
First Class/ Lecture One

Basic Concepts and Basic Laws

Basic Concepts

System of Units

The basic SI Units

Quantity	Basic unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	Second	S
Electric current	Amper	A
Potential difference	Volt	V
Electrical Power	Watt	W
Electrical Energy	Joule	J
Thermodynamic temperature	Keliven	K (K=273.15+ °C
Luminous intensity	candella	cd

The SI prefix

Multiplier	Prefix	Symbol
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10	deca	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

Examples:

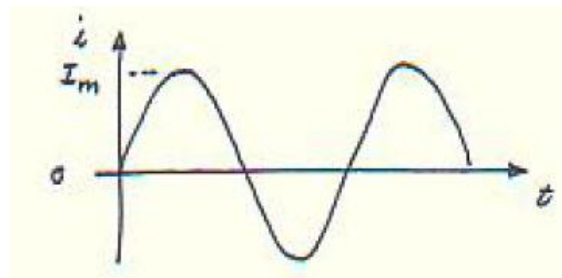
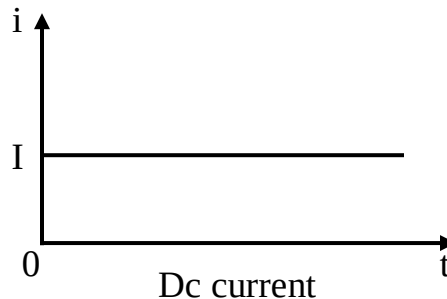
- 1) $10\text{MHz} = 10 \times 10^6 \text{ Hz}$,
- 2) $2\text{mA} = 2 \times 10^{-3} \text{ A}$,
- 3) $5\mu\text{s} = 5 \times 10^{-6} \text{ s}$
- 4) $1000000 \Omega = 1 \times 10^6 \Omega$
- 5) $100000 \text{ meter} = 100 \times 10^3 \text{ m} = 100\text{km}$
- 6) $0.00001 \text{ farad} = 1 \times 10^{-6} \text{ farad} = 1 \text{ microfarad } (\mu\text{f})$
- 7) $0.0001 \text{ second} = 1 \times 10^{-3} \text{ second} = 0.1 \text{ ms}$

Charge and Current: The electric charge is an electrical property of atomic particles of which matter consists, measured in coulombs (C). The charge of an electron is (-1.602×10^{-19}) .

Electric Current: is the rate of change of charge, measured in amperes (A). The current (I) is defined mathematically as:

$$i = \frac{dq}{dt}$$

$$\therefore q = \int_{t_1}^{t_2} i dt$$



- ❖ A direct current (dc) is current that remains constant with time. The symbol (I) is usually used to represent such a constant current.

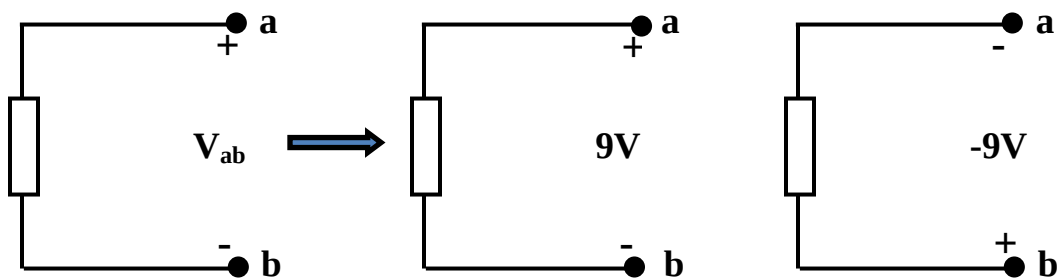
- ❖ An alternating current (ac) is a current that is varying sinusoidal with time. A time varying current is represented by the symbol (i).

Example: Determine the total charge entering a terminal between $t=1s$ and $t=2s$, if the current passing the terminal is $i = (3t^2 - t)$ A.

$$\text{Solution: } q = \int_{t_1}^{t_2} i \, dt = \int_1^2 (3t^2 - t) \, dt = \left(t^3 - \frac{t^2}{2} \right) \Big|_1^2$$

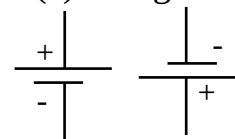
$$= (8 - 2) - \left(1 - \frac{1}{2} \right) = 5.5C$$

Voltage: The voltage (potential difference) is the energy required to move a unit charge through an element, measured in volt (V).



For the voltage V_{ab} $\Rightarrow$ this means that the potential of point (a) is higher than that of point (b).

$$V_{ab} = V_a - V_b$$



Power and Energy:

- ❖ Power is the time rate of expending or absorbing energy, measured in watt (W).

$$P = \frac{dw}{dt}$$

Where P is the power in watt (W), w is the energy in joules (J), and t is the time in second (s).

$$\text{We have; } P = \frac{dw}{dt} \Rightarrow P = \frac{dw}{dt} \cdot \frac{dq}{dq} \Rightarrow P = \frac{dw}{dq} \cdot \frac{dq}{dt} = v \cdot i$$

$$\therefore P = v \cdot i$$

The energy absorbed or supplied by an element

From time t_0 to time t is:

$$w = \int_{t_0}^t p dt = \int_{t_0}^t v \cdot i dt$$

Energy is the capacity to do work, measured in joules (J).

❖ The electric power utility companies measure energy in watt-hour (Wh), where:

$1\text{Wh}=3600\text{J}$

Example: How much energy does a 100W electric bulb consume in 2hours?

Solution:

$$W=pt = 100 \times 2 = 200\text{Wh}$$

$$\text{Or } w = pt = (100\text{w}) (2 \times 60 \times 60) = 720000\text{J} = 720\text{kJ}$$

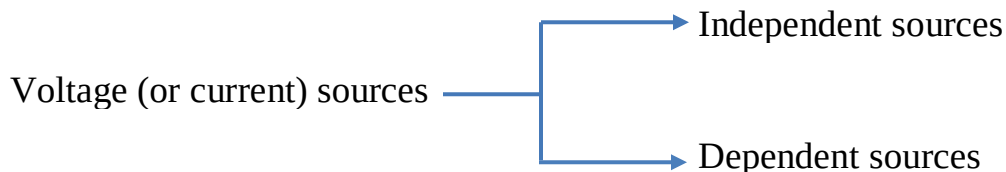
Which is the same result (if you convert from joules into Watt or versa)?

Circuit Elements: An electric circuit is an interconnection of electric element.

❖ Circuit analysis is the process of determining voltage across (or the current through) the elements of the circuit.

- 1) Passive elements (cannot generate energy) such as Resistors, capacitors and inductors.
- 2) Active elements (can generate energy) such as (generators, batteries, operational amplifiers).

The most important active elements are voltage or current sources that generally deliver power to the circuit connected to them.



❖ The **independent source** is an active element that provides a specific voltage or current that is completely independent of other circuit variables.

- ❖ **The dependent sources** (or controlled sources) are active elements in which the source quantity is controlled by another voltage or current (it will be discussed later).

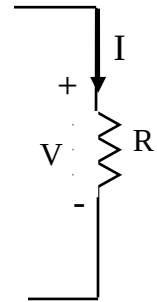
Basic Laws:

Ohms Law (1856): Ohm's Law states that the voltage V across a resistor is directly proportional to the current I flowing the resistor.

$$V \propto I$$

$$\Rightarrow V = IR \quad \text{Ohm's Law}$$

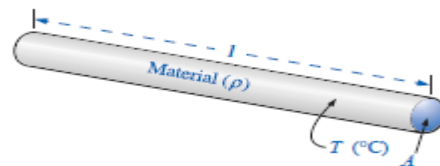
$$\text{OR } R = \frac{V}{I}$$



Where; R is the resistance. The resistance R denotes the ability of an element to resist the flow current, it is measured in Ohms (Ω).

For any material, the resistance R depends on its physical dimensions as follows:

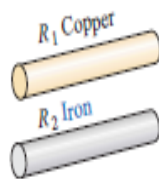
$$R = \rho \frac{\ell}{A}$$



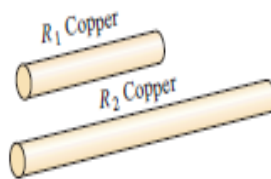
Where ρ is the resistivity of material.

Good conductors have low resistivities such as (copper, aluminum, etc...)

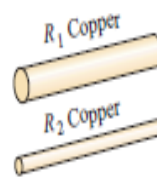
Insulators have high resistivities such as (mica, paper, etc...).



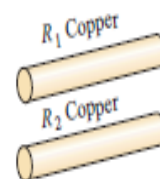
(a)



(b)



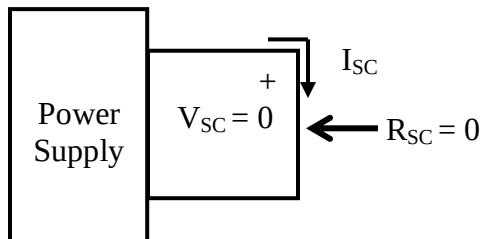
(c)



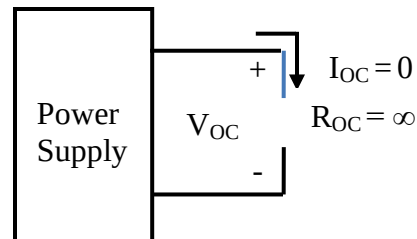
(d)

Material	Resistivity ($\Omega \cdot m$)	Usage
Silver	1.64×10^{-8}	Conductor
Copper	1.72×10^{-8}	=
Aluminum	2.80×10^{-8}	=
Gold	2.45×10^{-8}	=
Carbon	4.00×10^{-5}	Semiconductor
Germanium	47.0×10^{-2}	=
Silicon	6.4×10^{-2}	=
Paper	10^{10}	Insulator
Mica	5×10^{11}	=
Glass	10^{12}	=
Teflon	3×10^{12}	=

- ❖ The resistance of a short circuit element is approaching zero.
- ❖ The resistance of an open circuit element is approaching infinity.



Short circuit with $R_{SC} = 0$
 $V_{SC} = 0$



Open circuit with $R_{OC} = \infty$
 $I_{OC} = 0$

Conductance (G): A useful quantity in circuit analysis is the reciprocal of resistance $\mathcal{R}$, is called the conductance (G):

$$G = \frac{1}{R} = \frac{i}{v}$$

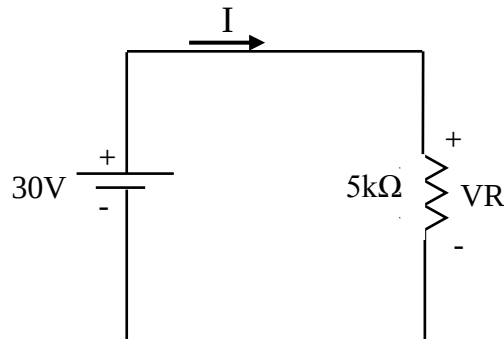
The conductance can be explained as the ability of an element to conduct electrical current; it is measured in mho ($\mathcal{O}$) or in Siemens (S).

$$\therefore i = Gv$$

$$\text{and } P = vi = i^2R = \frac{v^2}{R} \quad \text{watt (W)}$$

$$\text{or } P = vi = v^2G = \frac{i^2}{G} \quad \text{watt (W)}$$

Example: In the circuit shown, calculate the current (I), the conductance (G) and the power (P)



Solution:

$$\text{The current (I)} = \frac{V_R}{R} = \frac{30}{5 \times 10^3} = 6 \times 10^{-3} = 6mA$$

$$\text{The conductance (G)} = \frac{1}{R} = \frac{1}{5 \times 10^3} = 0.2 \times 10^{-3} = 0.2mS$$

$$\text{The Power (P)} = V_R I = 30(6 \times 10^{-3}) = 180mW$$

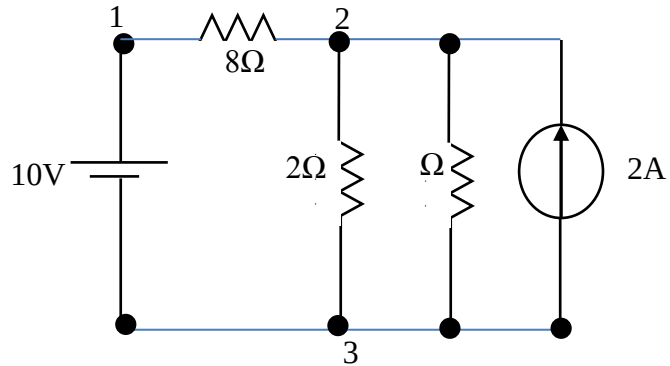
$$\text{OR Power (P)} = I^2 R = (6 \times 10^{-3})^2 (5 \times 10^3) = 180mW$$

$$\text{OR Power (P)} = V^2 G = (30)^2 (0.2 \times 10^{-3}) = 180mW$$

Nodes, branch and loops

- ❖ **A node:** represents the point of connection between two or more elements (branches).
- ❖ **A branch:** represents a single element in the electric circuit, such as a voltage source or a resistor etc.
- ❖ **A loop:** is any closed path in the circuit.

Example: For the circuit shown, determine the number of branches, nodes and independent loops.



Solution: Since there are 5 elements

Number of branches = 5 (10V, 5Ω, 2Ω, 3Ω and 2A)

Number of nodes = 3

The number of the independent loops = 3

Notes: There are more than 3 (dependent) loops in this example; we had only dependent loops calculated the independent loops which are only 3.

In General: Any circuit with b branches, n nodes and l independent loops, the following fundamentals theorem of network topology:

$$b = l + n - 1$$

- ❖ Two or more elements are in **SERIES** if they are cascaded sequentially and consequently carry the same Current.
- ❖ Two or more elements are in **PARALLEL** if they are connected to the same two nodes and have consequently the same Voltage across them.
- **Kirchoff's Laws** (1847)
- ❖ Kirchoff's Current Law (**KCL**): states that the algebraic sum of all current entering a node is zero or: The sum of current entering a node is equal to the sum of current leaving that node.

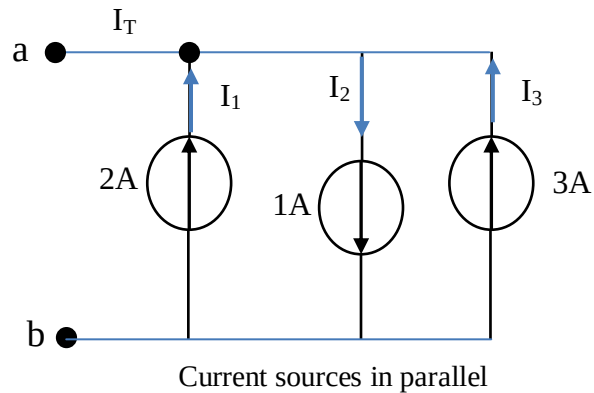
$$\sum_{n=1}^N I_n = 0$$

$$\sum_{m=1}^M I_{mi} = \sum_{n=1}^N I_{no}$$

Where: I_{mi} are the currents entering the node and I_{no} are the currents leaving the node.

Example: for the circuit shown, calculate the total current I_T .

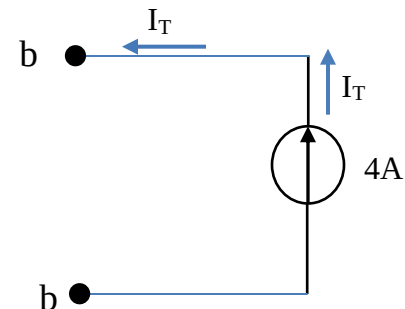
Solution: According to KCL;



$$I_T = I_1 - I_2 + I_3$$

$$I_T = 2 - 1 + 3 = 4A$$

The equivalent circuit of this network can be as shown



- ❖ Kirchoff's Voltage Law (**KVL**): states that the algebraic sum of all voltages around a closed path (or loop) is zero.

Mathematically KVL states that:

$$\sum_{m=1}^M V_m = 0$$

Where: M is the number of voltages in the loop (or the number of the branches in the loop), and the V_m is the m^{th} voltage.

Example: For the circuit shown, find the voltages V_1 and V_2

Solution:

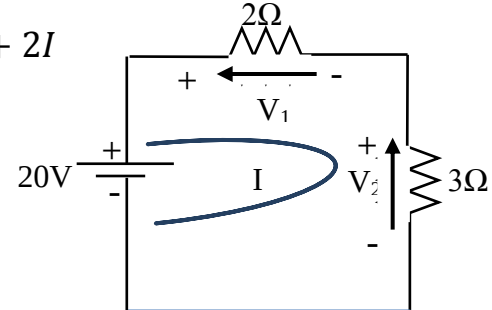
$$V_1 = 2I$$

$$V_2 = 3I$$

$$\text{From KVL: } \sum V = 0 \Rightarrow 20 - V_1 - V_2 = 0 \Rightarrow 20 = 3I + 2I$$

$$\Rightarrow 5I = 20 \Rightarrow I = 4A$$

$$\therefore V_1 = 2I = 8V \text{ and } V_2 = 3I = 12V$$



Tutorial Sheet

Example: Using Kichoff's laws.

Find the current and voltages in the circuit shown.

Solution:

Using Ohm's Law:

$$V_1 = I_1 R_1 = 8I_1$$

$$V_2 = I_2 R_2 = 3I_2$$

$$V_3 = I_3 R_3 = 6I_3$$

❖ Applying KVL at node **a**:

$$I_1 = I_2 + I_3 \Rightarrow I_1 - I_2 - I_3 = 0 \dots \text{Eq. (1)}$$

Applying KVL to loop1:

$$E - V_1 - V_2 = 0 \Rightarrow 30 - V_1 - V_2 = 0$$

$$\Rightarrow 30 - 8I_1 - 3I_2 = 0$$

$$\therefore I_1 = \frac{30 - 3I_2}{8} \dots \text{Eq. (2)}$$

❖ Applying KVL to loop2:

$$V_1 - V_2 = 0 \Rightarrow V_1 = V_2$$

$$\therefore 6I_3 = 3I_2$$

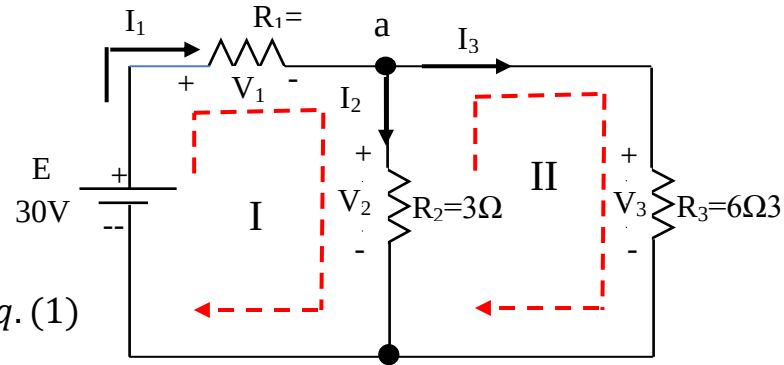
$$\therefore I_3 = \frac{I_2}{2} \dots \text{Eq. (3)}$$

From Eq. (1), Eq. (2) and Eq. (3)

$$\frac{30 - 3I_2}{8} - I_2 - \frac{I_2}{2} = 0 \Rightarrow I_2 = 2A$$

$$\text{and } I_1 = \frac{30 - 3I_2}{8} = \frac{30 - 3(2)}{8} = 3A$$

$$I_3 = \frac{I_2}{2} = \frac{2}{2} = 1A$$



$$\therefore V_1 = 8I_1 \Rightarrow V_1 = 8(3) = 24V$$

$$\text{Similarly } V_2 = 3I_2 = 3(2) = 6V$$

$$\text{and } V_3 = 6I_3 = 6(1) = 6V$$

$$\text{For Check } I_1 = I_2 + I_3$$

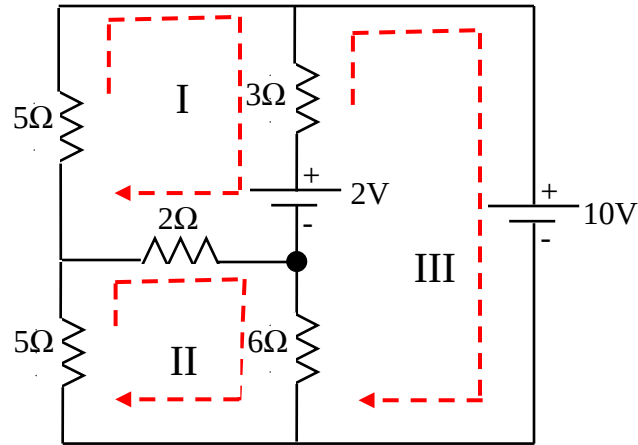
$$3 = 2 + 1 \Rightarrow 3 = 3$$

$$\text{Also } E = V_1 + V_2$$

$$\therefore 30 = 24 + 6$$

$$\therefore 30 = 30$$

Example: Determine the number of branches, nodes and independent loops in the circuit shown.



Solution:

There are 7 elements $\Rightarrow$ no. of branches = 7 $\Rightarrow b = 7$

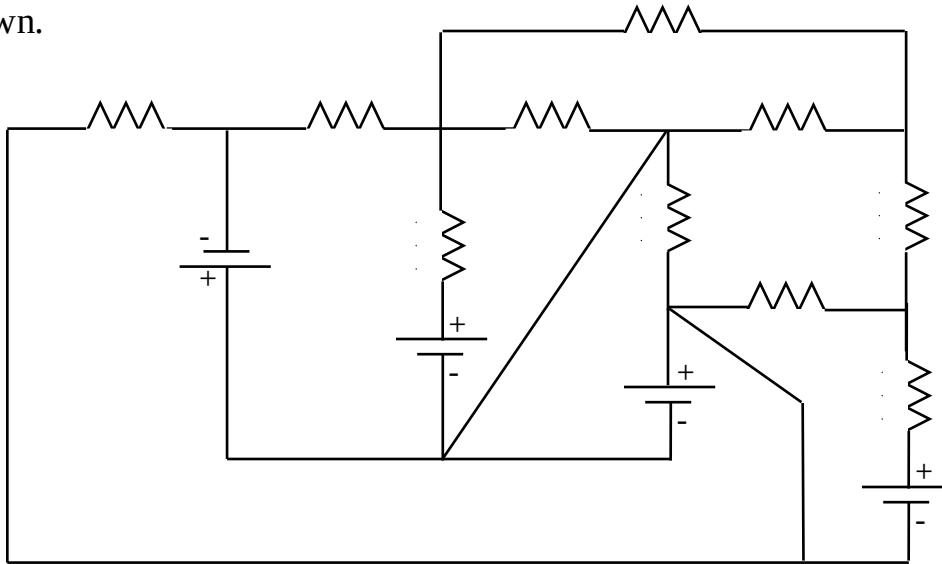
a, b, c, d, e, There are 5 nodes as shown in the circuit $\Rightarrow n = 5$

I, II, III, There are 3 independent loops $\Rightarrow \ell = 3$

$$\therefore b = \ell + n - 1 \quad \text{is satisfied}$$

$$\text{since } 7 = 3 + 5 - 1 \Rightarrow 7 = 7$$

Practice problem: Identify all nodes, branches and independent loops in the circuit shown.



Solution:

$$\text{no. of nodes} = 8 \Rightarrow n = 8$$

$$\text{no. of branches} = 14 \Rightarrow b = 14$$

$$\text{no. of independent loops} = 7 \Rightarrow \ell = 14$$

Check: Does this satisfy the fundamental theorem of network topology?

$$b = \ell + n - 1 = 7 + 8 - 1 = 14 \quad \text{Yes (satisfies)}$$

Example: Determine the currents and voltages in the circuit shown

Solution:

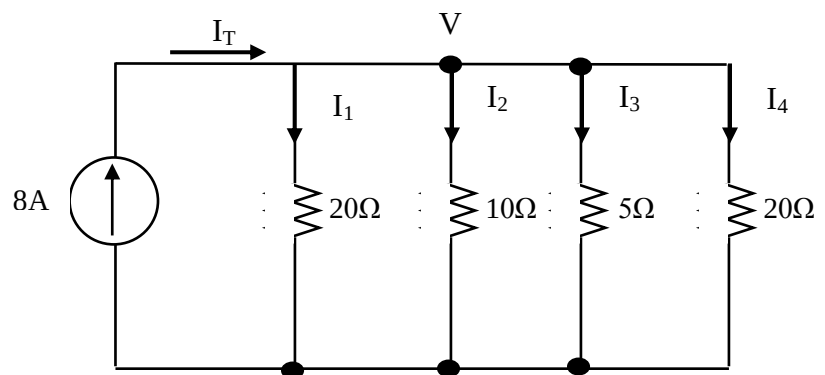
$$KCL \ I_T = I_1 + I_2 + I_3 + I_4 \Rightarrow 8 = I_1 + I_2 + I_3 + I_4$$

Ohm's Law:

$$V = 20I_1 \Rightarrow I_1 = \frac{V}{20}$$

$$V = 20I_2 \Rightarrow I_2 = \frac{V}{10}$$

$$V = \frac{20I_3}{15A} \Rightarrow I_3 = \frac{V}{5}$$



$$V = 20I_4 \Rightarrow I_4 = \frac{V}{20}$$

Substituting in the current equations:

$$\Rightarrow 8 = \frac{V}{20} + \frac{V}{10} + \frac{V}{5} + \frac{V}{20}$$

$$\therefore 160 = V + 2V + 4V + V$$

$$\therefore 160 = 8V$$

$$\therefore V = 20Volt$$

$$I_1 = \frac{20}{20} = 1A$$

$$I_2 = \frac{20}{10} = 2A$$

$$I_3 = \frac{20}{5} = 4A$$

$$I_4 = \frac{20}{20} = 1A$$

$$Check: I_T = I_1 + I_2 + I_3 + I_4 \Rightarrow 8 = 1 + 2 + 4 + 1$$

$$8 = 8$$