drops taken around the mesh is equal to the resultant e.m.f acting in that mesh which is also equal to zero

$$\sum e.m.f.s = \sum V_{drops}$$

@

$$\sum V_{close\ loop} = 0$$

Apply Kirchoff's Current Law and Kirchoff's Voltage Law in a DC circuit

PROCEDURE OF KIRCHHOFF'S LAW



STEP
01

STEP 01
Apply Kirchoff Current Law at determine node.

STEP
02

STEP 02
Write the KCL Equation
 $\sum I_{in} = \sum I_{out}$

STEP
03

STEP 03
Write the KVL equation to each mesh.

STEP
04

STEP 04
Solved the unknown current or voltage by using simultaneously equation

KIRCHOFF'S LAW

EXAMPLE 2.8 :

Referring to figure 2.8 , calculate I1, I2 and I3 using KVL and KCL method

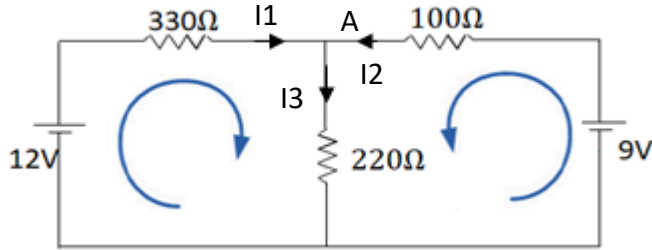


Figure 2.8

SOLUTION :

1. Write KCL equation at node A

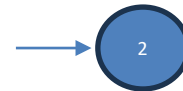
$$I_1 + I_2 = I_3$$



2. Write KVL for loop @ mesh 1

$$220I_3 - 12 + 330 I_1 = 0$$

$$330 I_1 + 220I_3 = 12$$



3. Write KVL for loop @ mesh 2

$$220 I_3 - 9 + 100 I_2 = 0$$

$$100 I_2 + 220 I_3 = 9$$



Using Simultaneous Equation

solve for I_1 I_2 and I_3 .

Insert eq. 1 into eq. 2 and 3

$$330I_1 + 220(I_1 + I_2) = 12$$

$$330I_1 + 220I_1 + 220I_2 = 12$$

$$550I_1 + 220I_2 = 12 \text{ -----eq. 4}$$

$$100I_2 + 220(I_1 + I_2) = 9$$

$$100I_2 + 220I_1 + 220I_2 = 9$$

$$220I_1 + 320I_2 = 9 \text{ -----eq. 5}$$

Apply simultaneous equation elimination method:

$$(550I_1 + 220I_2 = 12) \times 32 \text{-----eq. 4}$$

$$(220I_1 + 320I_2 = 9) \times 22 \text{-----eq. 5}$$

$$17600I_1 + 7040I_2 = 384 \text{ -----eq. 6}$$

$$4840I_1 + 7040I_2 = 198 \text{ -----eq. 7}$$

Eq. 6 – eq. 7

$$12760I_1 = 186$$

$$I_1 = 186/12760$$

$$I_1 = 0.0146A @ 14.577mA$$

From eq. 5 insert I_1

$$220(14.577mA) + 320I_2 = 9$$

$$3.207 + 320I_2 = 9$$

$$320I_2 = 9 - 3.207$$

$$320I_2 = 5.793$$

$$I_2 = 5.793/320$$

$$= 0.0181A @ 18.10mA$$

From eq. 1,

$$I_3 = I_1 + I_2$$

$$I_3 = 14.577mA + 18.10mA$$

$$I_3 = 32.677mA$$

So,

$$I_{R1} = 14.577mA$$

$$I_{R2} = 18.10mA$$

$$I_{R3} = 32.677mA$$

EXAMPLE 2.9 :

Referring to figure 2.9, calculate I_1 , I_2 and I_3 using KVL and KCL method

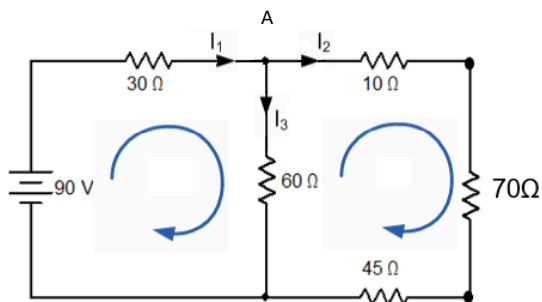


Figure 2.9

SOLUTION :

1. Write KCL equation at node A

$$I_1 = I_2 + I_3$$



2. Write KVL for loop @ mesh 1

$$60I_3 - 90 + 30I_1 = 0$$

$$30I_1 + 60I_3 = 90$$



3. Write KVL for loop @ mesh 2

$$10I_2 + 70I_2 + 45I_2 - 60I_3 = 0$$

$$125I_2 - 60I_3 = 0$$



Using Simultaneous Equation solve for I_1 , I_2 and I_3 .

Insert eq. 1 into eq. 2

$$30(I_2 + I_3) + 60I_3 = 90$$

$$30I_2 + 30I_3 + 60I_3 = 90$$

$$30I_2 + 90I_3 = 90 \text{ -----eq. 4}$$

Apply simultaneous equation elimination method:

$$(30I_2 + 90I_3 = 90) \times 6 \text{ -----eq. 4}$$

$$(125I_2 - 60I_3 = 0) \times 9 \text{ -----eq. 3}$$

$$180I_2 + 540I_3 = 540 \text{ -----eq. 5}$$

$$1125I_2 - 540I_3 = 0 \text{ -----eq. 6}$$

Eq. 6 + eq. 7

$$1305I_2 = 540$$

$$I_2 = 540/1305$$

$$I_2 = 0.414A @ 413.79mA$$

From eq. 3 insert I_2

$$125I_2 - 60I_3 = 0 \text{ -----eq.3}$$

$$125(413.79mA) - 60I_3 = 0$$

$$51.723 - 60I_3 = 0$$

$$-60I_3 = -51.723$$

$$I_3 = -51.723/-60$$

$$= 0.862A @ 862.05mA$$

From eq. 1,

$$I_1 = I_2 + I_3$$

$$I_1 = 413.79mA + 862.05mA$$

$$I_1 = 1.276A$$

So,

$$I_{30\Omega} = 1.276A$$

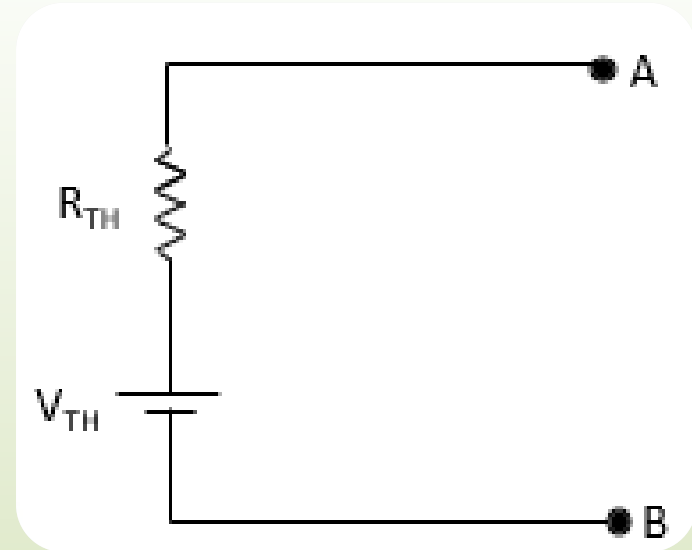
$$I_{10\Omega} = 413.79mA$$

$$I_{70\Omega} = 413.79mA$$

$$I_{45\Omega} = 413.79mA$$

$$I_{60\Omega} = 862.05mA$$

Thevenin's theorem states that any linear electrical network containing , current sources, and resistances can be replaced by an equivalent circuit consisting of a single voltage source (known as the Thevenin voltage) in series with a single resistance (known as the Thevenin resistance)



PROCEDURE OF THEVENIN THEOREM



STEP 01 Remove the resistance R_L from the branch.

STEP 02 Determine the open-circuit voltage, Voltage across the break (V_{TH}).

STEP 03 Remove each source and replace them by short circuit for voltage source and open circuit for current source

STEP 04 Determine the resistance (R_{TH}), 'looking-in' the break

STEP 05 Determine the resistance (R_{TH}), 'looking-in' the break



EXAMPLE 2.10 :

Referring to the figure 2.10 calculate current I_L using Thevenin's Theorem

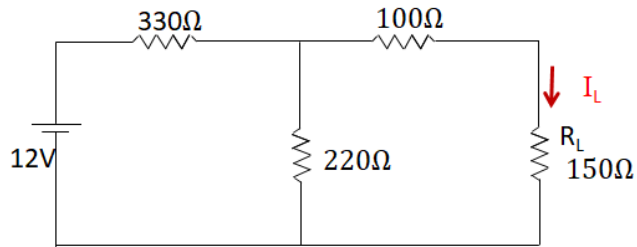
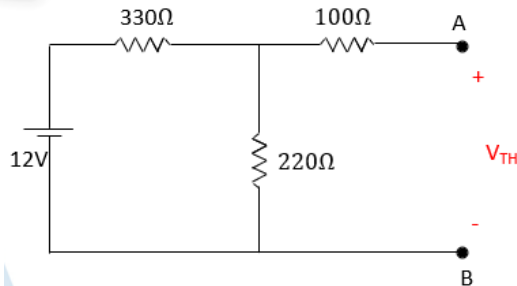


Figure 2.10

SOLUTION :

STEP 1

Remove R_L



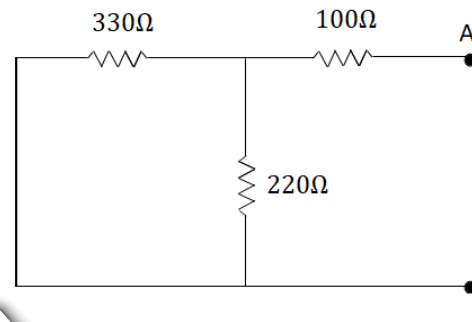
STEP 2

Calculate V_{TH}

$$V_{TH} = V_{220} = \frac{220}{330 + 220} \times 12 = 4.8 \text{ V}$$

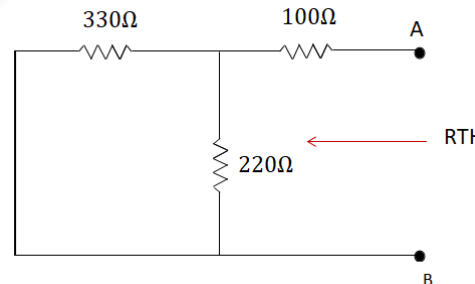
STEP 3

Remove voltage source and replace with short circuit



STEP 4

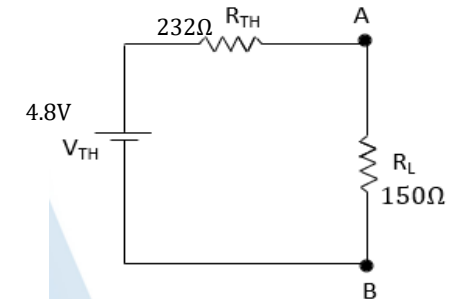
Calculate the R_{TH}



$$R_{TH} = \frac{330 \times 220}{330 + 220} + 100 = 232\Omega$$

STEP 5

Construct Thevenin Equivalent circuit and calculate current flow from the equivalent circuit



For this case:

$$I_L = I_{TH} = \frac{V_{TH}}{R_{TH} + R_L}$$

$$I_L = I_{TH} = \frac{4.8}{232 + 150} = 12.565 \text{ mA}$$



EXAMPLE 2.11 :

Referring to the figure 2.11 calculate current I_L using Thevenin's Theorem

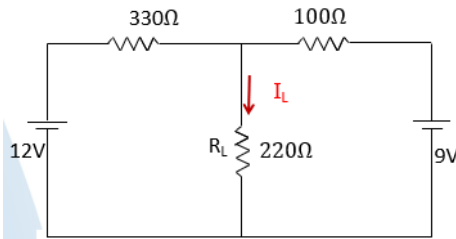
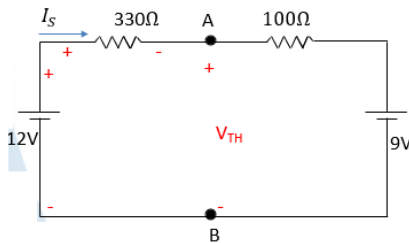


Figure 2.11

SOLUTION :

STEP 1

Remove R_L



STEP 2

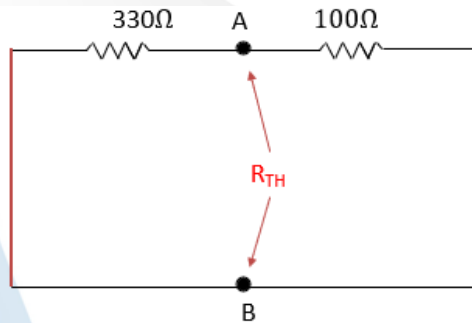
Calculate V_{TH}

$$I_S = \frac{12 - 9}{330 + 100} = 6.98 \text{ mA}$$

$$V_{TH} = 12 - (330 \times 6.98 \text{ mA}) = 9.69 \text{ V}$$

STEP 3

Remove voltage source and replace with short circuit



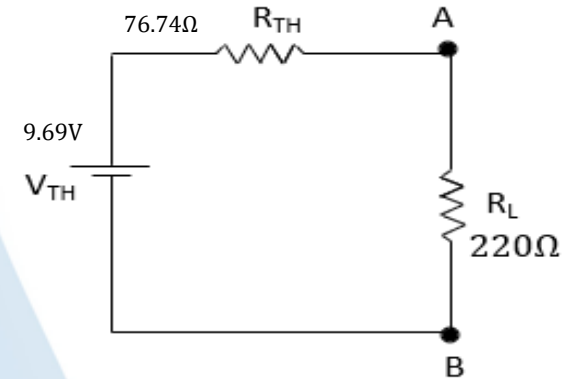
STEP 4

Calculate the R_{TH}

$$R_{TH} = \frac{330 \times 100}{330 + 100} = 76.74 \Omega$$

STEP 5

Construct Thevenin Equivalent circuit and calculate current flow from the equivalent circuit



For this case:

$$I_L = I_{TH} = \frac{V_{TH}}{R_{TH} + R_L}$$

$$I_L = I_{TH} = \frac{9.69}{76.74 + 220} = 32.65 \text{ mA}$$



EXAMPLE 2.12 :

Referring to the figure 2.12 calculate current I_L using Thevenin's Theorem

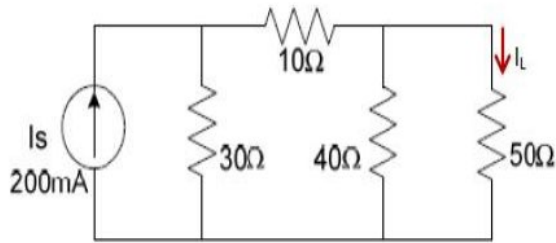
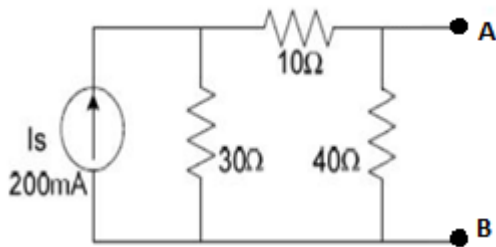


Figure 2.12

SOLUTION :

STEP 1

Remove R_L



STEP 2

Calculate V_{TH}

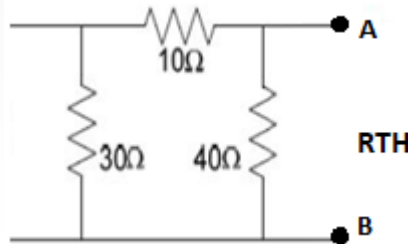
Used current divider to find current flow at resistor 40Ω

$$I_S = \frac{30}{30+50} \times 200 \text{ mA} = 75 \text{ mA}$$

$$V_{TH} = V_{40\Omega} = IR = 75 \text{ mA} \times 40\Omega = 3 \text{ V}$$

STEP 3

Remove current source and replace with open circuit



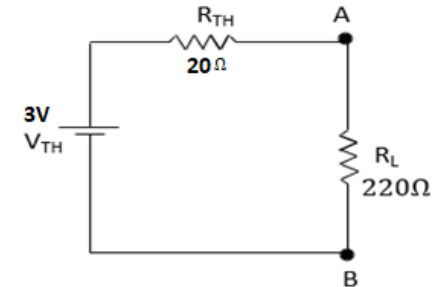
STEP 4

Calculate the R_{TH}

$$R_{TH} = \frac{(30+10) \times 40}{(30+10) + 40} = 20\Omega$$

STEP 5

Construct Thevenin Equivalent circuit and calculate current flow from the equivalent circuit



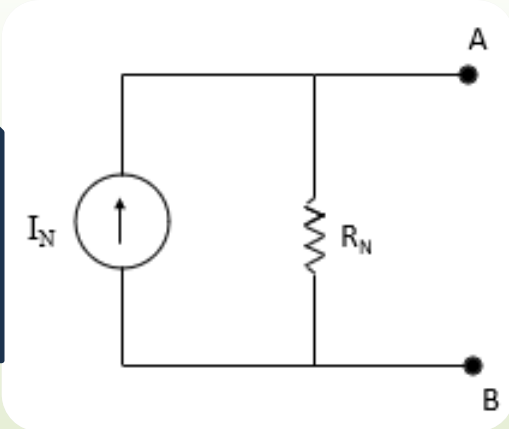
For this case:

$$I_L = I_{TH} = \frac{V_{TH}}{R_{TH} + R_L}$$

$$I_L = I_{TH} = \frac{3}{20 + 220} = 12.5 \text{ mA}$$



Norton's theorem states that any linear electrical network with multiple voltage or current sources can be replaced by an equivalent circuit containing a single current source, I_N in parallel with a single resistance, R_N . This equivalent circuit is known as the Norton equivalent circuit.



Remove the resistance R_L from the branch replace with short circuit



Determine the short-circuit current I_{sc} flowing in the branch ($I_{sc} = I_N$)



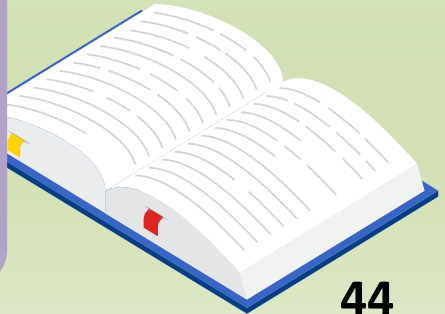
Remove each source and replace them by short circuit for voltage source and open circuit for current source



Determine the resistance (R_N), 'looking-in' the break



Construct Norton's Equivalent circuit and determine current flow from the equivalent circuit



EXAMPLE 2.13:

Referring to the figure 2.13, calculate current I_L using Norton's Theorem

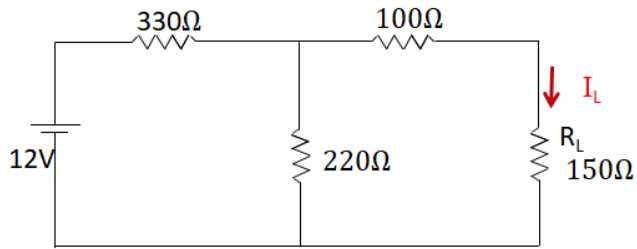
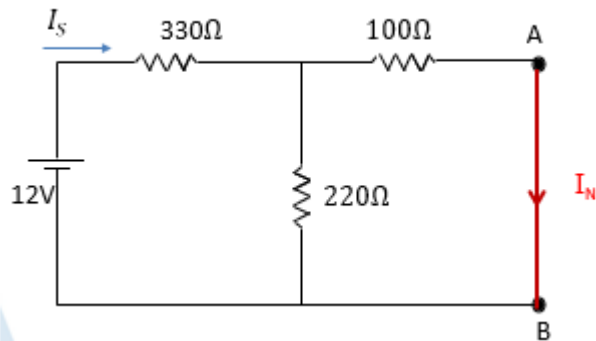


Figure 2.13

SOLUTION :

STEP 1 Remove R_L and replace with short circuit



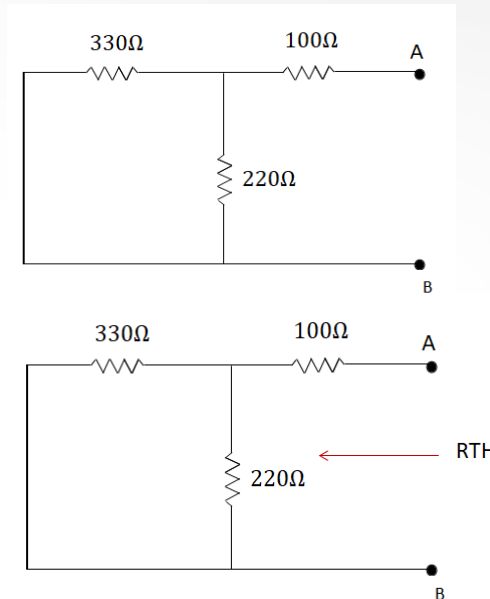
STEP 2 Calculate I_N

$$R_{\text{Total}} = \frac{220 \times 100}{220 + 100} + 330 = 398.75 \Omega$$

$$I_S = \frac{12}{398.75} = 30.09 \text{ mA}$$

$$\therefore I_N = I_{\text{SC}} = \frac{220}{100 + 220} \times 30.09 \text{ mA} = 20.69 \text{ mA}$$

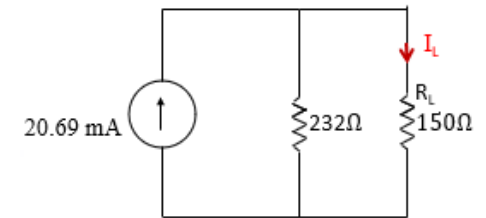
STEP 3 Remove voltage source and replace with short circuit



STEP 4 Calculate the R_N

$$R_N = \frac{330 \times 220}{330 + 220} + 100 = 232 \Omega$$

STEP 5 Construct Norton's Equivalent circuit and calculate current flow from the equivalent circuit



Calculate current I_L (Use CDR):

For this case:

$$I_L = \frac{R_N}{R_L + R_N} \times I_N$$

$$I_L = \frac{232}{232 + 150} \times 20.69 \text{ mA} = 12.46 \text{ mA}$$

EXAMPLE 2.14:

Referring to the figure 2.14, calculate current I_L using Norton's Theorem

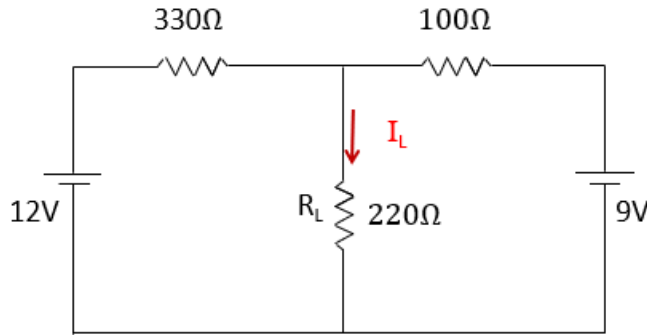
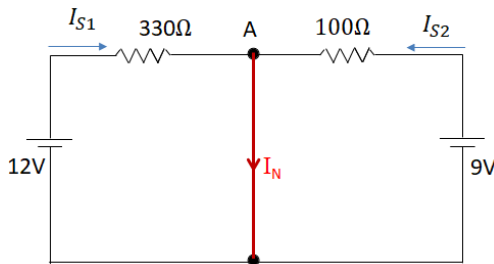


Figure 2.14

SOLUTION :

STEP 1 Remove R_L and replace with short circuit



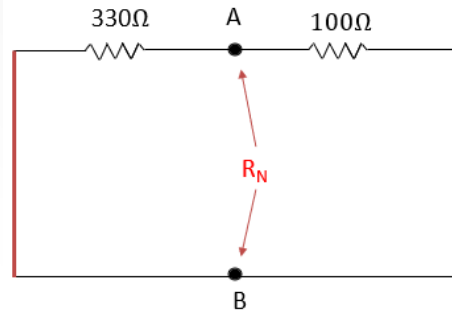
STEP 2 Calculate I_N

$$I_{S1} = \frac{12}{330} = 36.36 \text{ mA}$$

$$I_{S2} = \frac{9}{100} = 90 \text{ mA}$$

$$I_N = I_{S1} + I_{S2} = 36.36\text{m} + 90\text{m} = 126.36 \text{ mA}$$

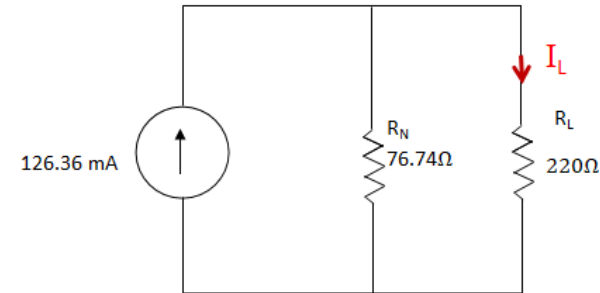
STEP 3 Remove voltage source and replace with short circuit



STEP 4 Calculate the R_N

$$R_N = \frac{330 \times 100}{330 + 100} = 76.74\Omega$$

STEP 5 Construct Norton's Equivalent circuit and calculate current flow from the equivalent circuit



Calculate current I_L (Use CDR):

For this case:

$$I_L = \frac{R_N}{R_L + R_N} \times I_N$$

$$I_L = \frac{76.74}{220 + 76.74} \times 126.36\text{m} = 32.68\text{mA}$$

EXAMPLE 2.15:

Referring to the figure 2.15, calculate current flow through 200Ω using Norton's Theorem

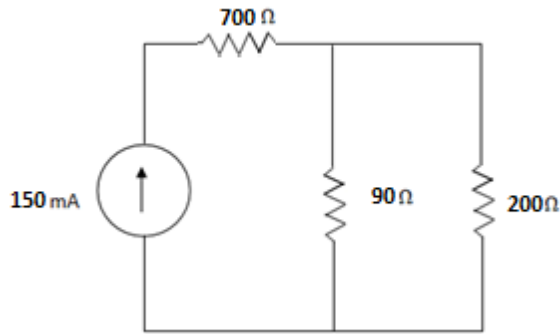
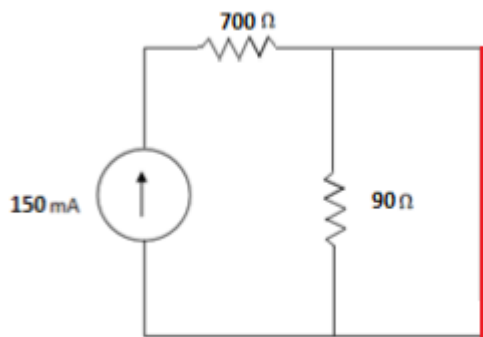


Figure 2.15

SOLUTION :

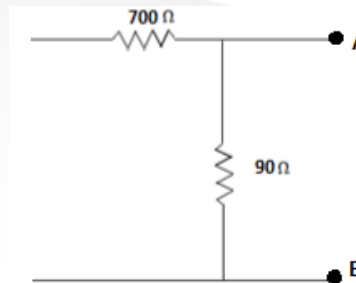
STEP 1 Remove R_L and replace with short circuit



STEP 2 Calculate I_N

90Ω will short circuit so;
 $I_N = 150 \text{ mA}$

STEP 3 Remove voltage source and replace with open circuit

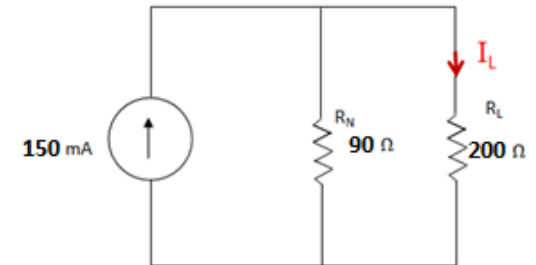


STEP 4 Calculate the R_N

When the current source is open circuit the resistor 700Ω will be open circuit, so

$$R_N = 90\Omega$$

STEP 5 Construct Norton's Equivalent circuit and calculate current flow from the equivalent circuit



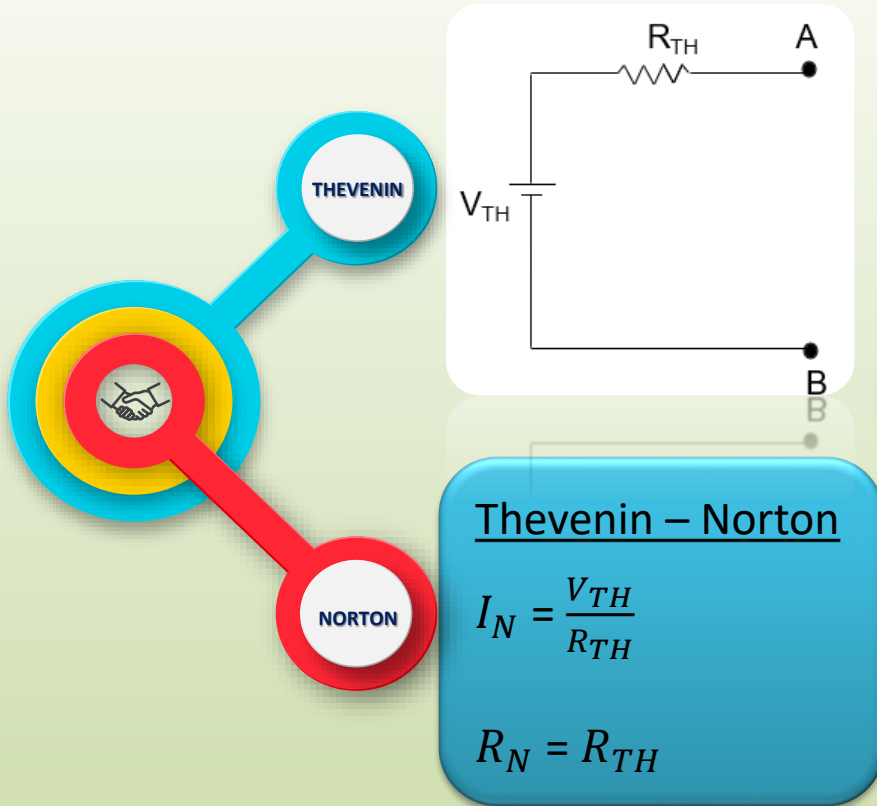
Calculate current I_L (Use CDR):

For this case:

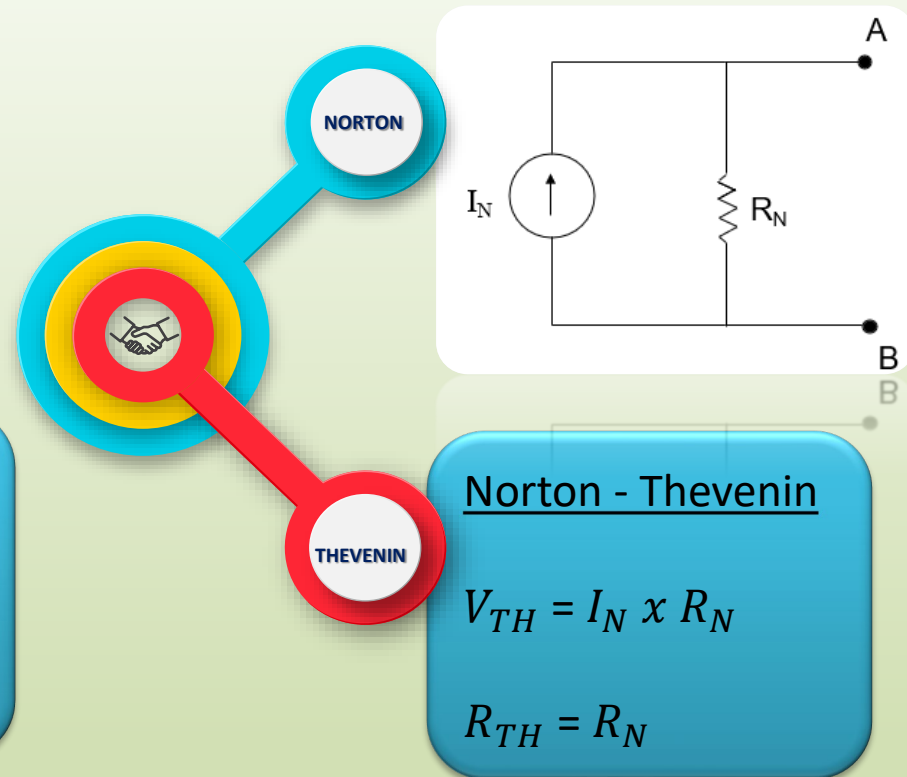
$$I_L = \frac{R_N}{R_L + R_N} \times I_N$$

$$I_L = \frac{90}{200 + 90} \times 150\text{m} = 46.55\text{mA}$$

THEVENIN TO NORTON CONVERSION



NORTON TO THEVENIN CONVERSION



EXAMPLE 2.15 :

Convert Norton's Equivalent to Thevenin's Equivalent

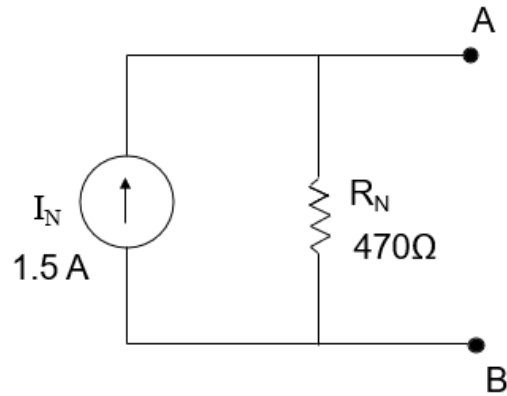


Figure 2.15

SOLUTION :

Find V_{TH}

$$V_{TH} = R_N \times I_N = 1.5 \times 470 = 705 \text{ V}$$

$$R_{TH} = R_N = 470\Omega$$

EXAMPLE 2.16 :

Convert Thevenin's Equivalent to Norton's Equivalent

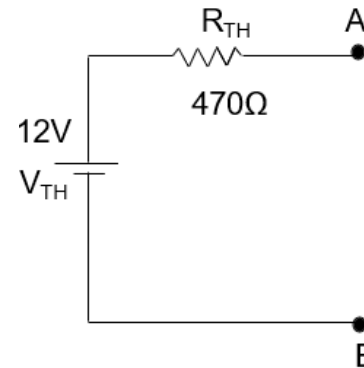


Figure 2.16

SOLUTION :

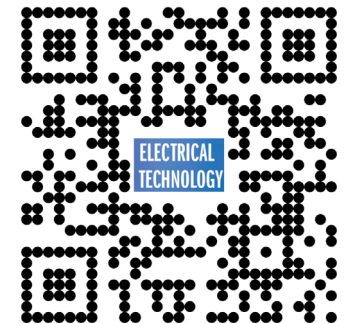
Find I_N

$$I_N = V_{TH} / R_{TH} = 12 / 470 = 25.53\text{mA}$$

$$R_N = R_{TH} = 470\Omega$$

“If you want something you’ve never had, you must willing to do something you’ve never done”

Scan QR code for more exercise



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