Difference between ELECTRICAL & ELECTRONICS

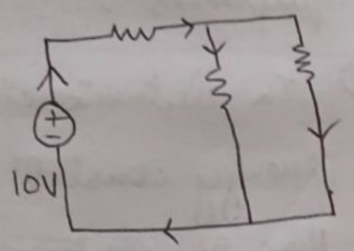
Electrical	Electronics
(1) Electrical technology deals with generation, distribution, storage & conversion of electrical energy.	(1) Electronic technology deals with amplifying and switching electrical energy with the help of different electronic equipments.
(2) Electrical energy consist of flow of electron	(2) In electronic circuit, energy consist of flow of electron and hole.
(3) Electrical devices produce voltage and current	(3) Electronic devices control voltage and current.
(4) Range of voltage is volt to kilo volt	(4) Range of voltage is mV to V.
(5) Conductors are used Ex – Copper, Al	(5) Only semiconductor used Ex Si, Ge
(6) Monitor or control high electrical power.	(6) Monitor or controls low power.
(7) Electrical energy can be converted to other forms of energy like heat, light, motion etc.	(7) It doesnot convert into other form
(8) Electrical devices large in size	(8) Electronic devices small in size.
(9) Ex → Transformer, generator, motor	(9) Ex → diode, transistor

FUNDAMENTALS

CIRCUIT

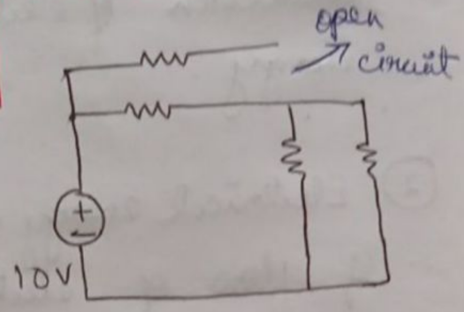
① current is intended to flow through all elements.

This closed path concept is called CIRCUIT



NETWORK

① Current doesnot necessarily flow through all the elements.



* Interconnection of circuit is a network.

Network (N|W) is like a building whereas circuits are like rooms in a building.

OHMs law

1. Linear Time Invariant (LTI) domain

There exist a linear relation between applied electric field and resultant current density at a constant temperature

current density → current per unit cross section area

$$\boxed{J = \frac{I}{A}}$$

Now, according to ohms law,

$J \propto E$

$\Rightarrow \boxed{J = \sigma E}$ ← 1st form of ohms law

$J \rightarrow$ current density

$\sigma \rightarrow$ conductivity

$E \rightarrow$ electric field

$\left[E = \frac{V}{l} \ , \ J = \frac{I}{A} \right]$

$\Rightarrow \frac{I}{A} = \sigma \frac{V}{l}$

$\Rightarrow V = \left(\frac{l}{\sigma A} \right) I$

But $\frac{1}{\sigma} = \rho$

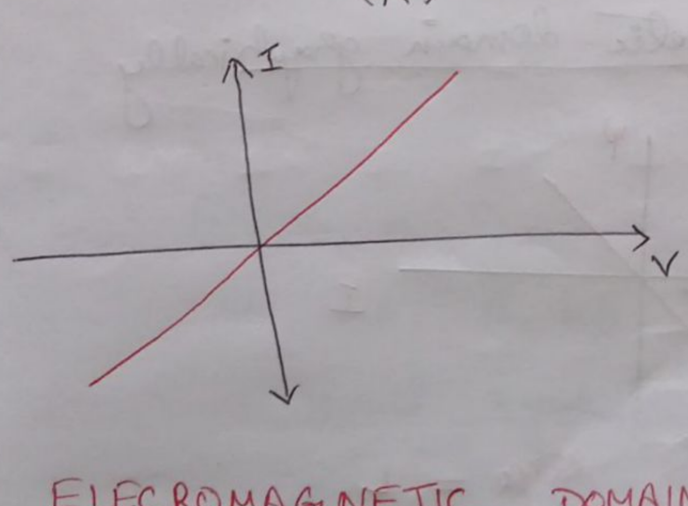
$\rho \rightarrow$ resistivity

$\therefore V = \left(\frac{\rho l}{A} \right) I$

$\Rightarrow V = RI$

$\Rightarrow \boxed{V = IR}$ ← 2nd form of Ohms law
circuital form

Graphically, $I = \left(\frac{1}{R} \right) V$



② ELECROMAGNETIC DOMAIN

$\Psi = LI$

$\Psi \rightarrow$ electric flux

$L \rightarrow$ inductance

$\phi \rightarrow$ magnetic flux

Now, $\Psi = N\phi$

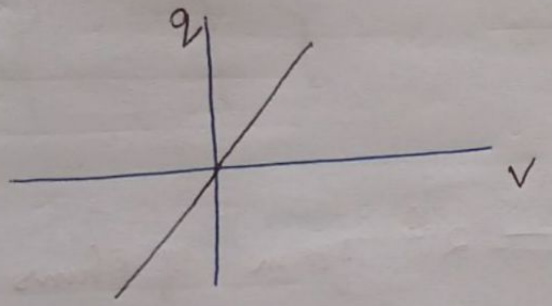
$\therefore \boxed{V = L \frac{dI}{dt}}$ 4^{th} form of Ohms law

3. ELECTROSTATIC DOMAIN

$\boxed{q = CV}$ $\longrightarrow$ 5^{th} form of Ohms law

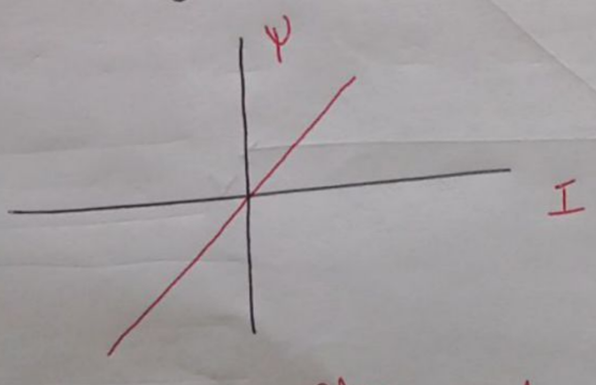
$\boxed{I = C \frac{dV}{dt}}$ $\rightarrow$ 6^{th} form of Ohms law

Graphically,



slope = C

Electromagnetic domain graphically



slope = L

1. VOLTAGE

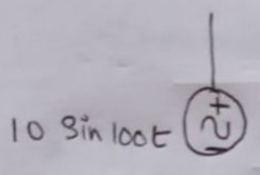
$$\boxed{V = \frac{w}{q}}$$

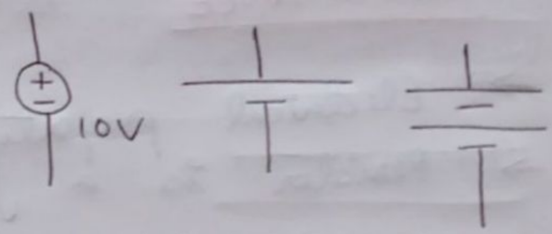
Unit → ~~[illegible]~~ volt or J/C

Range → mV , kV , V , MV

circuit symbol

AC DC





Ex → UPS
Inverter

Ex → Cell , Battery,
Solar panels

2. CURRENT

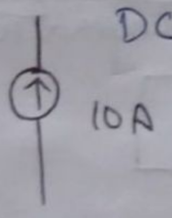
$$\boxed{I = \frac{Q}{t}}$$

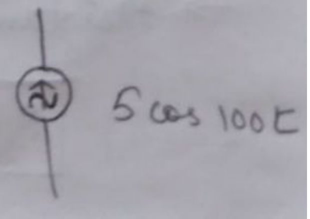
Units : Ampere or C/sec

Range : μA , mA , A , kA

circuit symbol

DC AC





Example

DC → A DC series generator can be modelled as DC current source

A BJT can be modelled as DC dependent current source.

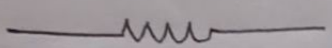
AC → A feeder can be modelled as AC current source.

3. RESISTANCE

→ Electrical property of matter
→ Resistor is a component to model it.

→ It is classified based on the material.

Carbon, ceramic, tungsten.



Unit : ohm Ω

Range : $\mu\Omega$, $m\Omega$, Ω, $k\Omega$, $M\Omega$, $G\Omega$

$$\boxed{V = IR}$$

$$\boxed{R = \frac{\rho l}{A}}$$

→ Resistance depends upon temperature.

$$\boxed{R_t = R_0 (1 + \alpha t)}$$

$\alpha \rightarrow$ temp^r. coefficient of resistance

$\alpha \rightarrow$ +ve $\rightarrow$ conductor

$\alpha \rightarrow$ −ve $\rightarrow$ semiconductor

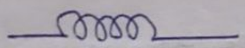
Ex $\rightarrow$ communication and transmission lines.

All industrial and domestic wiring.

4. Inductance

$\rightarrow$ electromagnetic property of matter
Inductor is a component to model it.

$\rightarrow$ It is classified based on core material
Iron, ferrite, air



unit : Henry (H)

Range : μH, mH, H

$$\boxed{V = L\frac{di}{dt}}$$

$$\boxed{L = \frac{\mu N^2 A}{l}}$$

$\mu \rightarrow$ permeability of core

$\mu = \mu_0 \mu_r$

$\mu_0 = 4\pi \times 10^{-7}$ H/m

$\mu_r = 1$ (air)

$\mu_r > 1000$ (iron)

Ex $\rightarrow$ filter, choke coils, windings

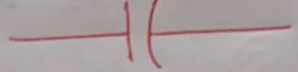
5. Capacitance

→ electrostatic property of matter
→ capacitor is a component to model it.
→ It is classified based on dielectric material → electrolytic, ceramic, polyster

Unit : ~~Faraday~~ (F) (or) $\frac{A - sec}{V}$

Range : pF , nF , uF , mF

$$\boxed{i = C \frac{dv}{dt}}$$



$$\boxed{C = \frac{\varepsilon A}{d}}$$

$\varepsilon = \varepsilon_0 \varepsilon_r$ ~~→ ε → permittivity~~

ε → permittivity

$\varepsilon_0 \rightarrow 8.85 \times 10^{-12}$ F/m

d → distance b/w plates.

Example

Filter, power system,
Transmission lines

Questions

1. What happens to conductivity of all conductors, if tempr. is increased beyond room temperature?

2. Why voltage drop occurs in any practical conductor when it carries electrical energy?

Ans → As E ↑, there is increase in collision b/w free electrons and immobile positive ions (larger in size) which results in fall in drift velocity.

$$E \uparrow \text{ ——— } v_d \downarrow$$

Now,

$$\text{kinetic energy} = \tfrac{1}{2} m v_d^2$$

When $v_d \downarrow$, $KE \downarrow \Rightarrow$ loss of KE

This loss in energy will be dissipated in the form of heat energy which results in voltage drop across conductor.

3. Why symbol of resistor is —www— ?

DC Supply

Properties

→ unipolar
→ unidirection
→ no change in phase / polarity
→ Frequency = 0 Hz

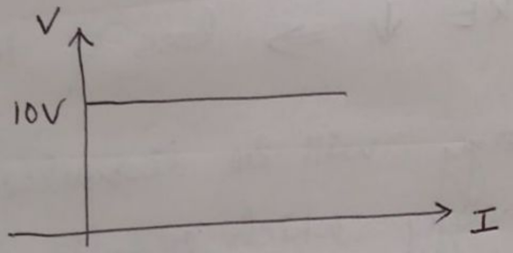
They are used in small, independent, isolated power supply systems, where electrical

electrical energy can be stored in small capacities.

Ex → Machine tools
Medical instruments
Cell phone
Toy
Defence application

} Precision
Accuracy

Standard DC waveform



AC supply

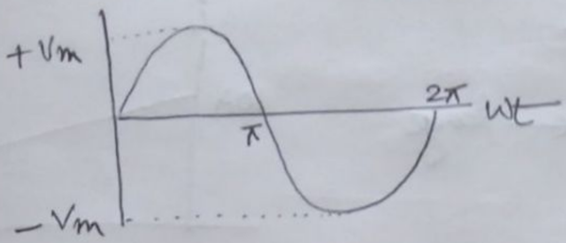
→ Bipolar
→ Bidirection
→ definite change in phase / polarity
→ Frequency exist (India = 50 Hz)

They are used in large, bulk power supply system where electrical energy cannot be stored.

Ex → Domestic
Industrial application

} Robust
Powerful

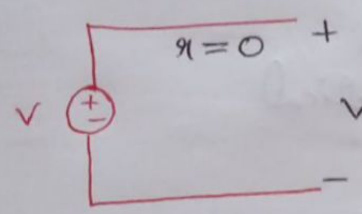
standard AC waveform

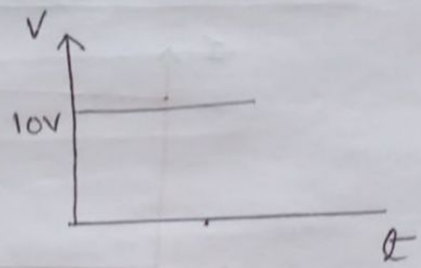


$V = V_m \sin wt$

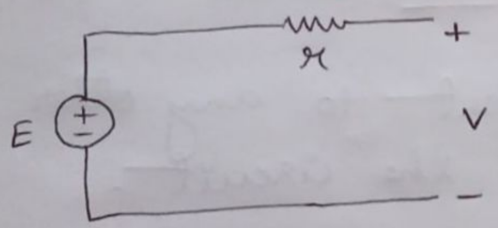
sinusoid — sine / cosine

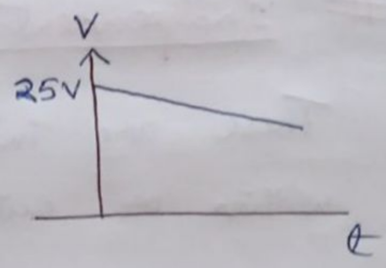
Ideal voltage source



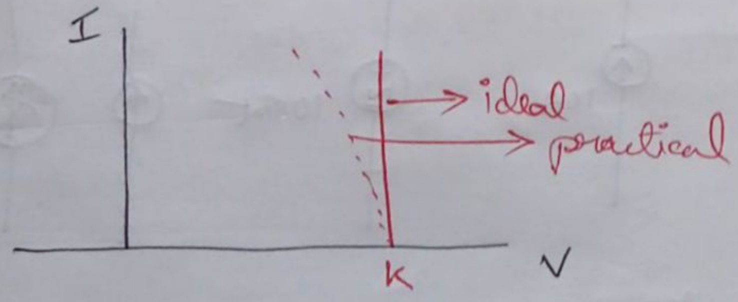


Practical voltage source

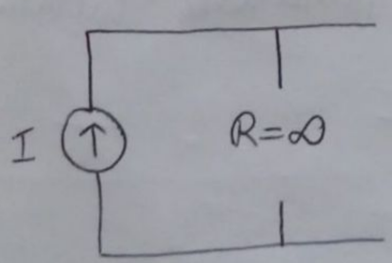


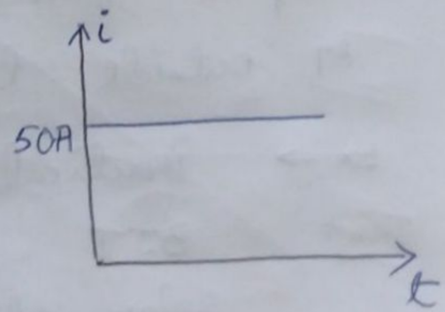


VI characteristics

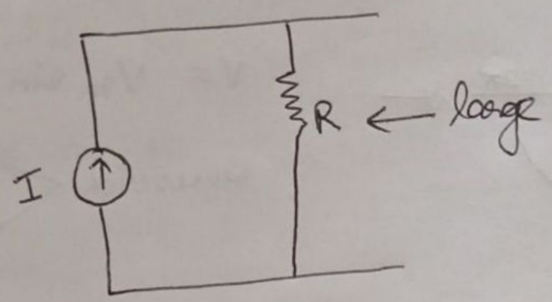


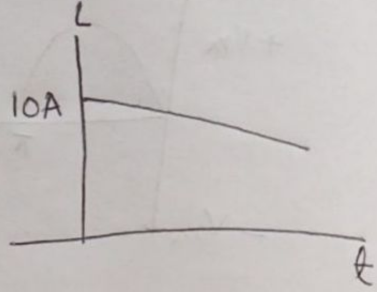
Ideal current source



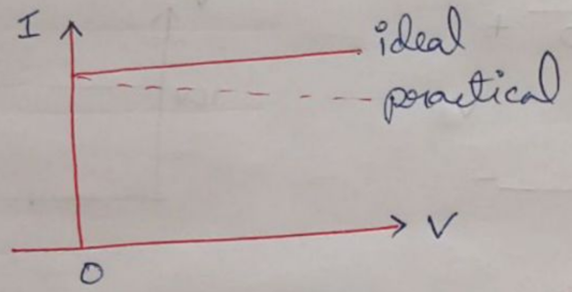


Practical current source





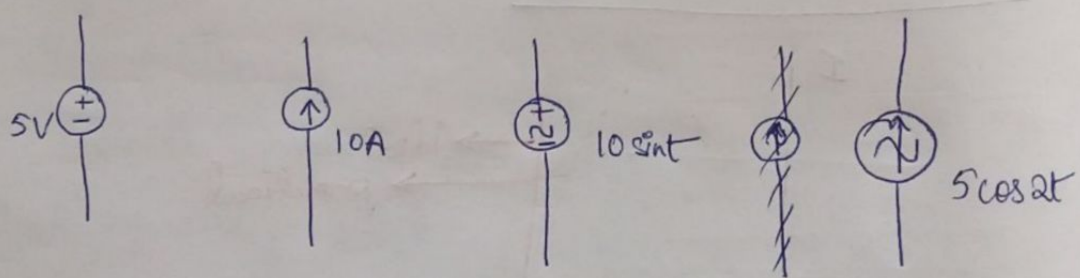
VI characteristics



Independent sources

These are independent to any other parameter within or outside the circuit.

Ex → Ideal sources

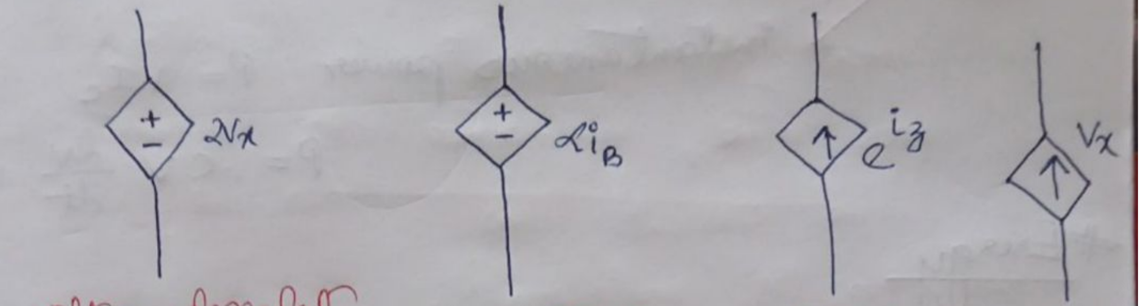


Dependent source

Depend upon any other parameter within or outside the circuit

Ex → Practical sources
BJT
solar cell

Types of dependent source



voltage dependent voltage source (VDVS) (or) voltage controlled voltage source (VCVS)

CDVS (or) CCVS

CDCS (or) CCCS

VDCS (or) VCCS

→ Unlike independent sources, dependent sources cannot be suppressed in terms of resistance, as these models themselves represent complex circuits

POWER

Rate of change in energy.

$P = \frac{E}{t}$ units : watts (or) J/sec

Rang : mW, W, kW, MW, GW

$\boxed{1 \text{ horse power} = 746 \text{ watts}}$

$\boxed{R}$

$$P_R = V.I = I^2R = \frac{V^2}{R}$$

$\boxed{L}$ → $P_{avg} = 0$

→ instantaneous power $P = V.I_L$
$= Li\, di/dt$

$\boxed{C}$ → $P_{avg} = 0$

→ instantaneous power $P = V I_c$

$P = C V \frac{dv}{dt}$ watts

Energy

Capacity to do work.

$$\boxed{E = P \times t}$$

Unit : Joules (or) Watt - sec

1 unit of electrical energy = 1 kWh

$1\,kWh = 1000W \times 1\,hr$

$= 500W \times 2\,hr$

$= 100\,W \times 10\,hr$

$= 2000\,W \times \frac{1}{2}\,hr$

$1\,kWh = 36 \times 10^5\,J$

$\boxed{R}$

$E_R = V.I.t = I^2.R.t = \frac{V^2}{R}.t$ Joules

$\boxed{L}$ $E_L = \frac{1}{2} L I^2 = \frac{1}{2} \psi I = \frac{1}{2} \frac{\psi^2}{L}$ Joules

$\boxed{C}$

$E_C = \frac{1}{2} C V^2 = \frac{1}{2} q V = \frac{1}{2} \frac{q^2}{C}$ Joules

Energy storage capacity in a battery = Ampere-hour (Ahr)

TYPES OF ELEMENTS

1. Linear and Non linear
2. Bilateral and unilateral
3. Active and Passive
4. Lumped and distributed
5. Time invariant and Time varying

1. Linear and Non linear

A two terminal element is said to be linear if for all time, its characteristics is a straight line through origin, otherwise, it is said to be non linear.

→ Most of our practical components / networks are non linear in nature, but any non linear system can be linearised for small incremental changes in time.

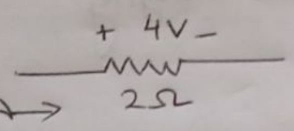
~~But same system under non linear mode of operation~~

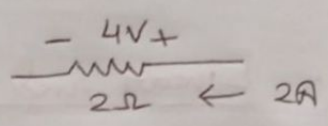
→ We design all our network practically for specified ratings and as long as they obey Ohm's law, Kirchoff's law etc, they are said to be LINEAR.

2. Bilateral and Unilateral

An element is said to be bilateral if it offers same impedance for different direction of same current flow, otherwise it is said to be unilateral.

* Bilateral → property independent to voltage polarity and current direction Ex → R, L, C

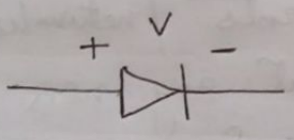


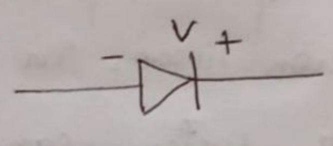


$P_{lost} = 8W$ $\qquad$ $P_{lost} = 8W$

* Unilateral → property depends on voltage polarity and current direction

Ex → BJT, FET, diode

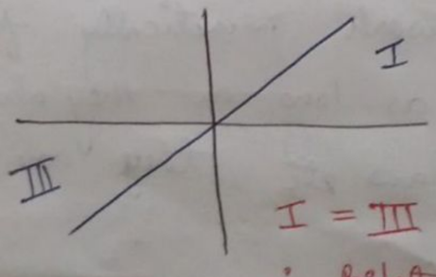




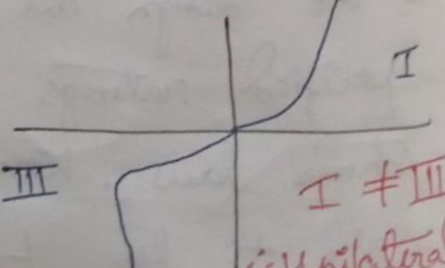
→ Forward bias
→ can conduct
→ R = 0 Ω

→ Reverse bias
→ can't conduct
→ R = ∞ Ω

Based on V I characteristics



I = III
∴ Bilateral



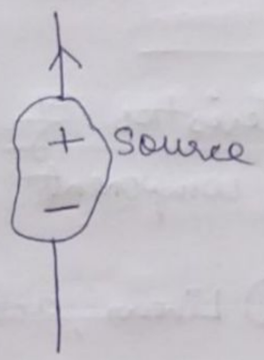
I ≠ III
∴ Unilateral

3. Active and Passive

Active elements (source)

Energize
Drive externally
Deliver
Give out

} Electrical energy



$P_{delivered} \Rightarrow +ve$

$P_{absorbed} \Rightarrow -ve$

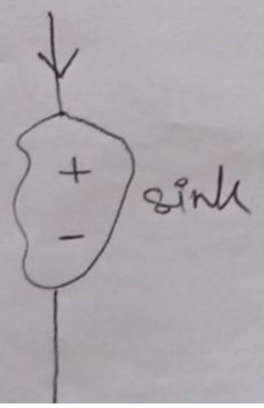
Ex → V, I

Passive elements (sink)

absorb
dissipate
waste
convert
store

} electrical energy

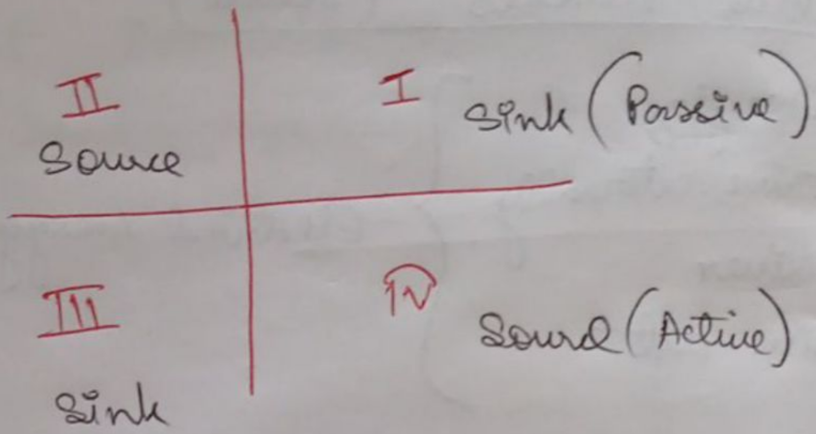
Ex → R, L, C



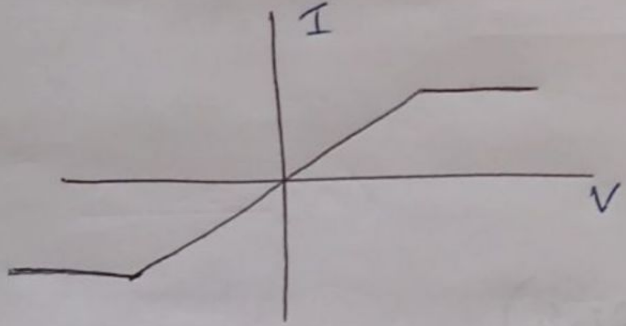
$P_{absorbed} \Rightarrow +ve$

$P_{delivered} \Rightarrow -ve$

Based on VI characteristics



Q) The static VI characteristics of component is shown below, then component is



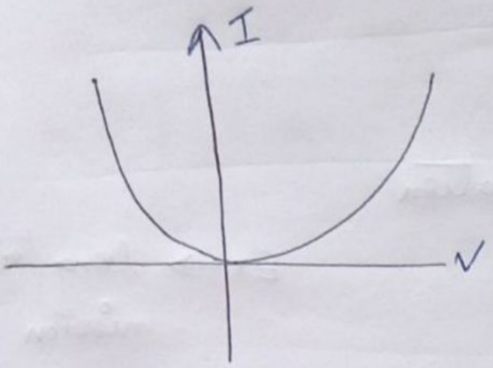
1. Linear, active, bilateral
2. Linear, passive, bilateral
3. Non linear, active, unilateral
4. Non linear, passive, bilatoral

Ans → Half Linear half non linear ⟹ Non linear

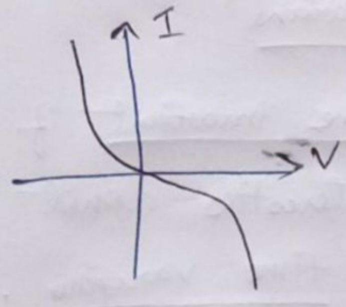
I and III → passive

I = III → bilateral

∴ (4) is correct.



→ Non linear, unilateral, both Active & passive
⇒ Overall active



→ Non linear, Active, Bilateral

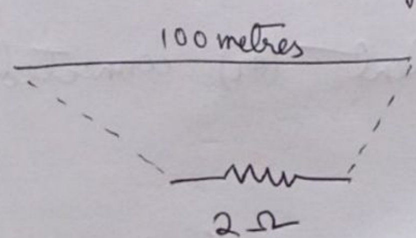
NOTE

Active elements can act as passive elements but passive elements can't act as active

~~Ex → capacitor always acts as a sink~~.

4. Lumped and Distributed

Lumped → simple
linear algebraic equation
solutions are fast
approximated values



Ex → PCB components

Distributed

complex

linear differential equation

solution are tedious

very accurate values

exact modelling.

Ex → long transmission lines

Antenna

5. Time Invariant and Time variant

An element is said to be time invariant if for all time 't', its characteristics donot change with time otherwise time varying.

NODE (n)

A node is a point of interconnection or junction between 2 or more components

BRANCH (b)

~~No. of branches~~

A branch is an elemental connection b/w two nodes.

Degree of a Node (δ)

No. of branches incident (or) connected at any node.

$\delta = 2 \longrightarrow$ simple node (n_s)

$\delta > 2 \longrightarrow$ principle node (n_p)

NOTE : For any circuit or network,

$$\boxed{\sum_{i=1}^{n} \delta_i = 2 \times b}$$

MESH (m)

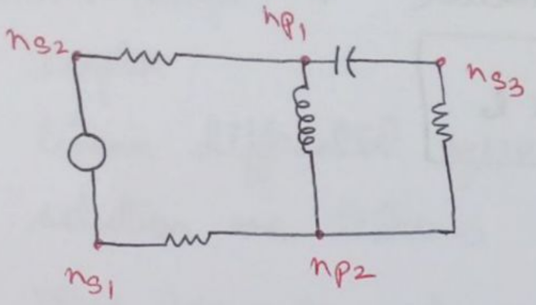
Mesh is a closed path which should not have any further closed path in it.

LOOPS (l)

Loops are all possible closed path of network.

NOTE

1. For any circuit or network $\boxed{m = b - n + 1}$
2. Minimum no. of equations to solve any circuit or network is $\boxed{m = b - n + 1}$
3. Meshes are specifically called as independent loops.
4. All meshes are by default loops but all loops are not meshes.
5. In nodal analysis we may neglect simple node and one of the principle node is considered as reference.



$n = 5$

$b = 6$

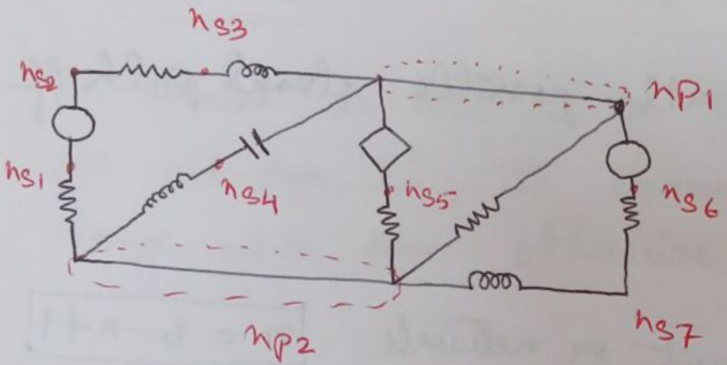
$m = 2$

$l = 2+1 = 3$

$\Sigma \delta_i = 2+2+2+3+3$

$= 12$

or $\Sigma \delta_i = b \times 2 = 12$



$n = 9$

$b = 12$

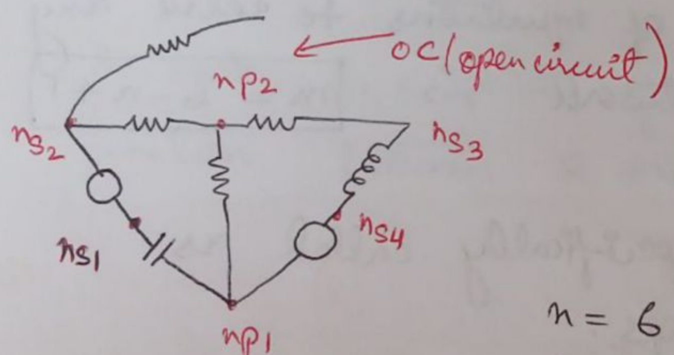
$m = 4$

$l = 4 + 6 = 10$

$\Sigma \delta_i = (7 \times 2) + 5 + 5$

$= 24$

$= 2 \times 12$

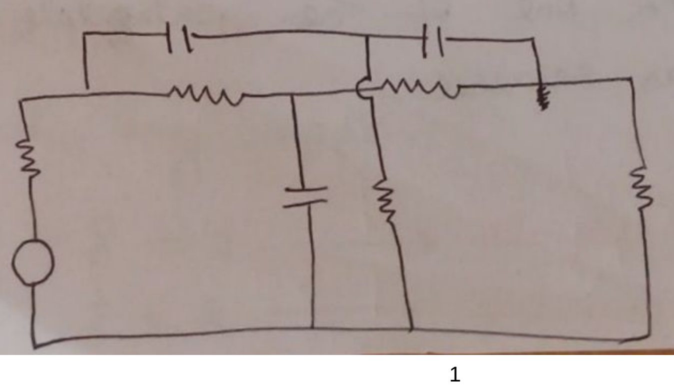


$n = 6$

$b = 7$

$m = 2$

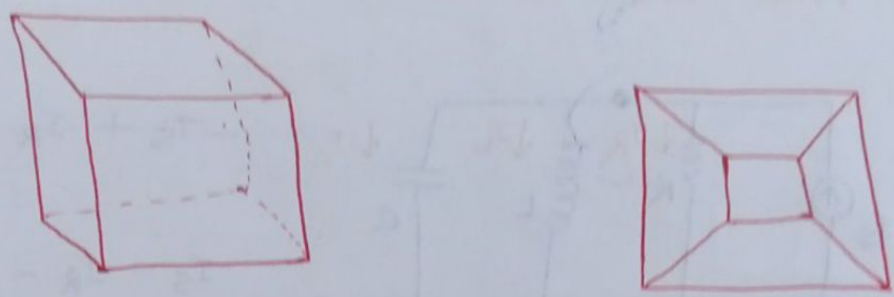
Q| Find the minimum number of equation required to solve the circuit below. Ans →



$m = b - n + 1$

$= 9 - 6 + 1$

$= 4$



Non planar ⟶ Planar

KIRCHOFF's Law

1. KCL — It is always defined at a node.

$$\Sigma I\Big|_{node} = 0 \longrightarrow$$ Based on law of conservation of charge.

$\frac{V}{R}$ $\quad \frac{1}{L}\int V dt \quad C\, dV/dt$

NOTE: KCL applies to any lumped electric circuit, it doesnot matter whether elements are linear, non linear, active, passive, time varying, time invariant.

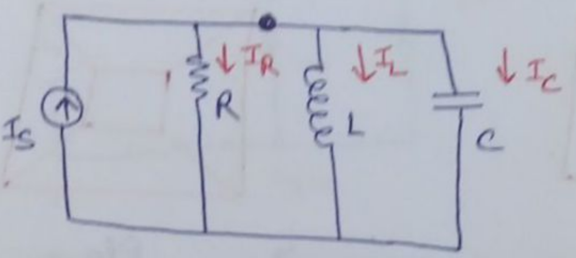
KCL is independent of the nature of elements connected to node.

2. KVL ⟶ It is always defined in a mesh or loop i.e. closed path.

$$\Sigma V\Big|_{mesh} = 0 \longrightarrow$$ Based on law of conservation of energy

$IR \quad L\frac{dI}{dt} \quad \frac{1}{C}\int I dt$

Q| Find the current.



~~$I_S + I_R + I_L + I_C = 0$~~

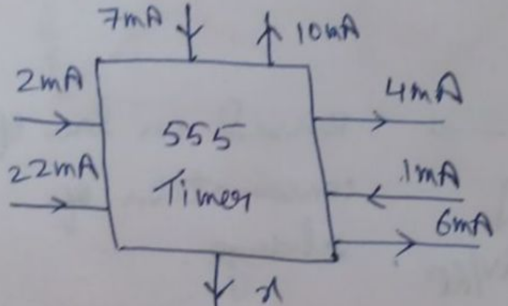
$I_S - I_R - I_L - I_C = 0$

(or)

$I_S = I_R + I_L + I_C$

$I_S = \frac{V}{R} + \frac{1}{L}\int V dt + C\frac{dv}{dt}$

entering → +
leaving → −



KCL

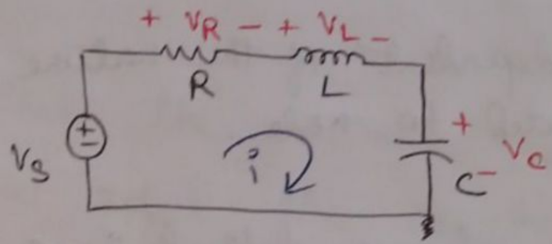
$2 + 22 + 7 + 1 =$

$x + 6 + 4 + 10$

$\Rightarrow x = 12mA$

Suppose you get $x = -12mA$, it will mean that current is coming out of node.

Q| Find voltage equation

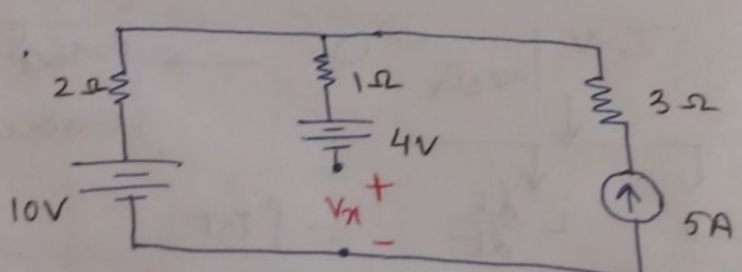


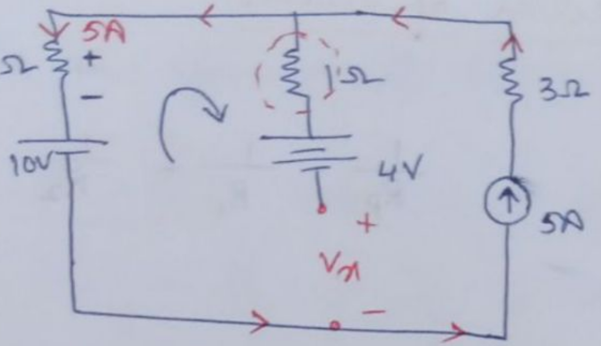
KVL

$-V_S + V_R + V_L + V_C = 0$

$V_S = iR + L\frac{di}{dt} + \frac{1}{C}\int i dt$

Q| Find V_x.



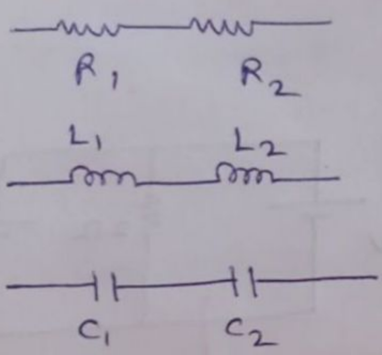


KVL

$$-10 - 10 + 4 + V_x = 0$$

$$\Rightarrow \boxed{V_x = 16V}$$

Series Connection of Elements

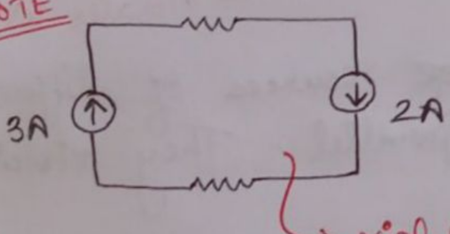


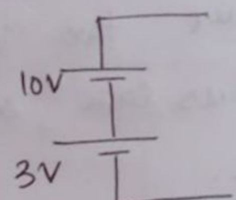
$$R_S = R_1 + R_2$$

$$L_S = L_1 + L_2$$

$$\frac{1}{C_S} = 1/C_1 + 1/C_2$$

NOTE





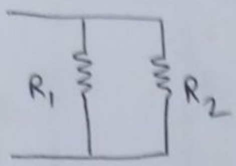
→ violating KCL

→ current sources of different values can never exist in series. They violate KCL.

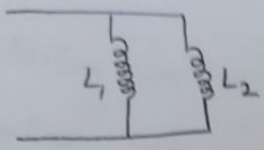
→ If 2 current sources are in series they must be equal both in magnitude and direction.

→ voltage sources of any value can be in series

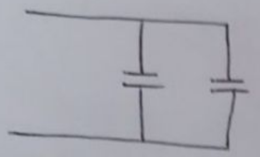
Parallel connection of elements



$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$$

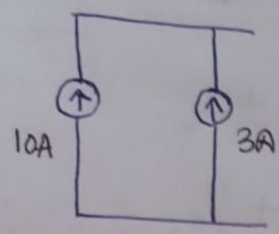


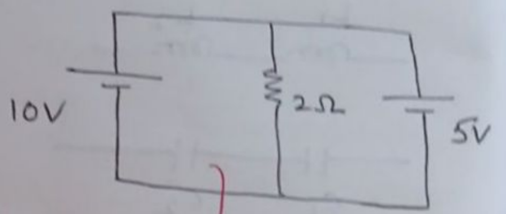
$$\frac{1}{L_p} = \frac{1}{L_1} + \frac{1}{L_2}$$



$$C_p = C_1 + C_2$$

NOTE





violates KVL

→ Never two ideal voltage sources of different values can exist in parallel. They violate KVL.

→ If 2 voltage sources exist in parallel, they must be equal both in magnitude and polarity.

→ Practical voltage sources can always exist in parallel.

→ current sources of any value can be in parallel.

Open circuit

→ In an open circuit (OC),

$\boxed{I = 0}$, for any voltage

$$R_{OC} = \frac{V}{I} = \frac{V}{0} = \infty\ \Omega$$

$$\therefore \boxed{R_{OC} = \infty\ \Omega}$$

Any passive element in series to open circuit can be neglected.

Short circuit

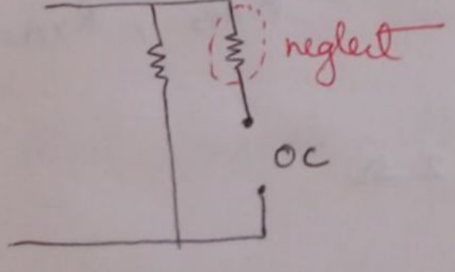
→ In a short circuit (SC),

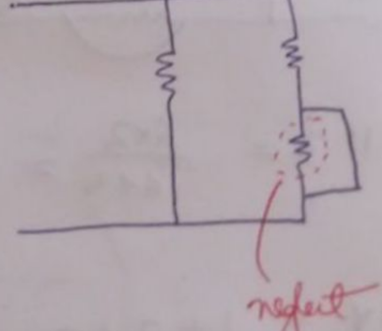
$\boxed{V = 0}$, for any current

$$R_{SC} = \frac{0}{i} = 0\ \Omega$$

$$\boxed{R_{SC} = 0\ \Omega}$$

Any passive element in parallel to S.C. can be neglected.





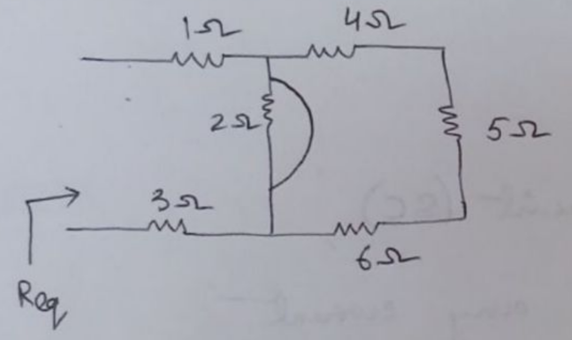
NOTE

In high voltage engineering, O.C. line wire faults are more dangerous than S.C. to human beings.

→ S.C. always have protection, both at high and low level voltage by designing correct rated fuses.

→ Resistance is offered by the path where current can flow as seen from target terminal.

Q/ Find equivalent resistance.

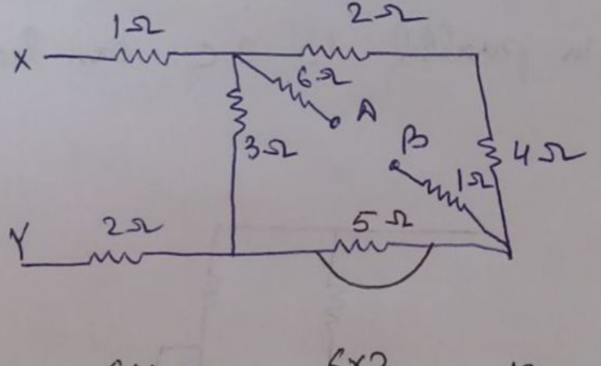


4Ω, 5Ω, 6Ω are in series

$\therefore R_s = 15\,\Omega$

But short circuit is there.

$\therefore R_{eq} = 1+3 = 4\,\Omega$



Find R_{XY}, R_{AB}, R_{XA}, R_{YB}

$$6 \| 3 = \frac{6\times3}{6+3} = \frac{18}{9} = 2\,\Omega$$

$$R_{XY} = 1+2+2 = 5\,\Omega$$

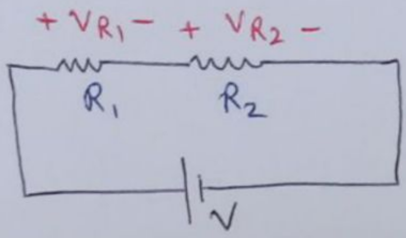
$$R_{AB} = (6\|2) + 6 + 1 = 2+6+1 = 9\,\Omega$$

$$R_{XA} = 1+6 = 7\,\Omega$$

$$R_{YB} = 1+2 = 3\,\Omega$$

Voltage Division Rule

For series connected elements only.



$$V_{R_1} = V\left(\frac{R_1}{R_2+R_1}\right) \qquad V_{L_1} = V\left(\frac{L_1}{L_1+L_2}\right)$$

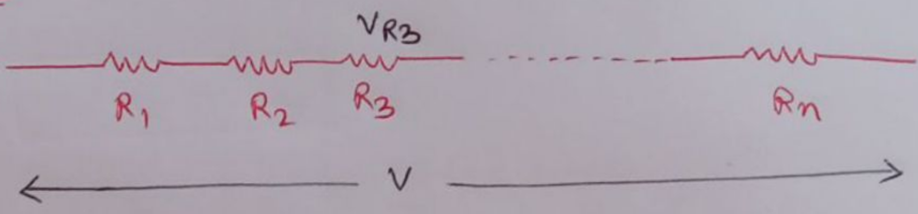
$$V_{R_2} = V\left(\frac{R_2}{R_1+R_2}\right) \qquad V_{L_2} = V\left(\frac{L_2}{L_1+L_2}\right)$$

$$V_{C_1} = V\left(\frac{C_2}{C_1+C_2}\right) \qquad V_{G_1} = V\left(\frac{G_2}{G_1+G_2}\right)$$

$$V_{C_2} = V\left(\frac{C_1}{C_1+C_2}\right) \qquad V_{G_2} = V\left(\frac{G_1}{G_1+G_2}\right)$$

NOTE

1

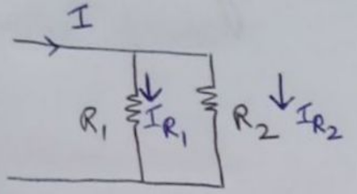


$$V_{R_3} = V\left(\frac{R_3}{\sum_{i=1}^{n} R_i}\right)$$

But suppose these are capacitors

$$V_{C_3} = V\left(\frac{1/C_3}{\sum_{i=1}^{n} 1/C_i}\right)$$

Current Division Rule : For parallel connected elements only.



$\boxed{R}$

$$I_{R_1} = I\left[\frac{R_2}{R_1+R_2}\right]$$

$$I_{R_2} = I\left(\frac{R_1}{R_1+R_2}\right)$$

$\boxed{L}$

$$I_{L_1} = I\left(\frac{L_2}{L_1+L_2}\right)$$

$$I_{L_2} = I\left(\frac{L_1}{L_1+L_2}\right)$$

$\boxed{C}$

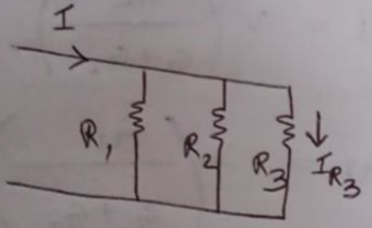
$$I_{C_1} = I\left(\frac{C_1}{C_1+C_2}\right)$$

$$I_{C_2} = I\left(\frac{C_2}{C_1+C_2}\right)$$

$\boxed{G}$

$$I_{G_1} = I\left(\frac{G_1}{G_1+G_2}\right)$$

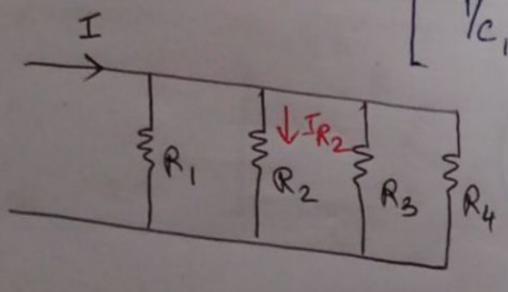
$$I_{G_2} = I\left(\frac{G_2}{G_1+G_2}\right)$$



$$I_{R_3} = I\left(\frac{R_1 \cdot R_2}{R_1R_2+R_2R_3+R_3R_1}\right)$$

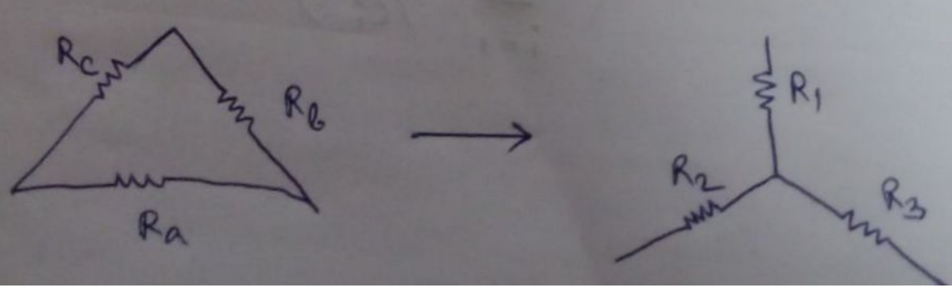
But suppose capacitors are there,

$$I_{C_3} = I\left[\frac{1/C_1 \cdot 1/C_2}{1/C_1 \cdot 1/C_2 + 1/C_2 \cdot 1/C_3 + 1/C_3 \cdot 1/C_1}\right]$$



$$I_{R_2} = I\left[\frac{R_1 \cdot R_3 \cdot R_4}{R_1R_2R_3 + R_2R_3R_4 + R_3R_4R_1 + R_4R_1R_2}\right]$$

DELTA to STAR



$$R_1 = \frac{R_b \cdot R_c}{R_a + R_b + R_c}$$

$$R_2 = \frac{R_a R_c}{R_a + R_b + R_c}$$

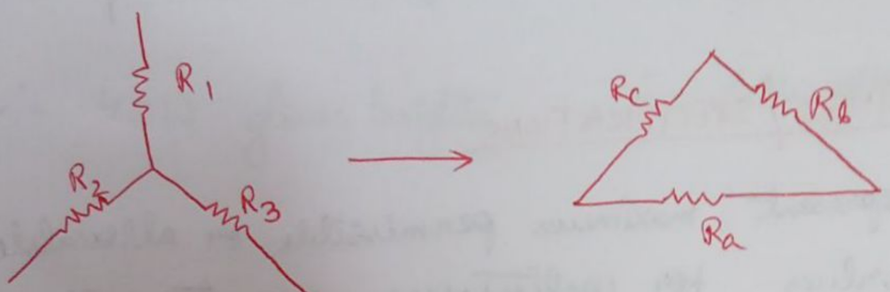
$$R_3 = \frac{R_a R_b}{R_a + R_b + R_c}$$

$$L_1 = \frac{L_b L_c}{L_a + L_b + L_c}$$

$$1/C_1 = \frac{1/C_b \cdot 1/C_c}{1/C_a + 1/C_b + 1/C_c}$$

$$1/G_1 = \frac{1/G_b \cdot 1/G_c}{1/G_a + 1/G_b + 1/G_c}$$

STAR to DELTA



$$R_a = R_2 + R_3 + \left(\frac{R_2 R_3}{R_1}\right)$$

$$R_b = R_1 + R_3 + \left(\frac{R_1 R_3}{R_2}\right)$$

$$R_c = R_1 + R_2 + \left(\frac{R_1 R_2}{R_3}\right)$$

$$\cancel{1/C_a} = \cancel{\frac{1}{R_2}} + \cancel{\frac{1}{R_3}} + \cancel{1/R_2}$$

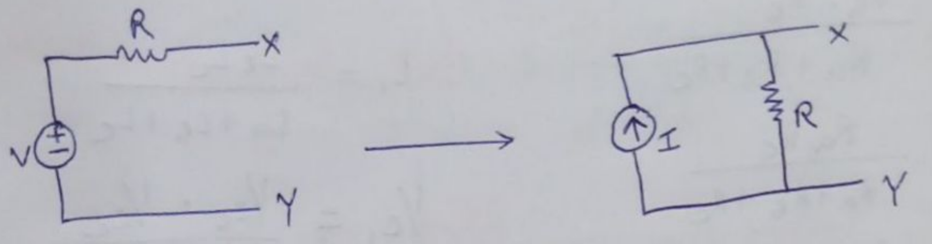
$$1/C_a = 1/C_2 + 1/C_3 + \left(\frac{1/C_2 \cdot 1/C_3}{1/C_1}\right)$$

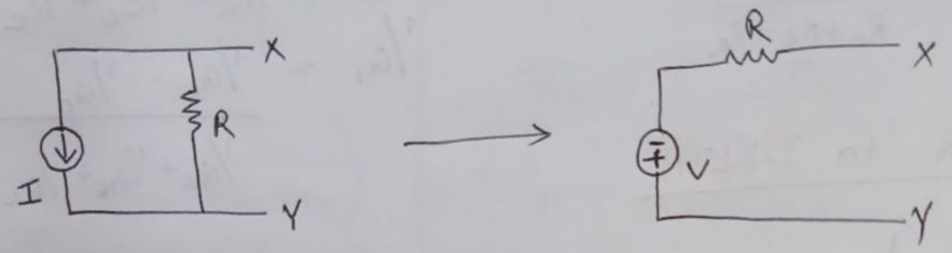
SOURCE TRANSFORMATION

A voltage source in series with resistance can be converted into current source in parallel with same resistance across the same terminal and vice-versa.

→ It is applicable only for practical sources.

→ It is applicable for dependent sources also.





RATINGS / SPECIFICATIONS

They represent maximum permissible or allowable safe values, for continuous operation of an electrical device.

→ Most of our electrical or ~~con~~ electronic components or networks will have voltage, current, power frequency rating etc.

Practically

$V, I \longrightarrow 2V, 2I$

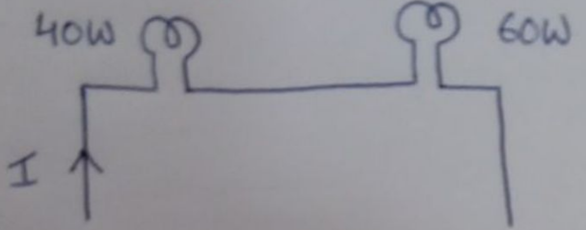
$I \uparrow \longrightarrow$ conductor cross sectional area ↑

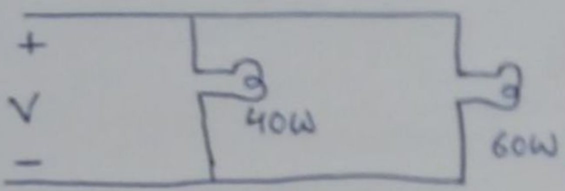
$V \uparrow \longrightarrow$ insulation ↑

Most of our electrical or electronic equipments are designed for constant voltage.

Low Wattage	High Wattage
I ↓	I ↑
A ↓	A ↑
V ↑	V ↓
R ↑	R ↓

Q| Which glows brighter?





For 40W → V ↑ R ↑

For 60W → V ↓ R ↓

∴ 40W glows brighter

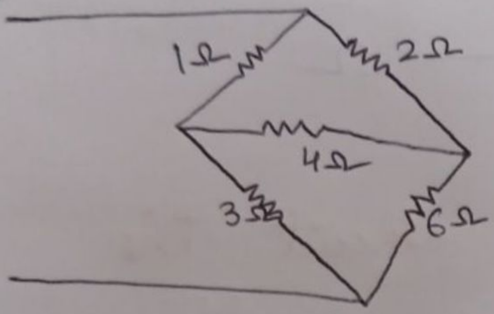
For 40W → ↓I ↑ R↓

For 60W → I ↑ R ↓

∴ 60W glows brighter

RESISTOR REDUCTION TECHNIQUE

1



Balanced bridge.

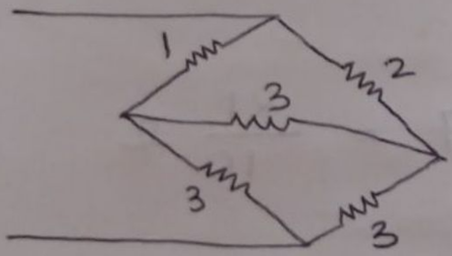
$\therefore$ 4 Ω neglected

$\therefore 4 \parallel 8 = \dfrac{4\times 8}{4+8}$

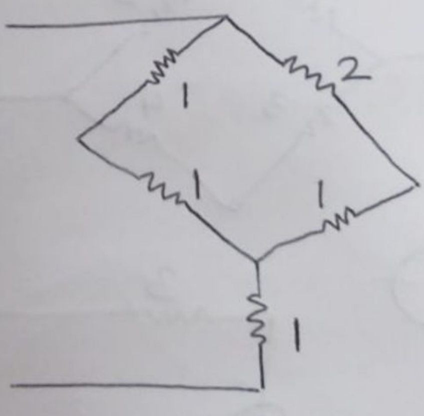
$= \dfrac{\cancel{32}\,8}{\cancel{12}\,3}$

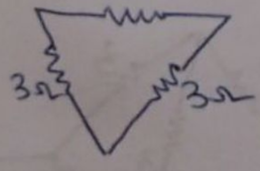
$= \dfrac{8}{3}\,\Omega$

2

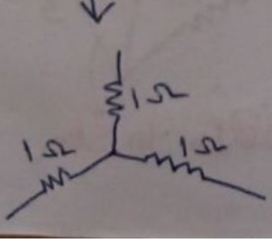


$\longrightarrow$





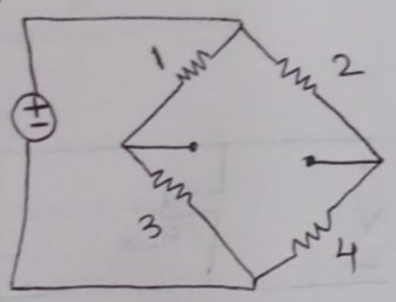
$\longrightarrow \dfrac{3\times 3}{3+3+3} = 1\,\Omega$



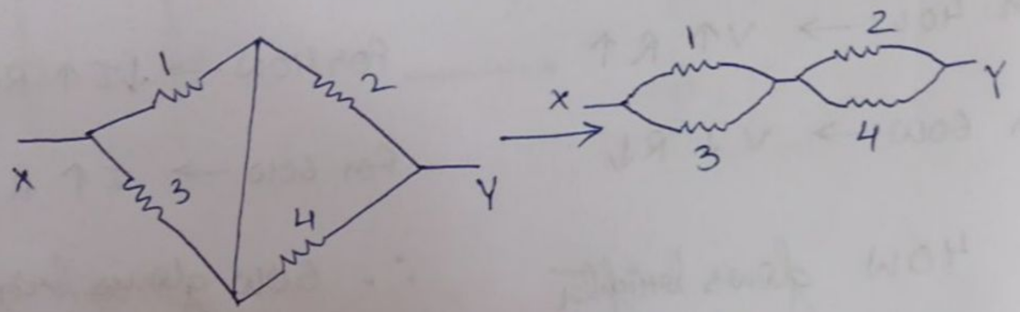
$1 + (2 \parallel 3)$

$= 1 + \dfrac{6}{5} = \dfrac{11}{5}\,\Omega$

(3)



* Make the voltage source short circuit

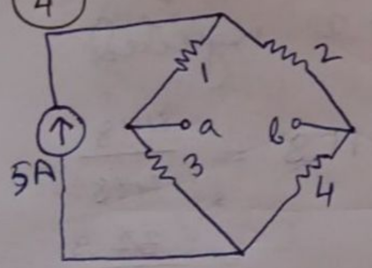


$$(1 \| 3) + (2 \| 4)$$

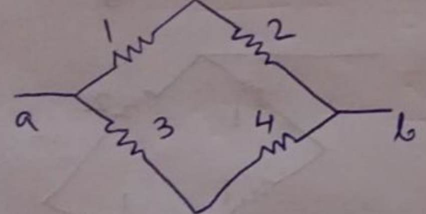
$$= \frac{3}{4} + \frac{8}{6}$$

$$= \frac{25}{12}\ \Omega$$

(4)

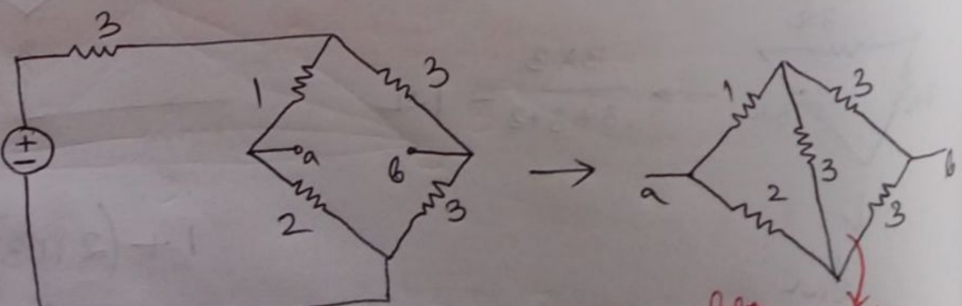


* open circuit the current source



$$3 \| 7 = \frac{21}{10}\ \Omega$$

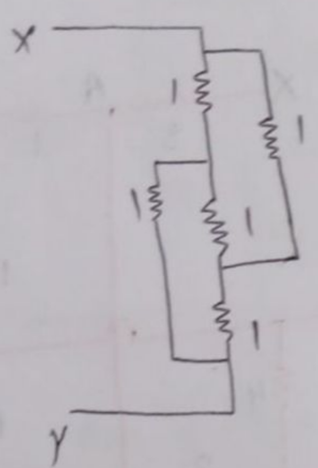
(5)

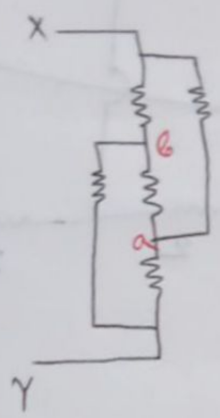


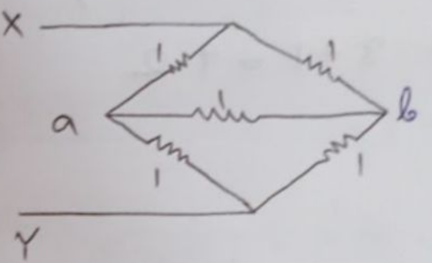
delta to star

(6)

Node shifting





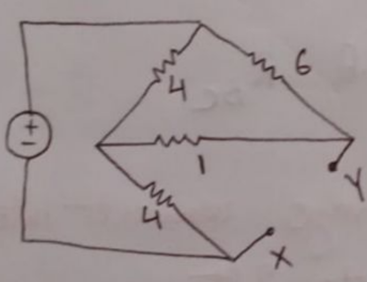


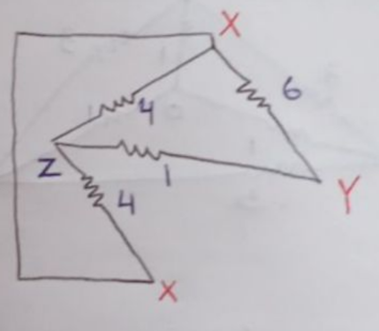
Balanced bridge

$\therefore$ Neglect $1\,\Omega$ arm(ab)

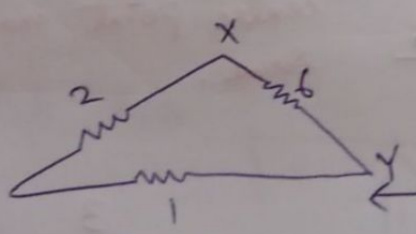
$2 \| 2 = 1\,\Omega$

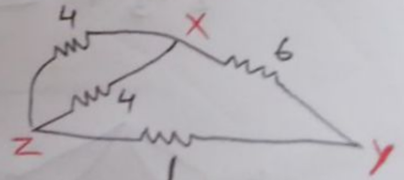
(7)

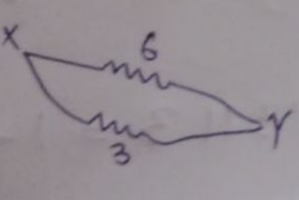




Short circuit voltage source

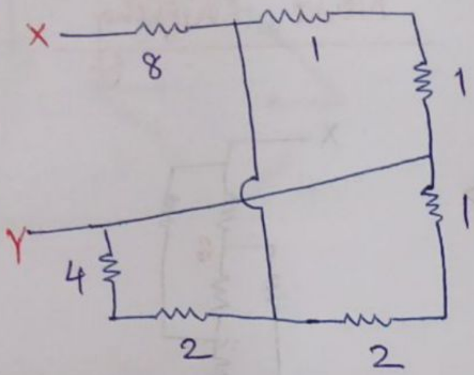


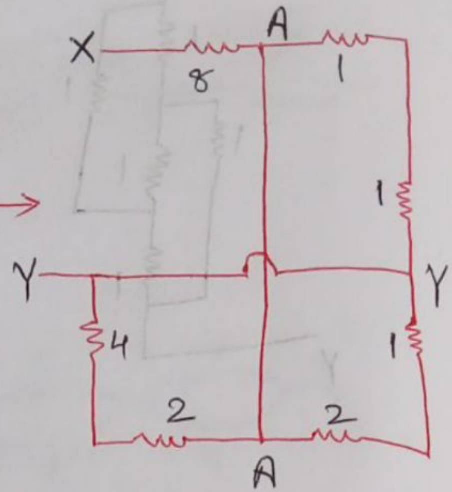


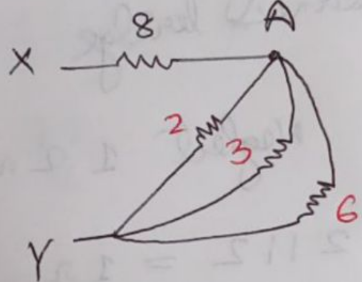


$6 \| 3 = 2\,\Omega$

8.



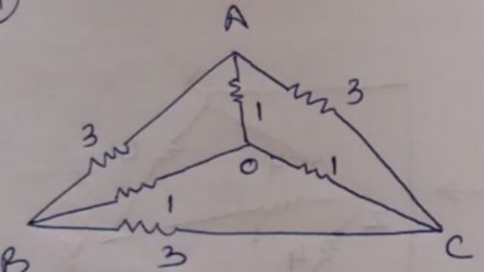




$$8 + (2 \parallel 3 \parallel 6)$$

$$= 8 + 1 = 9\,\Omega$$

9.



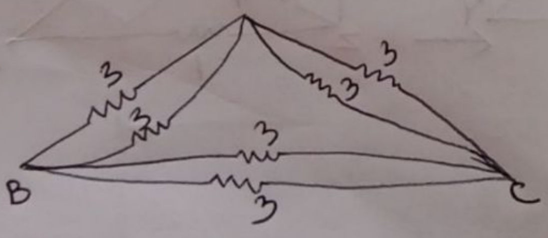
Find R_{BC}

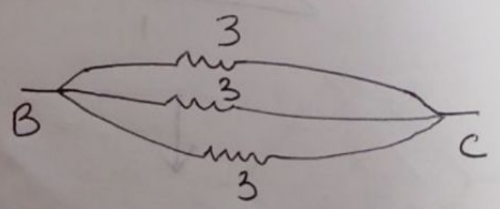
* Always convert internal star to delta.

∵ converting delta to star centre point may not be same.

$$1 + 1 + \frac{1 \cdot 1}{1} = 3$$

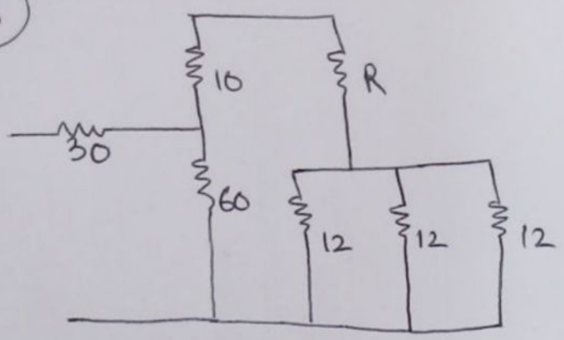
$$R_a = R_2 + R_3 + \frac{R_2 R_3}{R_1}$$





$$3 \parallel 3 \parallel 3 = 1\,\Omega$$

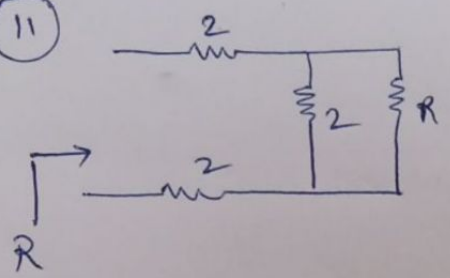
(10)



If $R_{eq} = 50$, find R

Ans → $R = 16\ \Omega$

(11)



$$R = 4 + (2 \parallel R)$$

$$\Rightarrow R = 4 + \frac{2R}{2+R}$$

$$\Rightarrow 2R + R^2 = 8 + 4R + 2R$$

$$\Rightarrow R^2 - 4R - 8 = 0$$

$$\Rightarrow R = \frac{-(-4) \pm \sqrt{16 - 4(-8)}}{2}$$

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

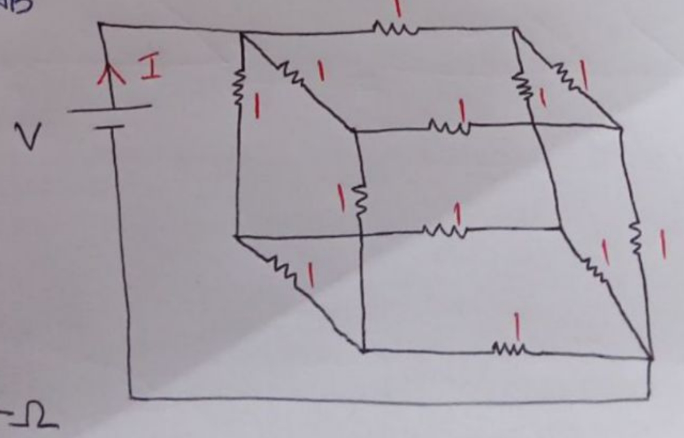
$$= \frac{4 \pm \sqrt{48}}{2}$$

$$= \frac{4 + 4\sqrt{3}}{2}$$

$$R = (2 \pm 2\sqrt{3})$$

$$\therefore\ R = (2 + 2\sqrt{3})\ \Omega$$

(12) Find R_{AB}



Ans → $R_{AB} = \frac{5}{6}\ \Omega$

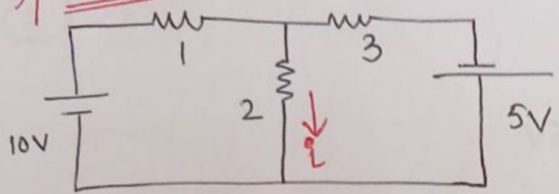
METHODS OF ANALYSIS

① Mesh Analysis → KVL + Ohm's Law

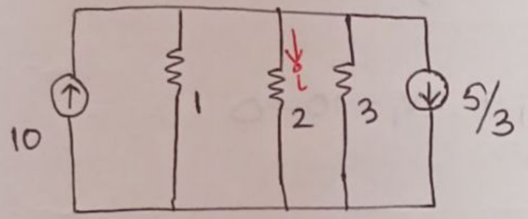
② Nodal Analysis → KCL + Ohm's Law

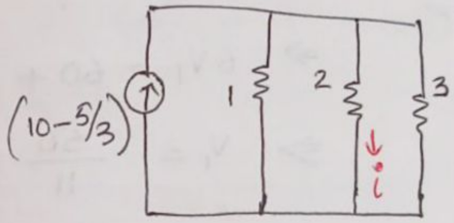
In nodal analysis, we can eliminate the use of simple nodes, if not required.

Q| Find 'i'



① solving using source transformation

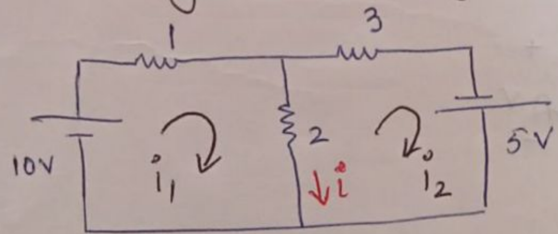




$$i = \left(10 - \frac{5}{3}\right)\left(\frac{3}{2+3+6}\right)$$

$$= \frac{25}{3} \times \frac{3}{11} = \frac{25}{11} \text{ A}$$

② Using Mesh Analysis



① $-10 + i_1 + 2(i_1 - i_2) = 0$

$\Rightarrow 3i_1 - 2i_2 = 10 \rightarrow ①$

$2(i_2 - i_1) + 3i_2 - 5 = 0$

$\Rightarrow 5i_2 - 2i_1 = 5$

$\Rightarrow 2i_1 - 5i_2 = -5 \rightarrow ②$

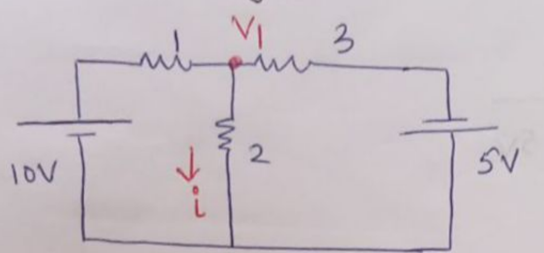
From ① and ②,

$$i_1 = \frac{60}{11} \qquad i_2 = \frac{35}{11}$$

Now,

$$i = i_1 - i_2 = \frac{25}{11}\ A$$

③ Nodal Analysis



$$\frac{V_1 - 10}{1} + \frac{V_1}{2} + \frac{V_1 - 5}{3} = 0$$

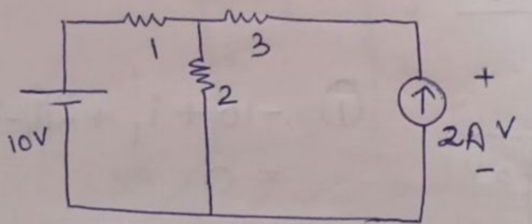
$$\Rightarrow 6V_1 - 60 + 3V_1 + 2V_1 - 10 = 0$$

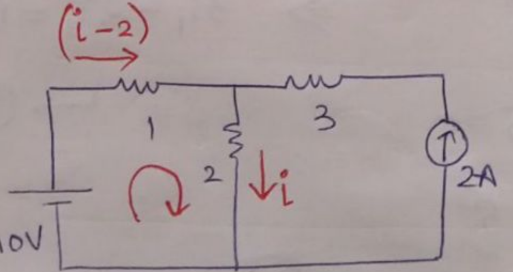
$$\Rightarrow V_1 = \frac{50}{11}\ V$$

Now,

$$i = \frac{V_1}{2} = \frac{25}{11}\ A$$

2| Find power delivered by current source





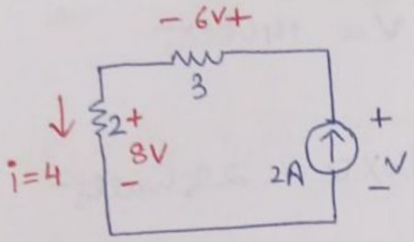
Normal method

$$-10 + (i-2) + 2i = 0$$

$$\Rightarrow 3i = 12$$

$$\Rightarrow i = 4A$$

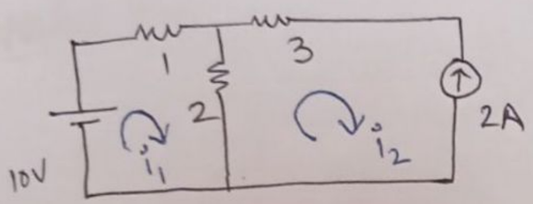
$\therefore P_{delivered} = \overset{I}{2} \times \overset{V}{14} = 28\ W$



$-8 - 6 + V = 0$

$\Rightarrow V = 14$ volts

② Mesh Analysis

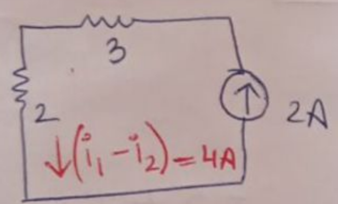


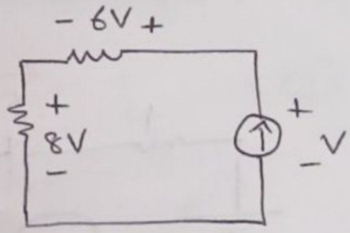
Here, $i_2 = -2 \rightarrow ①$

$-10 + i_1 + 2(i_1 - i_2) = 0$

$\Rightarrow 3i_1 - 2i_2 = 10 \rightarrow ②$

$\therefore i_1 = 2$



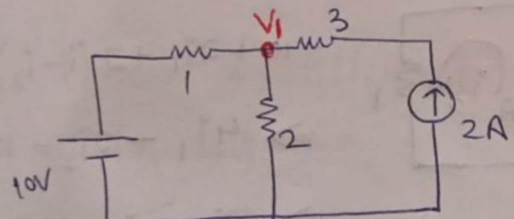


$\Rightarrow -8 - 6 + V = 0$

$\Rightarrow V = 14$ volts

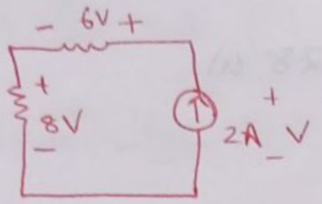
$\therefore$ Power $= 2 \times 14 = 28\ W$

③ Nodal Analysis



$$\frac{V_1 - 10}{1} + \frac{V_1}{2} - 2 = 0$$

$\Rightarrow V_1 = 8\ V$

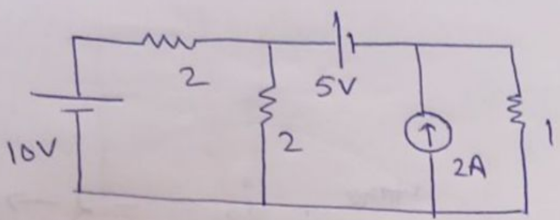


$$-8-6+V=0$$

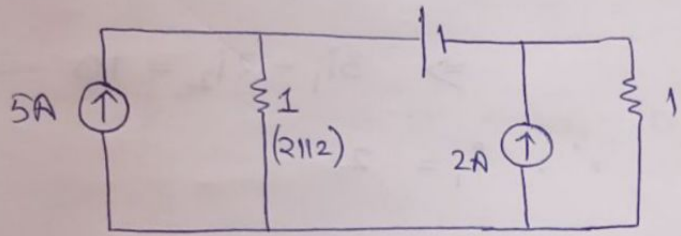
$$\Rightarrow \quad V = 14\text{ volts}$$

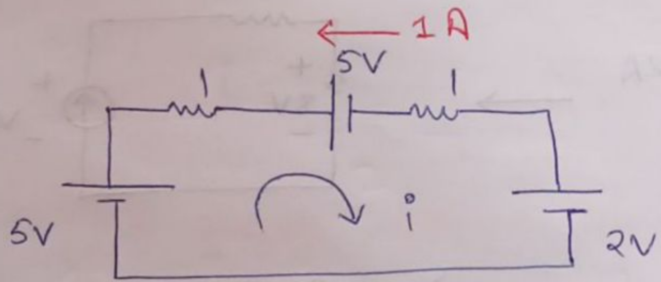
$$P_{del} = 14\times 2 = 28\text{ Watts}$$

Q| Find the power delivered by 5V source.



① Source transformation



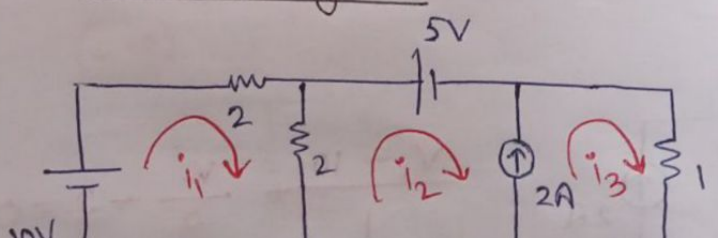


$$-5+2i+5+2=0$$

$$\Rightarrow \quad i = -1\text{ A}$$

$$\therefore \; P_{del} = 1\times 5 = 5\text{ watts}$$

② Mesh Analysis



$$-10+2i_1+2(i_1-i_2)=0$$

$$\Rightarrow 4i_1 - 2i_2 = 10$$

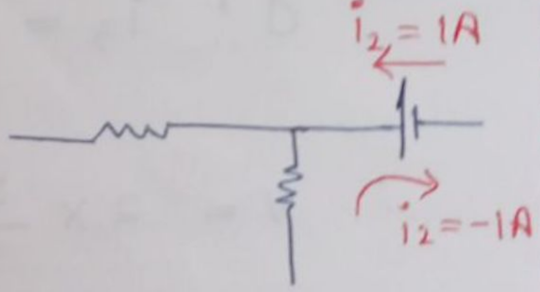
$$\Rightarrow 2i_1 - i_2 = 5 \rightarrow ①$$

$2(i_2 - i_1) + 5 + i_3 = 0$

$\Rightarrow -2i_1 + 2i_2 + i_3 = 5 \longrightarrow (2)$

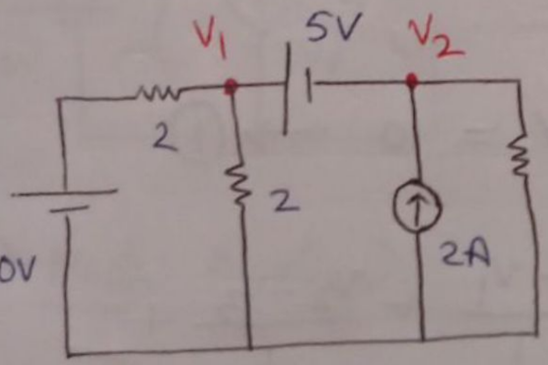
$-i_2 + i_3 = 2 \longrightarrow (3)$

$\therefore \quad i_2 = -1A$



$\therefore \quad P_{delivered} = 5 \times 1 = 5\,W$

(3) Nodal Analysis



$$\frac{V_1 - 10}{2} + \frac{V_1}{2} - 2 + \frac{V_2}{1} = 0$$

$\Rightarrow V_1 - 10 + V_1 - 4 + 2V_2 = 0$

$\Rightarrow 2V_1 + 2V_2 = 14$

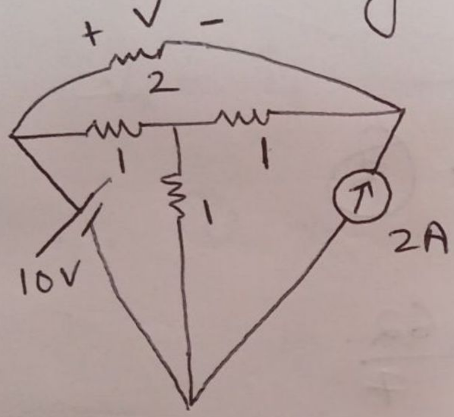
$\Rightarrow V_1 + V_2 = 7 \longrightarrow (1)$

$V_1 - V_2 = 5 \longrightarrow (2)$

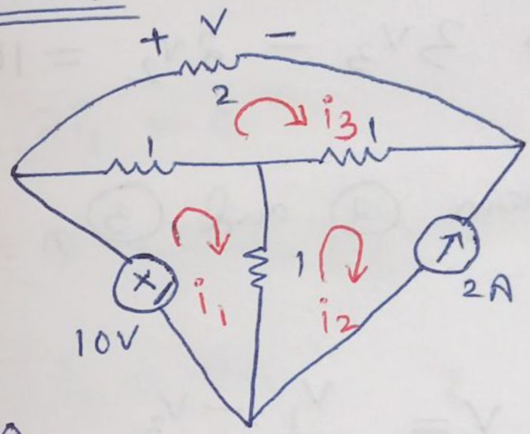
$\therefore \; P_{delivered} = 5 \times 1$

$= 5$ watts

Q| Find V using mesh and nodal analysis.



Mesh



$$-10 + (i_1 - i_3) + (i_1 - i_2) = 0$$

$$\Rightarrow 2i_1 - i_2 - i_3 = 10 \longrightarrow (1)$$

$$i_2 = -2 \longrightarrow (2)$$

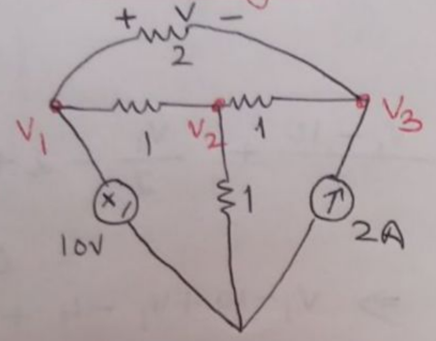
$$(i_3 - i_1) + 2i_3 + (i_3 - i_2) = 0$$

$$\Rightarrow 4i_3 - i_1 - i_2 = 0 \longrightarrow (3)$$

Solving, $i_3 = \frac{4}{7}$ A

$$\therefore V = 2 \times \frac{4}{7} = \frac{8}{7} \text{ volts}$$

Nodal Analysis



$$V_1 = 10 \longrightarrow (1)$$

$$\frac{V_2 - V_1}{1} + \frac{V_2 - V_3}{1} + \frac{V_2}{1} = 0$$

$$\Rightarrow 3V_2 - V_3 = 10 \longrightarrow (2)$$

$$\frac{V_3 - V_2}{1} + \frac{V_3 - V_1}{2} - 2 = 0$$

$$\Rightarrow 2(V_3 - V_2) + V_3 - 10 - 4 = 0$$

$$\Rightarrow 3V_3 - 2V_2 = 14 \longrightarrow (3)$$

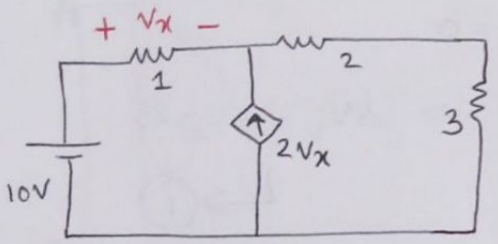
From (2) and (3), $V_3 = \frac{62}{7}$

$$\therefore V = V_1 - V_3$$

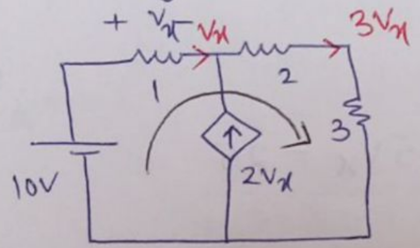
$$= 10 - \frac{62}{7}$$

$$= \frac{8}{7} \text{ V}$$

Q/ Find V_x using mesh and nodal.



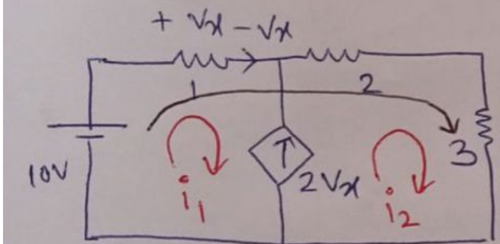
① Using KVL



$$-10 + V_x + 15V_x = 0$$

$$\Rightarrow \boxed{V_x = \frac{5}{8}\ V}$$

② Mesh Analysis



$$-10 + i_1 + 5i_2 = 0$$

$$\Rightarrow i_1 + 5i_2 = 10 \longrightarrow (1)$$

$$-i_1 + i_2 = 2V_x \longrightarrow (2)$$

Link equation

$$V_x = i_1 \longrightarrow (3)$$

$$\therefore (2) \Rightarrow -i_1 + i_2 = 2i_1 = 0$$

$$\Rightarrow -3i_1 + i_2 = 0 \longrightarrow (4)$$

solving (1) and (4) $\Rightarrow$ $i_2 = 2A$

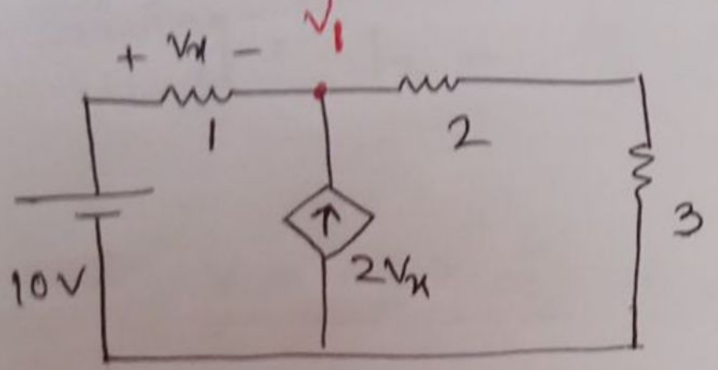
$$i_1 = \frac{5}{8} A$$

$$\therefore V_x = \frac{5}{8} V$$

Nodal

$$\frac{V_1 - 10}{1} - 2V_x + \frac{V_1}{5} = 0$$

$$\Rightarrow 6V_1 - 10V_x = 50 \Rightarrow 3V_1 - 5V_x = 25 \rightarrow (1)$$



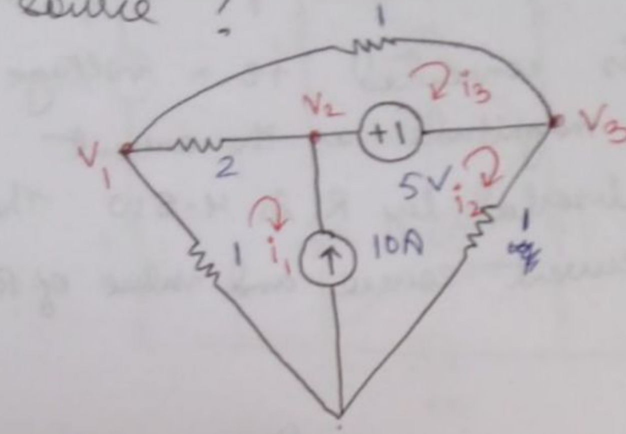
$$V_x = 10 - V_1 \rightarrow (2)$$

$$\therefore (1) \Rightarrow 3(10 - V_x) - 5V_x = 25$$

$$\Rightarrow -8V_x = -5$$

$$\Rightarrow V_x = \frac{5}{8} \text{ V}$$

9) What is the power delivered by voltage source ?



Mesh

$$i_2 - i_1 = 10 \longrightarrow (1)$$

$i_3 \rightarrow$ ~~mesh~~ $i_3 - 5 + 2(i_3 - i_1) = 0$

$$\Rightarrow 3i_3 - 2i_1 = 5 \longrightarrow (2)$$

$i_1, i_2 \rightarrow 3i_1 + 5 + i_2 = 0$

$$\Rightarrow 3i_1 + i_2 = -5 \longrightarrow (2)$$

$(1) - (2) \Rightarrow$

$$\cancel{i_2} - i_1 = 10$$
$$\cancel{i_2} + 3i_1 = -5$$
$$(-) \quad (-) \quad (+)$$

$$-4i_1 = 15$$

$$\Rightarrow i_1 = \frac{15}{4}$$

$i_2 = 10 + i_1 =$

$$i_1 + 2(i_1 - i_3) + 5 + i_2 = 0$$

$$\Rightarrow 3i_1 - 2i_3 + i_2 = -5$$

$\Rightarrow 3i_1 - 2i_3 + (i_1+10) = -5$

$\Rightarrow \cancel{8}\, 4i_1 - 2i_3 = -15 \longrightarrow (3)$

$(2) \times 2 \Rightarrow \quad 6i_3 - \cancel{4i_1} = 10$

$(3) \times 1 \Rightarrow \quad -2i_3 + \cancel{4i_1} = -15$

$\quad -4i_3 = -5$

$\Rightarrow \boxed{i_3 = -\frac{5}{4}}$

$(3) \Rightarrow \quad 4i_1 - 2(-5/4) = -15$

put i_3 in

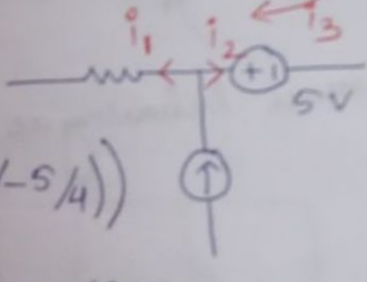
$\Rightarrow 4i_1 = -15 - \frac{5}{2}$

$\Rightarrow i_1 = \frac{-35}{8}$

$\therefore (1) \Rightarrow$ Put i_1 in $(1) \Rightarrow i_2 = 10 - \frac{35}{8}$

$i_2 = \frac{45}{8}$

$\therefore P_{del} =$



$-5\left(\frac{45}{8} - (-5/4)\right)$

$= -\frac{275}{8}$ watts

Nodal

$$\frac{V_1}{1} + \frac{V_1 - V_2}{2} + \frac{V_1 - V_3}{1} = 0$$

$\Rightarrow 2V_1 + V_1 - V_2 + 2V_1 - 2V_3 = 0$

$\Rightarrow 5V_1 - V_2 - 2V_3 = 0 \longrightarrow (1)$

$V_2 - V_3 = 5 \longrightarrow (2)$

$$\frac{V_2 - V_1}{2} - 10 + \frac{V_3}{1} + \frac{V_3 - V_1}{1} = 0$$

$$\Rightarrow -3V_1 + V_2 + 4V_3 = 20 \longrightarrow (3)$$

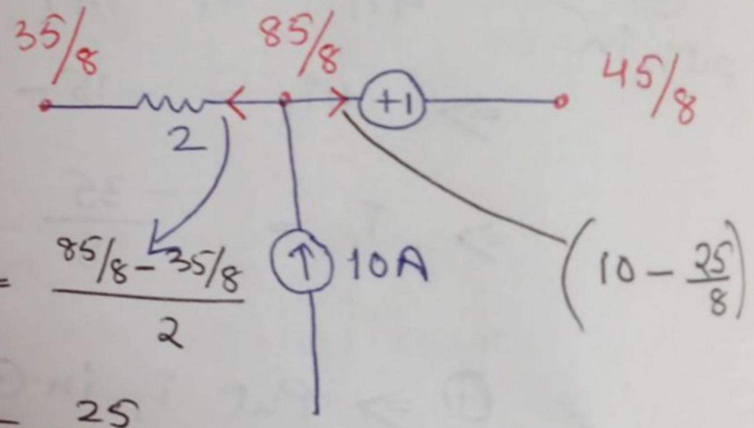
From (1) and (2) $\Rightarrow$ $7V_1 - V_2 = 20$

From (2) and (3) $\Rightarrow$ $5V_1 - 3V_2 = -10$

$$16V_1 = 70$$

$$V_1 = \frac{35}{8}$$

$$V_2 = \frac{85}{8}$$



$$I = \frac{85/8 - 35/8}{2}$$

$$= \frac{25}{8}$$

$$\therefore P_{delivered} = -5\left(10 - \frac{25}{8}\right) = -\frac{275}{8}\,W$$

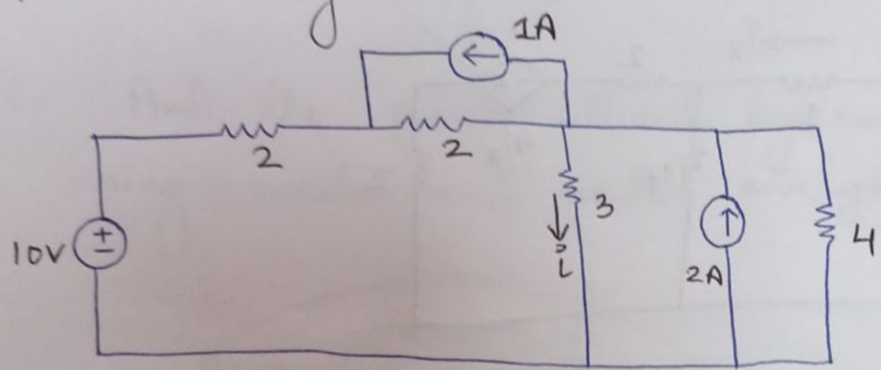
source behaving as sink.

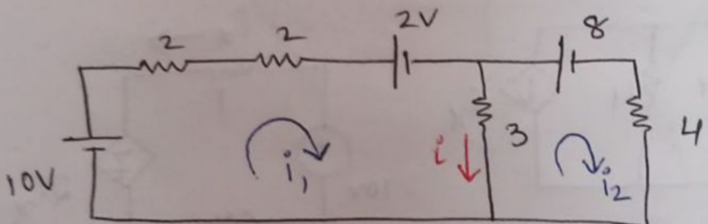
Chapter 7 : NETWORK THEOREMS

Theorem 1 : Source Transformation Technique

A voltage source in series with a resistance can be converted into current source in parallel with same resistance.

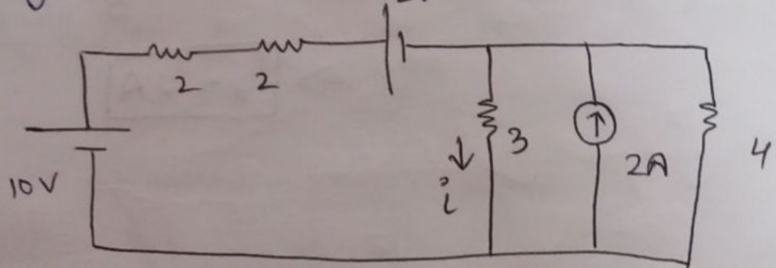
Q) Find i using S.T.T.

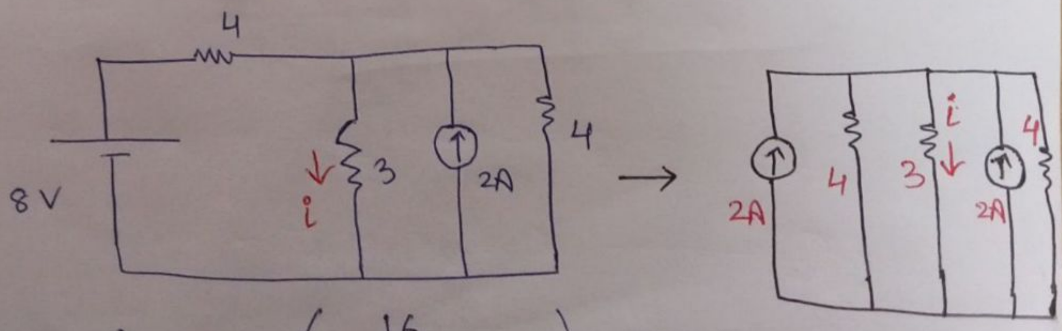




S.T.T + Mesh.

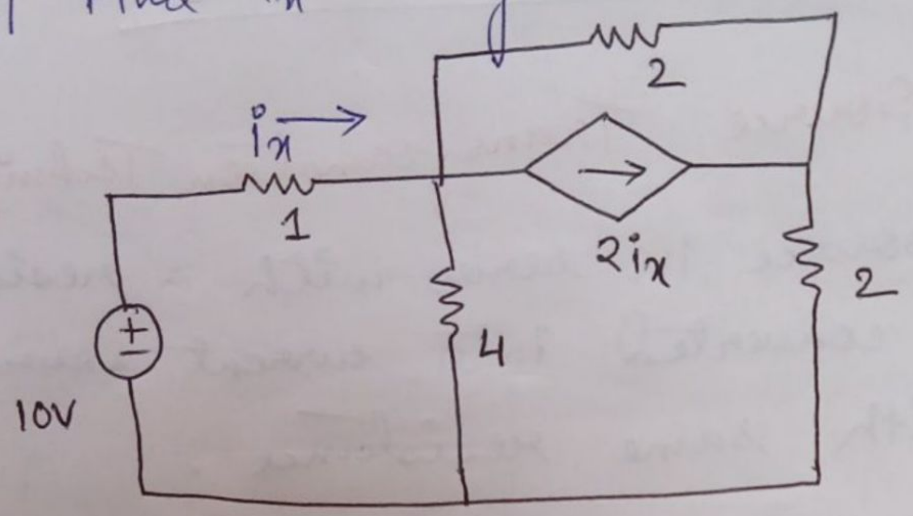
only STT

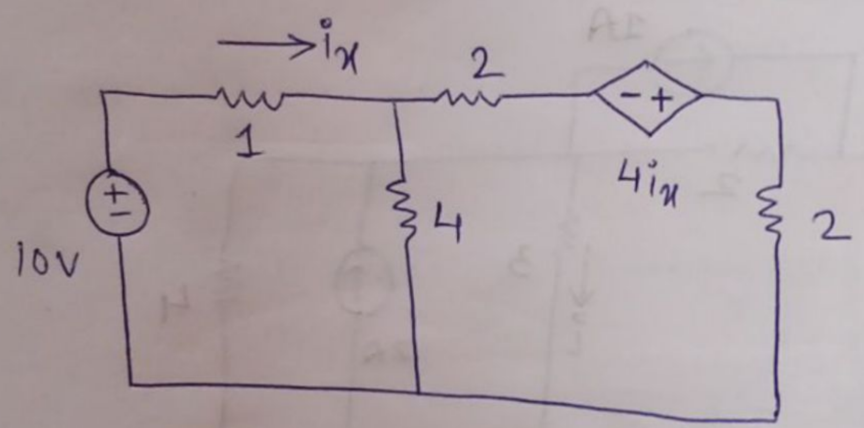


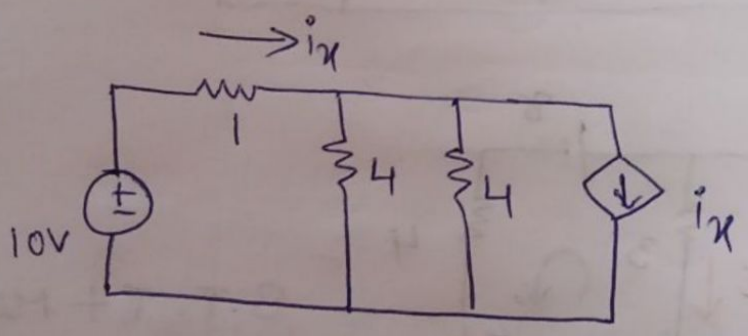


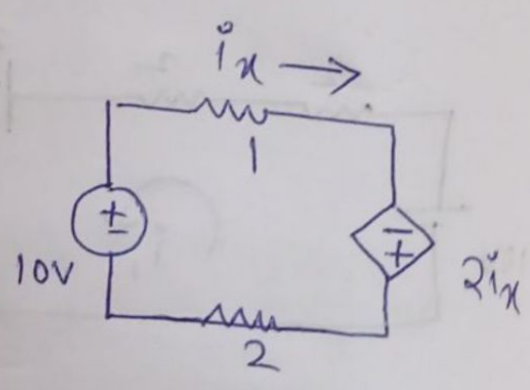
$$i = 4\left(\frac{16}{12+12+16}\right) = \frac{8}{5}\ A$$

Q| Find i_x using S.T.T.









$$\therefore\ i_x = \frac{10 - 2i_x}{3}$$

$$\Rightarrow \boxed{i_x = 2A}$$

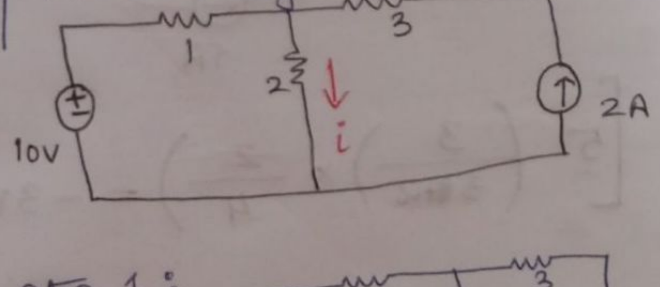
Theorem 2 : Superposition Theorem

In any linear, active, bilateral network consisting of no. of energy sources, resistances etc ; the effect produced in any element when all sources act at a time is equal to sum of effect in same element when each source is considered independently.

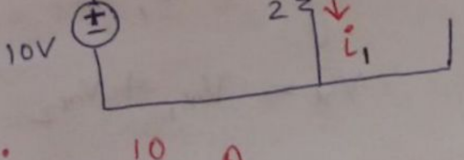
While applying S.P.T, we consider only 1 independent source in every subcircuit where ~~other~~ voltage sources are replaced by short circuit and current sources are replaced by open circuit.

→ However dependent sources cannot be suppressed. Voltages have unique polarities and current have unique direction and they must be respected while applying S.P.T.

Q/ Find i using S.P.T.

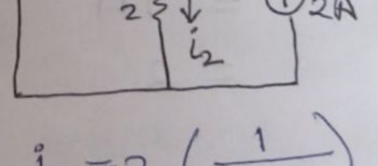


step 1 :



$$i_1 = \frac{10}{3} \text{ A}$$

Step 2 :

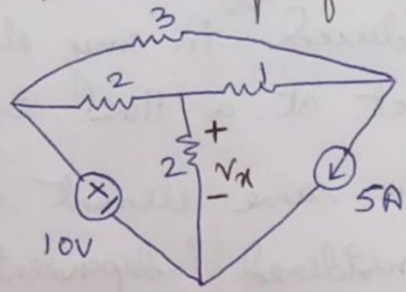


$$i_2 = 2\left(\frac{1}{2+1}\right) = 2/3 \text{ A}$$

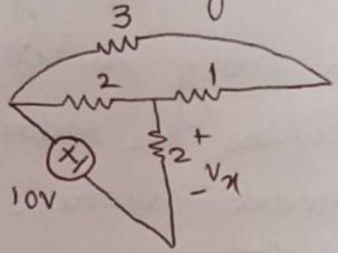
By S.P.T. $\rightarrow$ $i = i_1 + i_2 = \frac{10}{3} + \frac{2}{3}$

$= \frac{12}{3} = 4A$

Q/ Find V_x with help of SPT.



Step 1 : 10V only

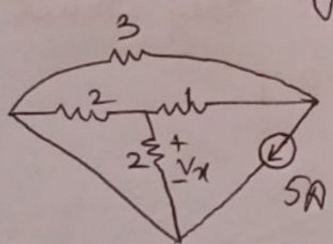


$V_{x_1} = 10\left(\frac{2}{2+4/3}\right)$

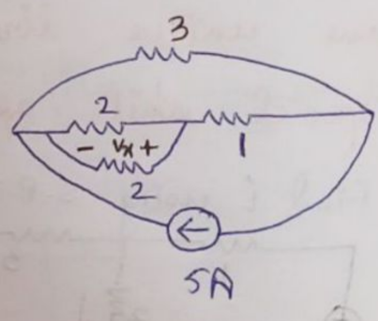
$V_{x_1} = 6V$

$4 \| 2 = \frac{8}{6} = \frac{4}{3}$

Step 2 : 5A only



$\rightarrow$



$V_{x_2} = -2 \times \left[5\left(\frac{3}{3+2}\right) \times \frac{2}{4}\right) = -3V$

$R_s = (2 \| 2) + 1$

$= 1+1$

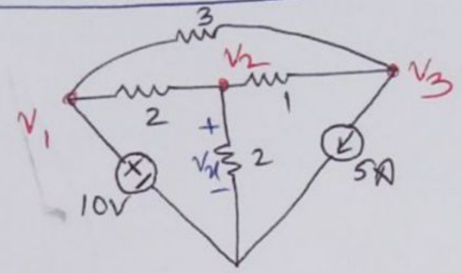
$= 2$

Using SPT,

$V_x = V_{x_1} + V_{x_2}$

$= 6 - 3 = 3V$

check Nodal



$V_1 = 10 \longrightarrow (1)$

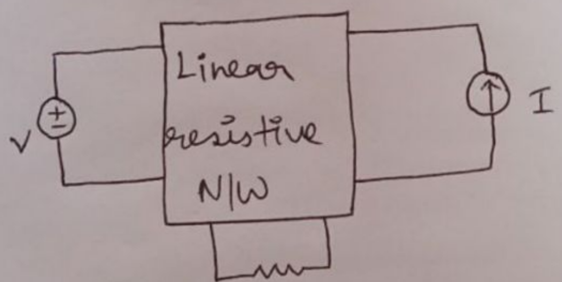
$$\frac{V_2-10}{2} + \frac{V_2}{2} + \frac{V_2-V_3}{1} = 0$$

$$5 + \frac{V_3-V_2}{1} + \frac{V_3-10}{3} = 0 \Rightarrow 4V_2 - 2V_3 = 10 \longrightarrow (2)$$

$$\Rightarrow -3V_2 + 4V_3 = -5 \longrightarrow (3)$$

Solving, $V_2 = 3V = V_x$

Q/ ~~Find~~ The power lost in resistor when voltage source alone act is 9W and when current source alone act is 4W. what is the total power lost in resistor R when both sources act simultaneously.



V act alone

$$P_1 = I_1^2 R = 9$$

$$\Rightarrow I_1 = \frac{3}{\sqrt{R}}$$

I act alone

$$P_2 = I_2^2 R = 4$$

$$\Rightarrow I_2 = \frac{2}{\sqrt{R}}$$

Now,

$$I_{net} = \pm I_1 \pm I_2$$

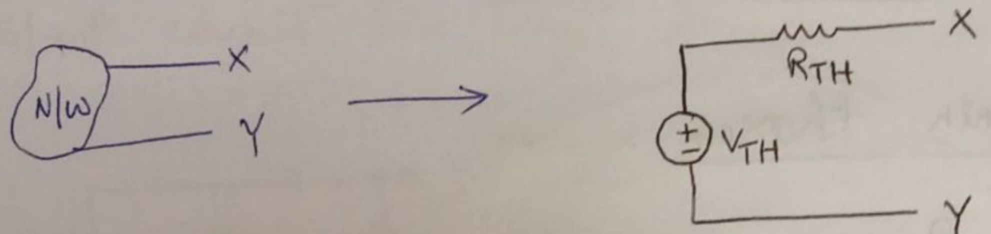
$$P_{Total} = I_{net}^2 R = (\pm I_1 \pm I_2)^2 R = \left(\pm \frac{3}{\sqrt{R}} \pm \frac{2}{\sqrt{R}}\right)^2 R = (\pm 3 \pm 2)^2 \text{ Watts}$$

$P_T = 1\,W$ (I_1 and I_2 different dir^n)

$= 25\,W$ (I_1 and I_2 same dir^n)

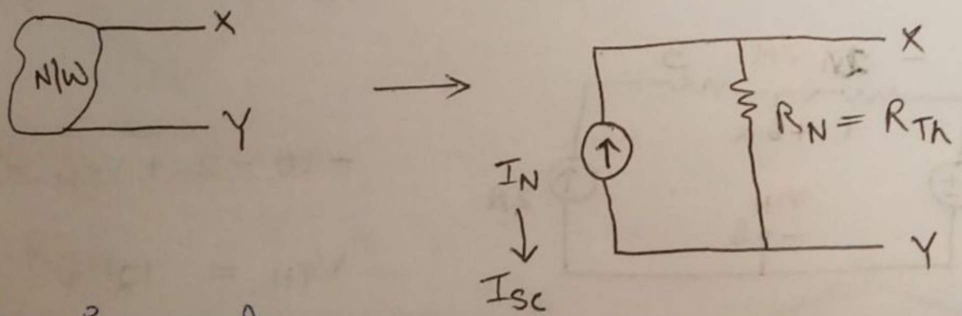
Theorem 3 : Thevenins Theorem

In any linear, bilateral, active network consisting of energy sources, resistors etc with open output target terminal can be converted into a simple network consisting of voltage source in series with resistance.



Theorem 4 : Nortons Theorem

In any linear, active, bilateral n/w consisting of no. of energy sources, resistance etc with open target terminals defined can be converted into a simple n/w consisting of current source in parallel with resistance.

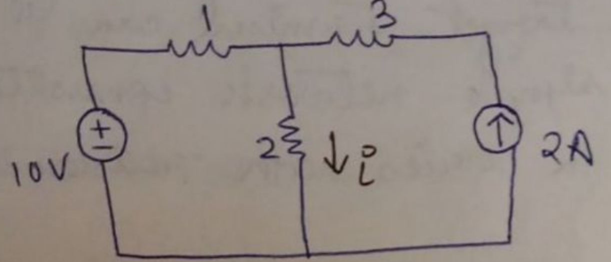


Thevenins and Nortons equivalent are duals of each other i.e. they are source transformable

Category 1 : Problems with only independent sources.

Q) Determine current i using (1) Thevenin theorem

(2) Norton theorem

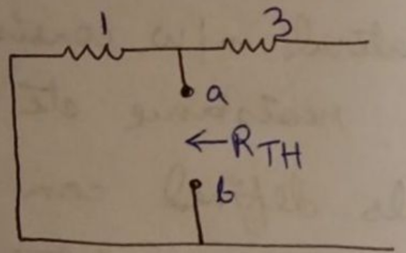


Thevenin theorem

1. R_{TH} $\rightarrow$ open circuit I source

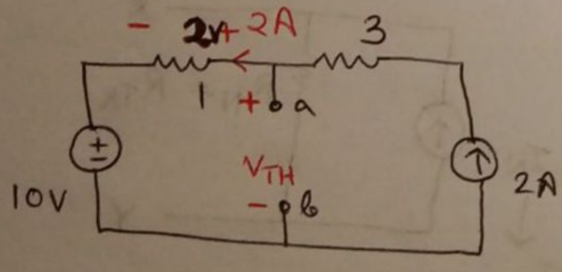
SC voltage source

Remove the target ~~terminal~~ branch



$\therefore R_{TH} = 1\,\Omega$

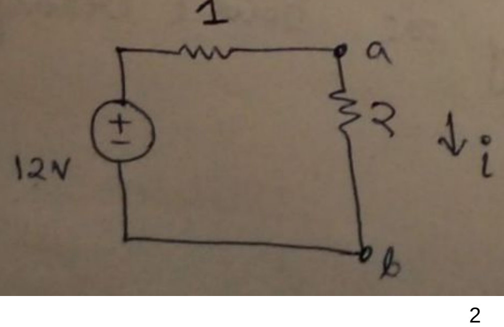
2. V_{TH} $\longrightarrow$ Remove target ~~terminal~~ branch



$$-10 - 2 + V_{TH} = 0$$

$$V_{TH} = 12\text{ V}$$

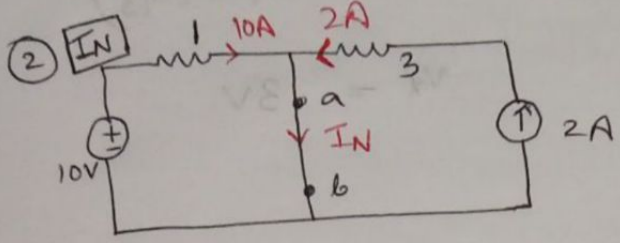
3.



$$i = \frac{12}{3} = 4A$$

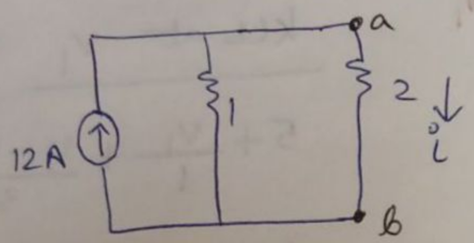
Nortons Theorem

① $R_N = R_{TH} = 1\,\Omega$

② 

$I_N = 10 + 2 = 12A$

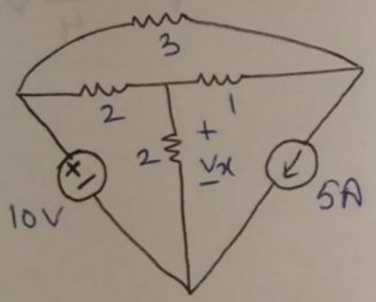
Short circuit the target branch.

3. 

$i = 12\left(\frac{1}{1+2}\right)$

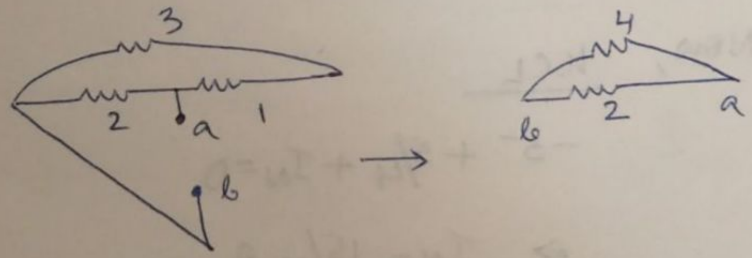
$i = 4A$

Q| Find V_x.

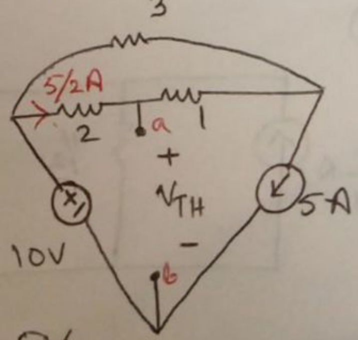


Thevenin Theorem

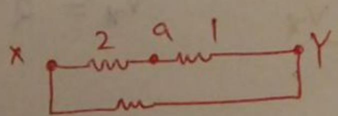
① R_{TH}



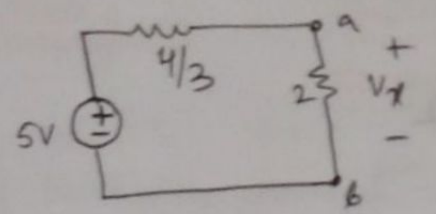
$R_{TH} = 2 \| 4 = \frac{4}{3}\,\Omega$



② V_{TH}



$-10 + \frac{5}{2}(2) + V_{TH} = 0 \Rightarrow V_{TH} = 5V$



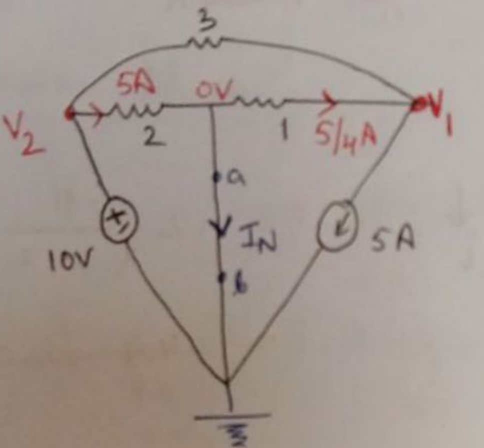
$$V_x = 5\left(\frac{2}{2+4/3}\right)$$

$$V_x = 3V$$

Nortons theorem

① $R_N = R_{TH} = \frac{4}{3}\ \Omega$

②



KCL at V_1

$$5 + \frac{V_1}{1} + \frac{V_1 - V_2}{3} = 0$$

$$\Rightarrow 5 + V_1 + \frac{V_1 - 10}{3} = 0$$

$$\Rightarrow V_1 = \frac{-5}{4}\ V$$

$V_2 = 10V$

$$I = \frac{0 - (-5/4)}{1} = \frac{5}{4}\ A$$

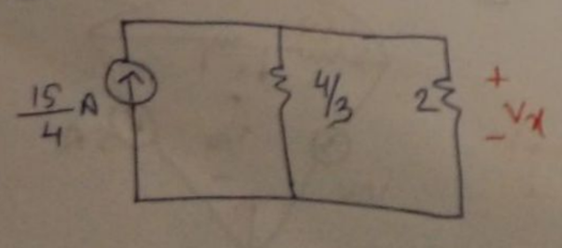
$$\frac{V_2 - 0}{2} = \frac{10}{2} = 5A$$

Now, KCL

$$-5 + 5/4 + I_N = 0$$

$$\Rightarrow I_N = 15/4\ A$$

③



$$V_x = 2\left[\frac{15}{4}\left(\frac{4/3}{4/3+2}\right)\right]$$

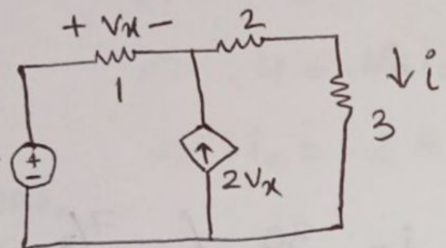
$$V_x = 3V$$

Category 2 : Problems with both dependent and independent sources.

Dependent sources cannot be suppressed directly in terms of their resistances. So here, finding R_{TH} or R_N is not possible directly.

Hence we use Ohm's law where

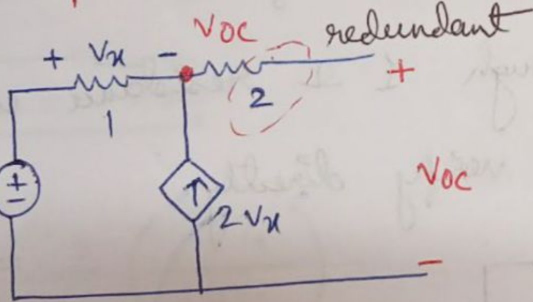
$$\boxed{R_{TH} = R_N = \frac{V_{OC}}{I_{SC}}}$$ at target terminals

Q| 

Find current i using Thevenin and Norton theorem.

Sol^n To find Voc

* open circuit the target terminal.

Voc 

$$\frac{V_{OC} - 10}{1} - 2V_x = 0$$

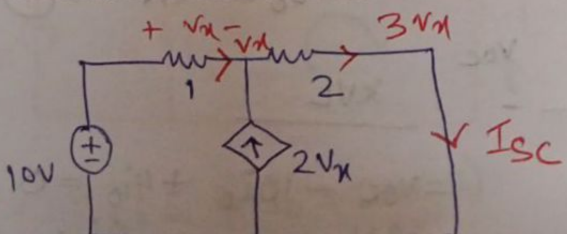
$$\Rightarrow V_x = \frac{V_{OC}}{2} - 5 \rightarrow (1)$$

$$-10 + V_x + V_{OC} = 0$$

$$\Rightarrow -10 + \frac{V_{OC}}{2} - 5 + V_{OC} = 0$$

$$\Rightarrow 2V_{OC} = 20 \Rightarrow \boxed{V_{OC} = 10\,V}$$

To find Isc : SC target terminal



$$I_{SC} = 3V_x \rightarrow (1)$$

KVL

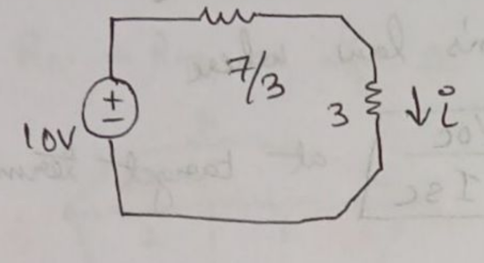
$$-10 + V_x + 6V_x = 0$$

$$\Rightarrow V_x = 10/7$$

$① \Rightarrow I_{sc} = 3V_x = 3 \times \frac{10}{7} = \frac{30}{7} A$

$R_{TH} = R_N = \frac{V_{oc}}{I_{sc}} = \frac{10}{30/7} = \frac{7}{3} \ \Omega$

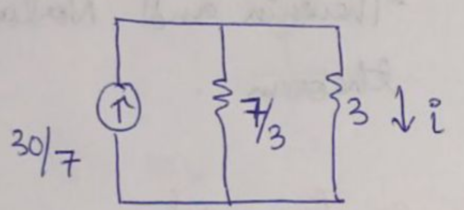
Thevenin equivalent



$i = \frac{10}{3 + 7/3}$

$= \frac{15}{8} A$

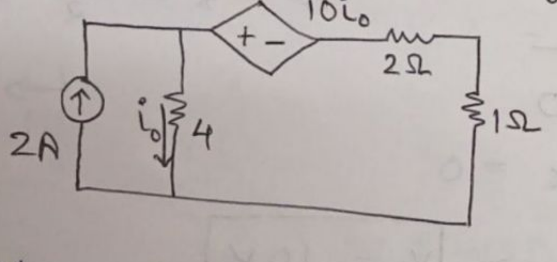
Norton equivalent



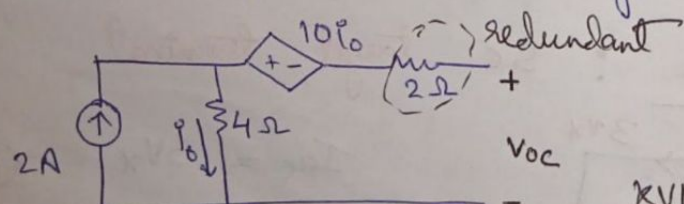
$i = \frac{30}{7}\left(\frac{7/3}{3 + 7/3}\right)$

$= \frac{15}{8} A$

Q/ Find current through 1 Ω resistance using Norton theorem and verify directly.



$\underline{V_{oc}}$: open circuit target branch 1Ω.



$i_o = 2A \rightarrow ①$

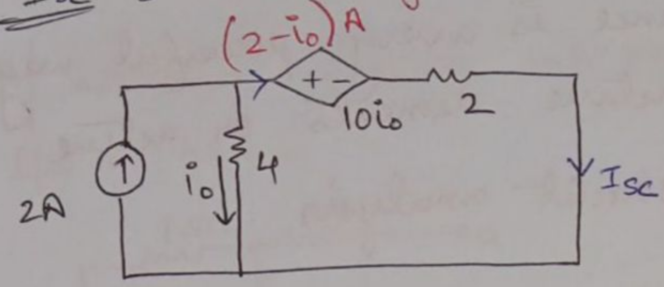
KVL

$-V_{oc} - 10 i_o + 4 i_o = 0$

$\Rightarrow -V_{oc} = 6 i_o$

$\Rightarrow \quad V_{oc} = -6 \times 2 = -12\,V$

I_{sc} : SC target branch



KVL

$$-4i_0 + 10i_0 + 2(2-i_0) = 0$$

$$\Rightarrow +6i_0 + 4 - 2i_0 = 0$$

$$\Rightarrow 4 = -4i_0$$

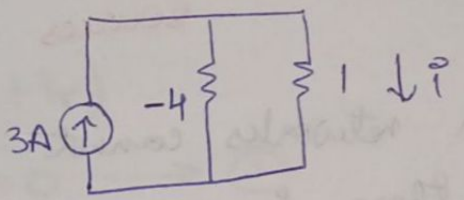
$$\Rightarrow i_0 = -1\,A$$

Now,

$$I_{sc} = 2 - i_0 = 2-(-1) = 3\,A$$

$$R_N = \frac{V_{oc}}{I_{sc}} = \frac{-12}{3} = -4\,\Omega$$

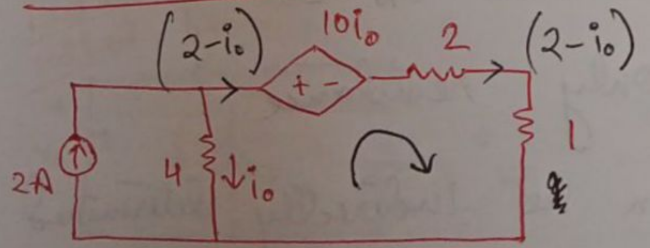
$$\boxed{R_N = -4\,\Omega}$$



$$i = 3\left(\frac{-4}{-4+1}\right)$$

$$\boxed{i = 4A}$$

Direct approach



KVL

$$-4i_0 + 10i_0 + 3(2-i_0) = 0$$

$$\Rightarrow 6i_0 + 6 - 3i_0 = 0$$

$$\Rightarrow i_0 = -2\,A$$

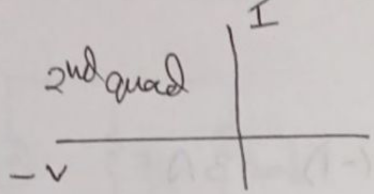
$$\therefore I_{1\Omega} = 2 - i_0 = 2-(-2) = 4A$$

NOTE : In the above problem R_{TH} or R_N is negative

→ Negative resistance is a very powerful way of modelling active elements or active networks in circuit analysis.

Ex → Transistor as an amplifier is active.

VI characteristics of this n/w is in 2nd quadrant. Hence it is active.



Category 3 : Problems with only dependent sources.

Such networks cannot function on their own as there is no independent active element to drive it.

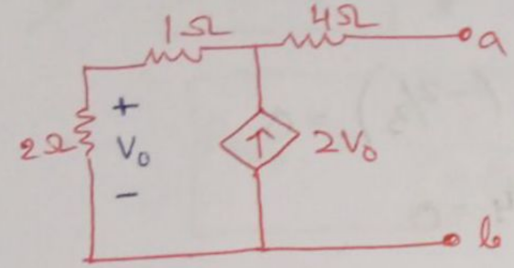
In Thevenins equivalent $V_{TH} = 0$

In Nortons equivalent $I_N = 0$

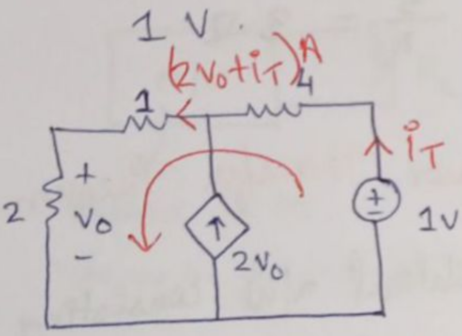
But they have only resistance.

This resistance can be indirectly determined by Ohm's law by externally exciting them where $\boxed{R_{TH} = R_N = \frac{V_T}{1A} = \frac{1V}{i_T}}$

Q| Determine Thevenin and Nortons equivalent b/w a and b.



Solⁿ * Introduce a ~~current~~ voltage source of 1 V.



$$-1 + 4i_T + 3(2V_0 + i_T) = 0$$

$$\Rightarrow -1 + 4i_T + 6V_0 + 3i_T = 0$$

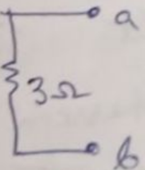
$$\Rightarrow 7i_T + 6V_0 = 1 \quad \rightarrow (1)$$

Now, $V_0 = 2(2V_0 + i_T)$

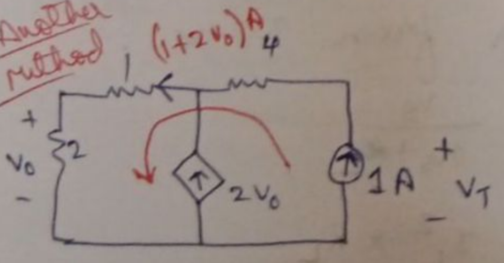
$$\Rightarrow 3V_0 + 2i_T = 0 \longrightarrow (1)$$

$\therefore$ solving, $i_T = \frac{1}{3}$ A

$$R_{TH} = R_N = \frac{1}{i_T} = \frac{1}{1/3} = 3\Omega$$



Another method



KVL

$$-V_T + 4 + 3(1+2V_0) = 0$$

$$\Rightarrow -V_T + 7 + 6V_0 = 0 \quad \rightarrow (1)$$

$V_0 = 2(1+2V_0)$

$\Rightarrow V_0 = 2 + 4V_0$

$\Rightarrow -3V_0 = 2$

$\Rightarrow V_0 = -2/3 \ V$

$\therefore$ (i) $\Rightarrow -V_T + 7 + 6(-2/3) = 0$

$\Rightarrow -V_T + 7 - 4 = 0$

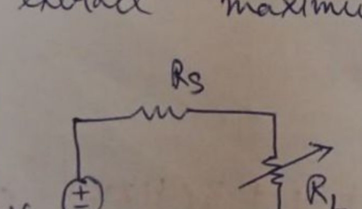
$\Rightarrow V_T = 3 \ V$

$\therefore R_{TH} = R_N = \frac{V_T}{1A} = \frac{3}{1} = 3\Omega$.

Theorem 5 : Maximum Power Transfer Theorem

In any linear, active, bilateral n/w consisting of no. of energy sources with their internal resistances, maximum power is transferred to the load when load resistance is equal to its equivalent resistance as seen by the load into the supply circuit.

It is indirectly application of Thevenins theorem in designing the electrical loads to extract maximum power from source.



$I_L = \frac{V_S}{R_S + R_L}$

$P_L = I_L^2 \times R_L$

$= \frac{V_S^2}{(R_S+R_L)^2} \cdot R_L$

$$\frac{\partial P_L}{\partial R_L} = 0$$

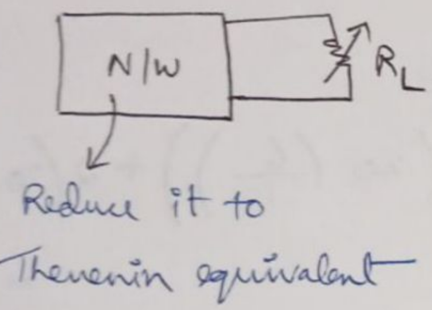
$$\Rightarrow \quad V_S^2 \left(\frac{(R_S+R_L)^2 \cdot 1 - R_L \cdot 2 \cdot (R_S+R_L)}{(R_S+R_L)^4} \right) = 0$$

$$\Rightarrow (R_S+R_L)^2 = R_L \cdot 2 \cdot (R_S+R_L)$$

$$\Rightarrow \quad \boxed{R_L = R_S} \quad ***$$

$$\therefore \quad \boxed{P_{max} = \frac{V_S^2}{4 R_S}} \text{ watts}$$

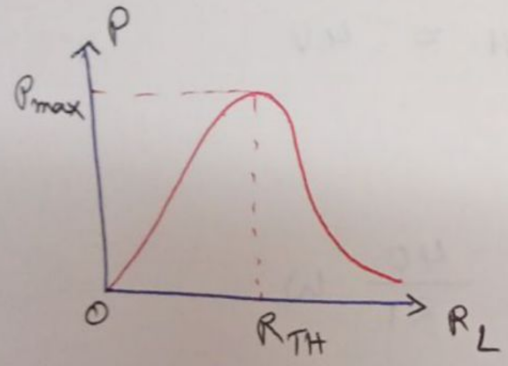
In general,



P_{max} occurs in load when

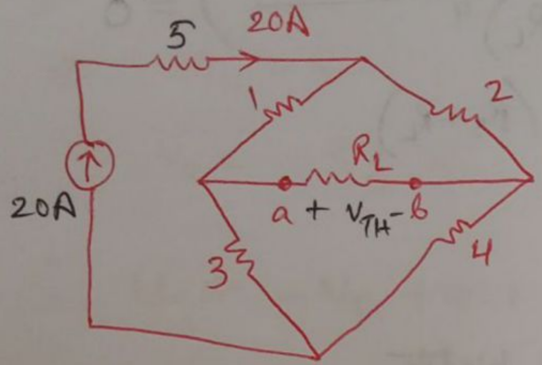
$\boxed{R_L = R_{TH}}$ and

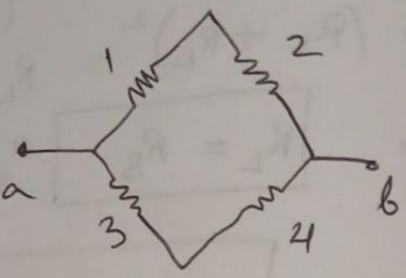
$$\boxed{P_{max} = \frac{|V_{TH}|^2}{4 R_{TH}}} \text{ W}$$



During P_{max} transfer to the load the output efficiency is 50%

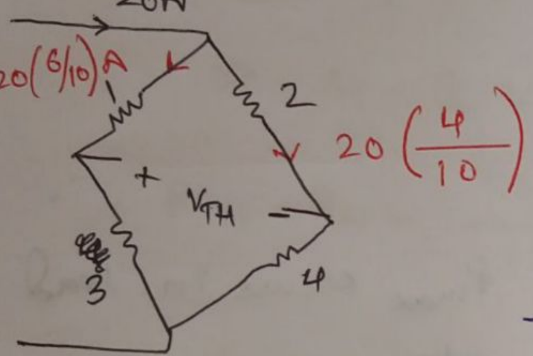
Q| What is the maximum power transferred to the load.





$R_{TH} = 3 \| 1 \| 7$

$= \frac{21}{10}$



KVL

$$-V_{TH} - 1\left(20\left(\frac{6}{10}\right)\right) + 2\left(20\left(\frac{4}{10}\right)\right) = 0$$

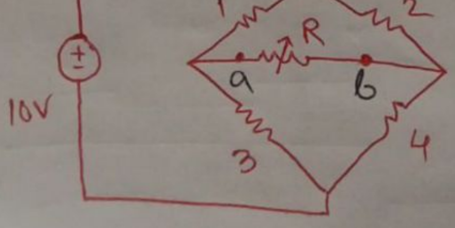
$$\Rightarrow V_{TH} = -12 + 16$$

$$V_{TH} = 4V$$

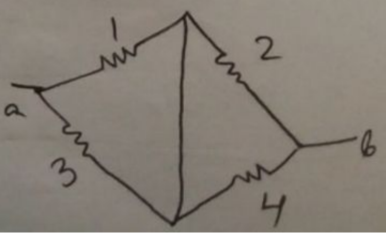
$$P_{max} = \frac{V_{TH}^2}{4R_{TH}}$$

$$= \frac{16}{4(21/10)} = \frac{40}{21} \text{ W}$$

Q| What is the value of R for which maximum power is transferred to load?



$\longrightarrow$



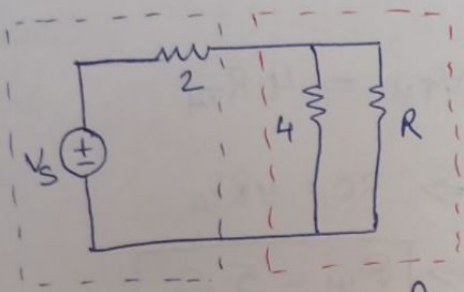
$$R_{TH} = (1 \| 3) + (2 \| 4)$$

$$= \frac{3}{4} + \frac{4}{3}$$

$$= \frac{25}{12} \ \Omega$$

Q| What is the value of R for which maximum power is transferred from source to load?

Sol^n



$R_L = R_S$

$\Rightarrow 4 \| R = 2$

$\Rightarrow R = 4\ \Omega.$

Q|

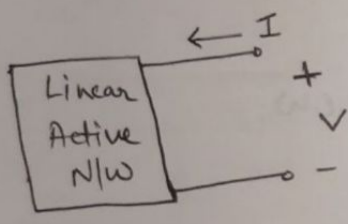


Fig (a)

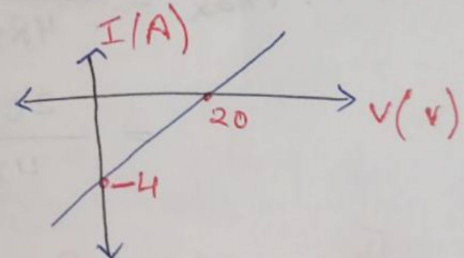
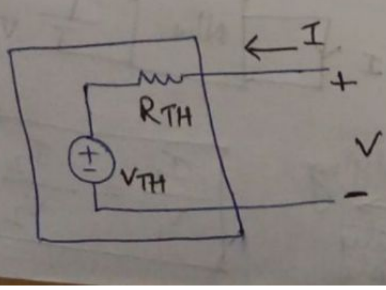


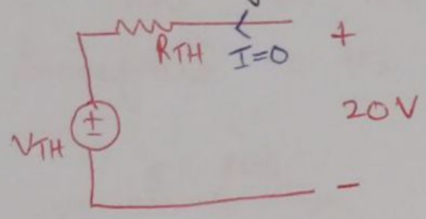
Fig (b)

The static VI characteristics of n/w shown in fig (a) is plotted in fig (b). What is the maximum power that can be drawn from the n/w.

Sol^n : 4^{th} quadrant : Active elements are present in n/w

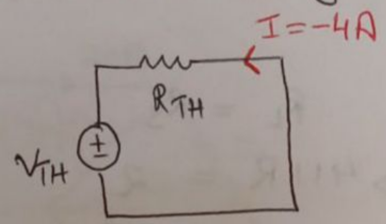


→ 1^{st} operating point : $I = 0$, $V = 20\,V$



$$\therefore \boxed{V_{TH} = 20\,V}$$

→ 2^{nd} operating point : $I = -4A$, $V = 0$



$\therefore V_{TH} = 4R_{TH}$

$\Rightarrow 20 = 4R_{TH}$

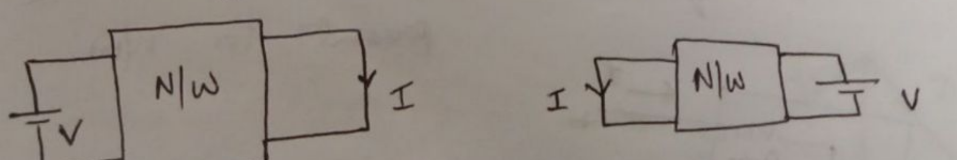
$\Rightarrow \boxed{R_{TH} = 5\,\Omega}$

$$\therefore P_{max} = \frac{V_{TH}^2}{4R_{TH}}$$

$$= \frac{20 \times 20}{4 \times 5} = 20\,W$$

Theorem 6 : Reciprocity Theorem

In any linear, passive, bilateral network excited with only a single source, the ratio of response to excitation remains constant even if the positions of source and load are interchanged.



$\boxed{\frac{I}{V} = \text{constant}}$ $\xrightarrow[\text{Homogenity principle}]{\text{By applying}}$ $\boxed{\frac{I_1}{V_1} = \frac{I_2}{V_2}}$

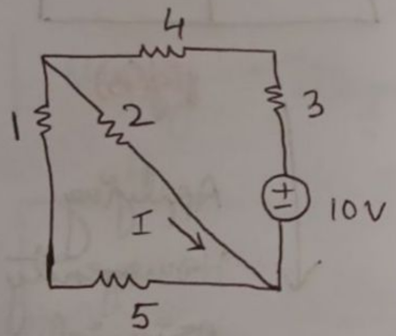
NOTE

① This theorem is valid for n/w excited with single source only.

② This theorem cannot be applied for n/ws with dependent source, since dependent sources can make n/w active.

③ Ideal independent voltage sources are connected in series to the target branch and ideal independent current sources are connected in parallel to target branch.

Q| Verify reciprocity theorem for circuit shown below in finding current I



Step 1

$$\text{Total current} = \frac{V}{R_{total}}$$

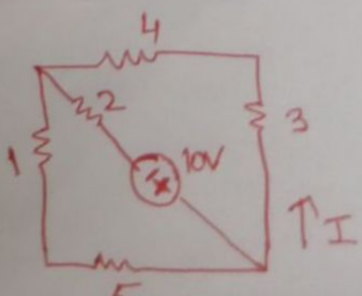
$$= \frac{10}{7+(6\|2)}$$

$$= \frac{10}{17/2} = \frac{20}{17}\ A$$

$$\therefore I = \frac{20}{17} \times \left(\frac{6}{6+2}\right)$$

$$= \frac{15}{17}\ A$$

Step 2 : Reciprocal N/W



$$\text{Total current} = \frac{10}{2+(7\|6)}$$

$$= \frac{10}{68/13} = \frac{65}{34} A$$

$$I = \frac{65}{34} \times \left(\frac{6}{6+7}\right)$$

$$= \frac{\cancel{65}^{5}}{\cancel{34}_{17}} \times \frac{\cancel{6}^{3}}{\cancel{13}}$$

$$I = \frac{15}{17}\ A$$

8| Use the data given in fig. (A) to find current I in fig (B)

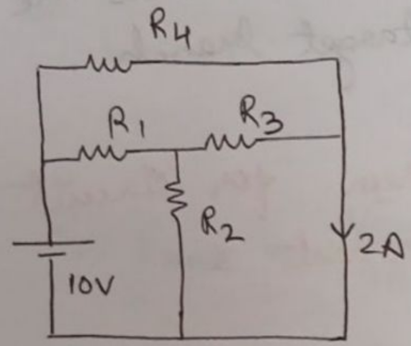
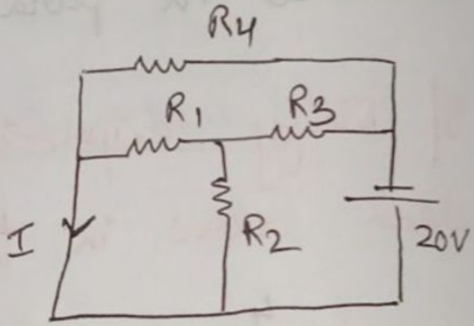


fig (A)

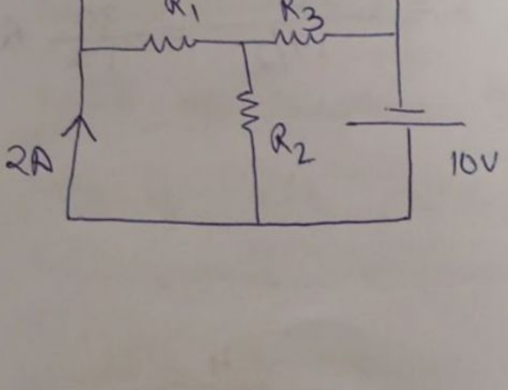


fig(B)

Reciprocal n/w

Applying Homogenity principle

$$\boxed{I = -4A}$$



Theorem 7 : Tellegens Theorem

This theorem is verification of law of conservation of energy.

However in any linear, time invariant system power at an instant is like ~~an~~ energy over a period.

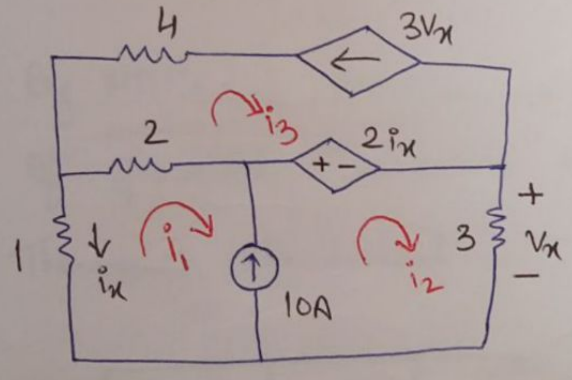
So in this theorem, we ~~use~~ need to verify

$$\boxed{\sum_{k=1}^{n} V_k \cdot I_k = 0}$$

where $n \to$ no. of elements in n/w

i.e $\boxed{\Sigma VI \big|_{source} = \Sigma VI \big|_{sink}}$

Q| Verify Tellegens theorem for the circuit.



Mesh

$$i_1 + 2(i_1 - i_3) + 2i_x + 3i_2 = 0 \longrightarrow (1)$$

$$-i_1 + i_2 = 10 \longrightarrow (2)$$

$$i_3 = -3V_x \longrightarrow (3)$$

$$i_x = -i_1 \longrightarrow (4)$$

$$V_x = 3i_2 \longrightarrow (5)$$

Nodal

$$\frac{V_1}{1} + \frac{V_1 - V_2}{2} - 3V_x = 0 \longrightarrow (1)$$

$$\frac{V_2 - V_1}{2} + \frac{V_3}{3} - 10 + 3V_x = 0 \longrightarrow (2)$$

$$V_2 - V_3 = 2i_x \longrightarrow (3)$$

$$i_x = \frac{V_1}{1} \longrightarrow (4)$$

$$V_x = V_3 \longrightarrow (5)$$

solving using nodal,

$$V_1 = \frac{105}{11} \text{ V}$$

$$V_2 = \frac{225}{11} \text{ V}$$

$$V_3 = \frac{15}{11} \text{ V}$$

$$i_x = \frac{105}{11} \text{ A}$$

$$V_x = \frac{15}{11} \text{ V}$$

solving using mesh,

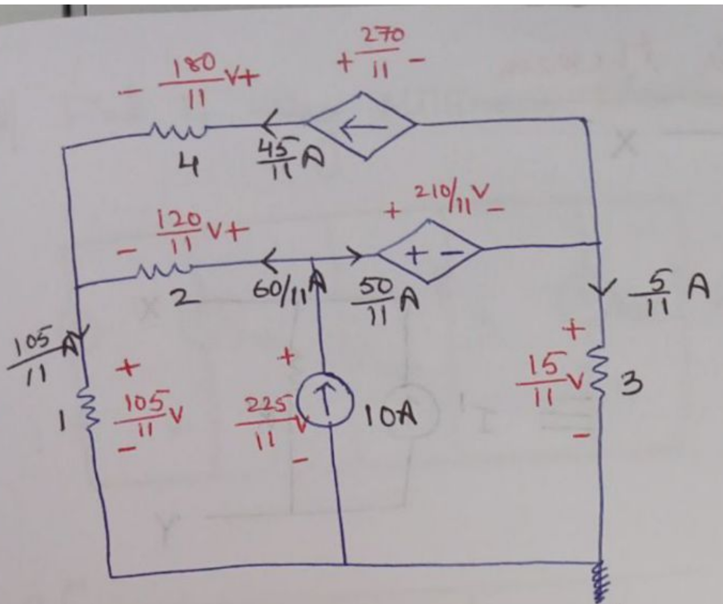
$$i_1 = -\frac{105}{11} \text{ A}$$

$$i_2 = \frac{5}{11} \text{ A}$$

$$i_3 = -45/11 \text{ A}$$

$$V_x = \frac{15}{11} \text{ V}$$

$$i_x = \frac{105}{11} \text{ A}$$



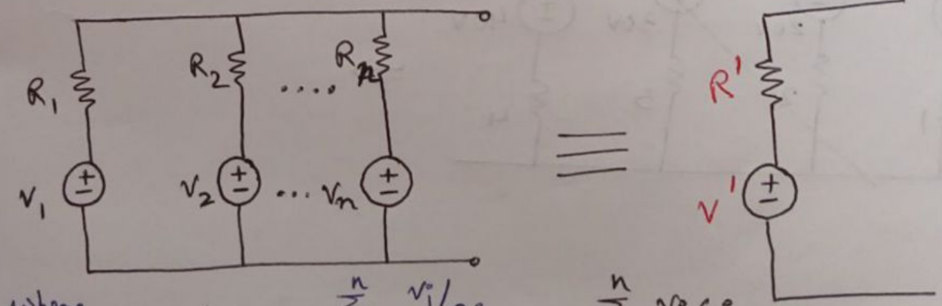
$$\Sigma P_{source} = \left(\frac{225}{11} \times 10\right) + \left(\frac{270}{11} \times \frac{45}{11}\right) = 304.95\ W$$

$$\Sigma P_{sink} = \left(\frac{105}{11} \times \frac{105}{11}\right) + \left(\frac{120}{11} \times \frac{60}{11}\right) + \left(\frac{15}{11} \times \frac{5}{11}\right) + \left(\frac{180}{11} \times \frac{45}{11}\right) + \left(\frac{210}{11} \times \frac{50}{11}\right)$$

$$\Sigma P_{sink} = 304.95\ W$$

Theorem 8: Millman's Theorem [Parallel Generator Theorem]

By Millman's theorem, we can replace 'n' no. of parallel Thevenin's equivalent into a single Thevenin's equivalent.



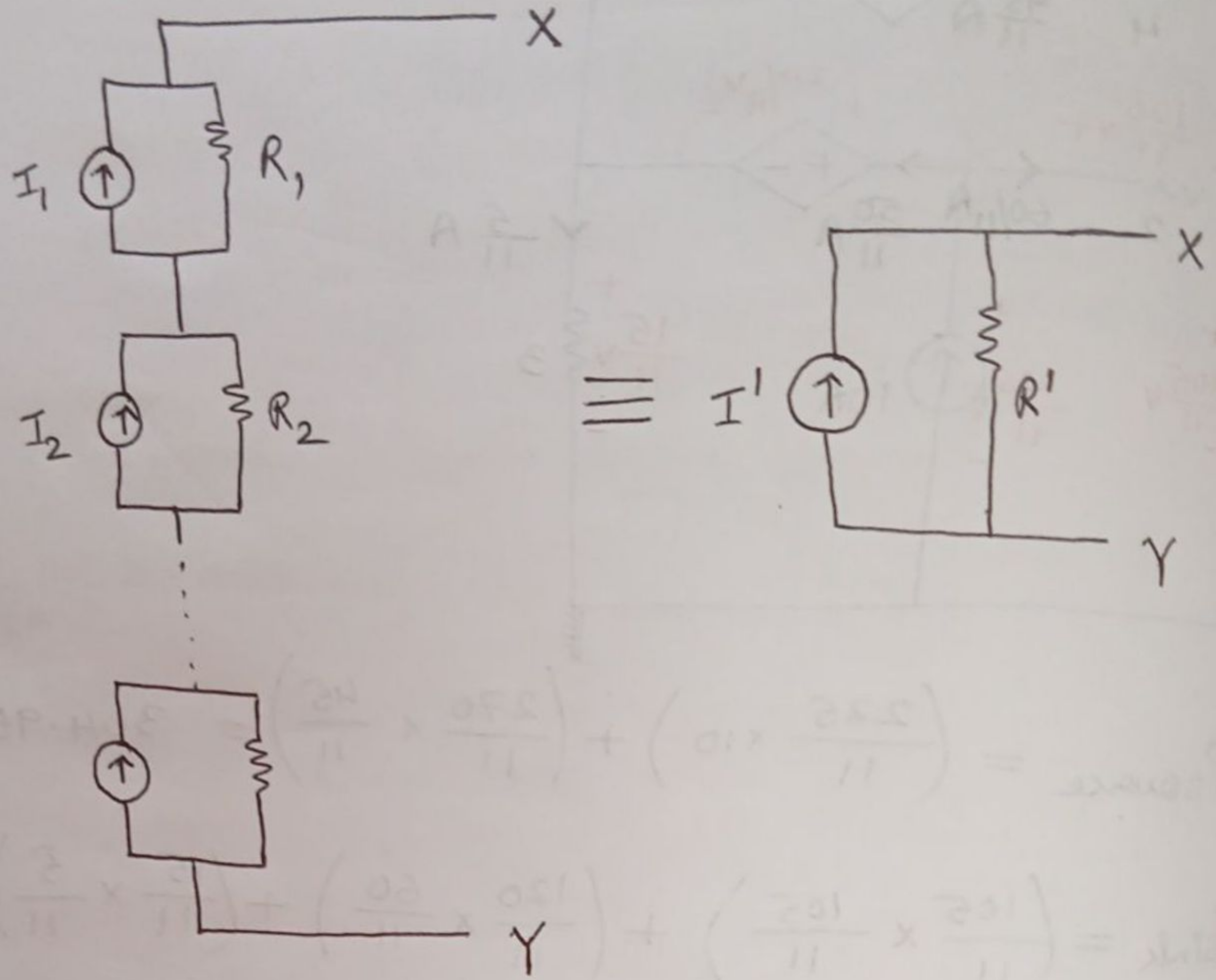
where,

$$V' = \frac{\sum_{i=1}^{n} V_i/R_i}{\sum_{i=1}^{n} 1/R_i} = \frac{\sum_{i=1}^{n} V_i G_i}{\sum_{i=1}^{n} G_i}$$

$$R' = \frac{1}{\sum_{i=1}^{n} 1/R_i} = \frac{1}{\sum_{i=1}^{n} G_i}$$

~~Dual of Millmans~~

Dual of Millman's theorem



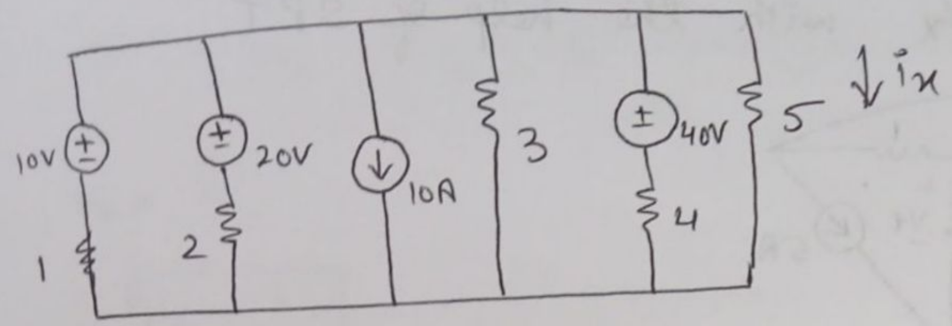
where,

$$I' = \frac{\sum_{i=1}^{n} I_i R_i}{\sum_{i=1}^{n} R_i}$$

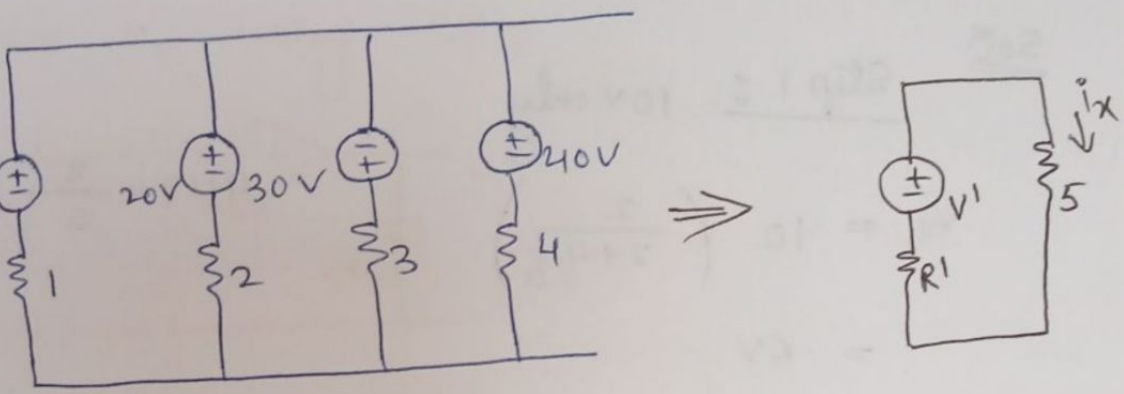
$$R' = \sum_{i=1}^{n} R_i$$

Q

Q| Find i_x using Millimans theorem.



Sol^n



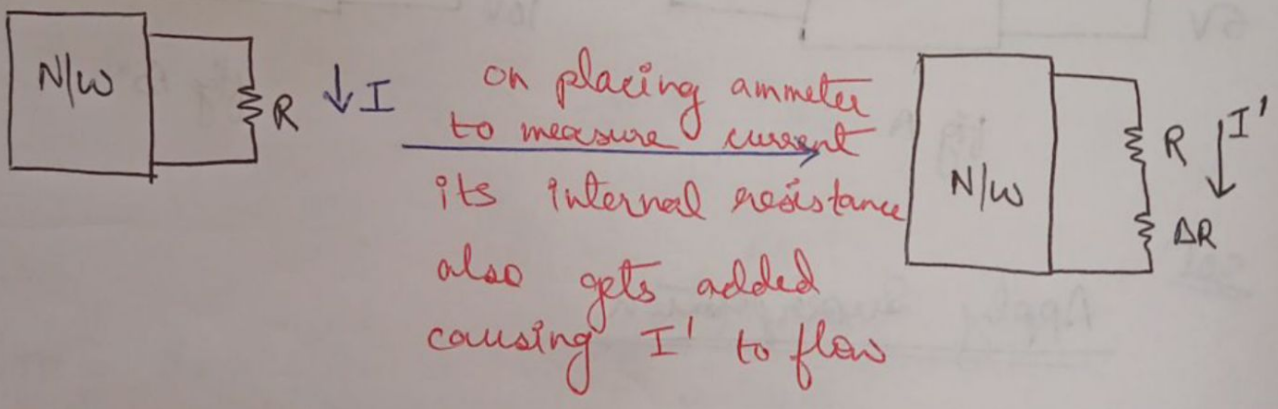
$$V' = \frac{\frac{10}{1} + \frac{20}{2} - \frac{30}{3} + \frac{40}{4}}{1/1 + 1/2 + 1/3 + 1/4} = 9.61\,V$$

$$R' = \frac{1}{1/1 + 1/2 + 1/3 + 1/4} = 0.48\,\Omega$$

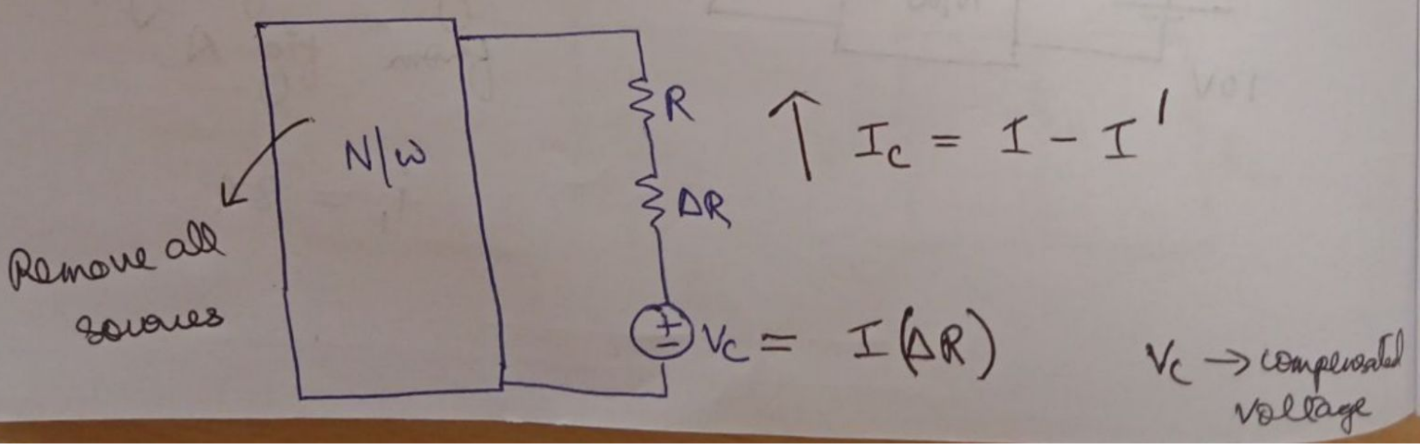
$$i_x = \frac{V'}{5 + R'} = \frac{9.61}{5.48} = 1.75\,A$$

THEOREM 9 : COMPENSATION THEOREM

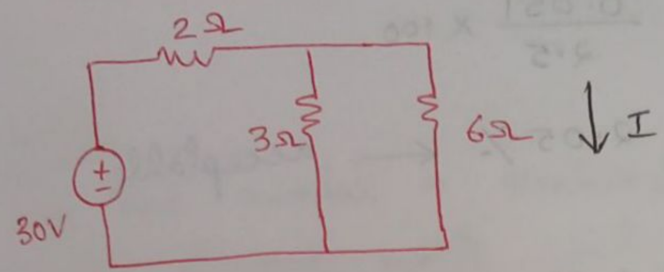
This theorem is exclusively used to determine steady state error in measuring instruments, as practical meters with their internal resistances will alter the ideal values when they are connected into the circuit.



compensated N|W



| Find the change in current introduced by ammeter with an internal resistance of 0.15 Ω while measuring the current in 6Ω resistance branch. Also determine steady state error introduced by the meter.



Sol^n : Step 1: Find I (theoritically)

~~Total current = 30 (~~

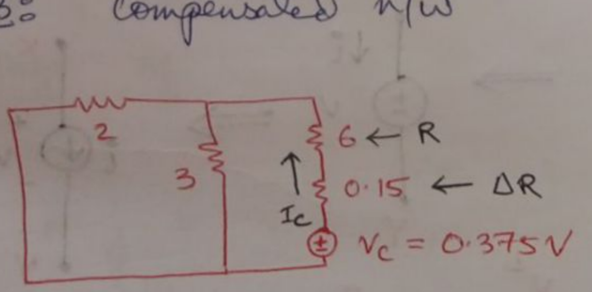
$$\text{Total current} = \frac{30}{2+(3\|6)} = \frac{30}{2+2} = \frac{15}{2}\,A$$

$$I = \frac{15}{2} \times \frac{3}{3+6} = \frac{\cancel{15}^{5}}{2} \times \frac{\cancel{3}}{\cancel{9}_{3}} = \frac{5}{2}\,A$$

Step 2: calculate compensated voltage

$$V_c = I(\Delta R) = \frac{5}{2}(0.15) = 0.375\,V$$

Step 3: Compensated n/w



$$I_c = \frac{0.375}{6.15 + (2\|3)} = 0.051\,A$$

∴ By connecting an ammeter with internal resistance of 0.15Ω, current in the 6Ω branch is reduced by 0.051A

$$\% \text{ error} = \frac{I - I'}{I} \times 100$$

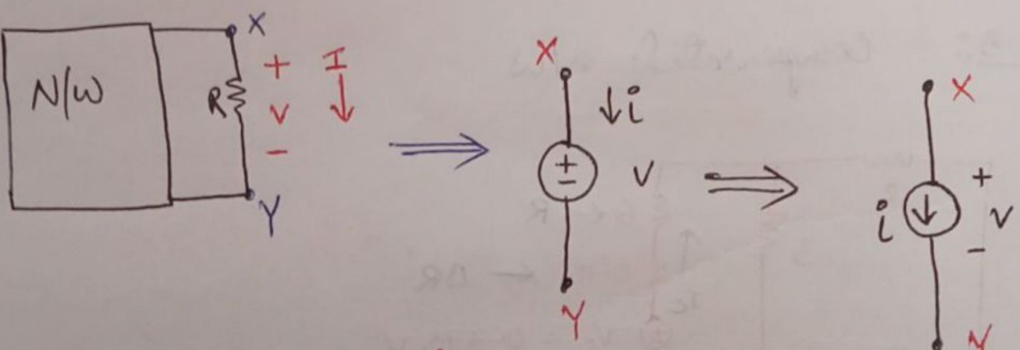
$$= \frac{I_c}{I} \times 100$$

$$= \frac{0.051}{2.5} \times 100$$

$$= 2.05\% \leftarrow \text{acceptable}$$

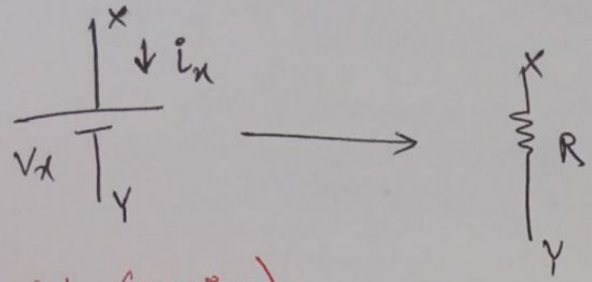
Theorem 10 : Substitution Theorem

In any linear, active, bilateral n/w consisting of no. of energy sources, passive elements etc ; any passive element can be substituted in terms of its equivalent voltage or current for further analysis of the n/w without disturbing the rest of the n/w, provided power absorbed by this passive element and its equivalently substituted source is same.



$$P_{absorbed} = \frac{V^2}{R} = I^2 R = VI$$

Vice versa

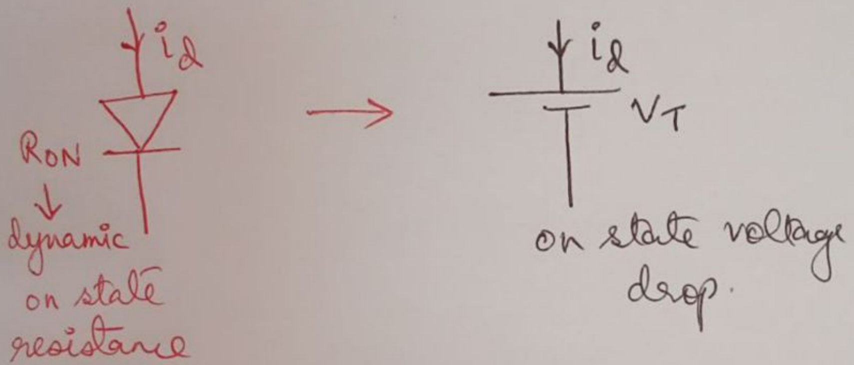


$$R = \frac{V_x}{i_x}$$

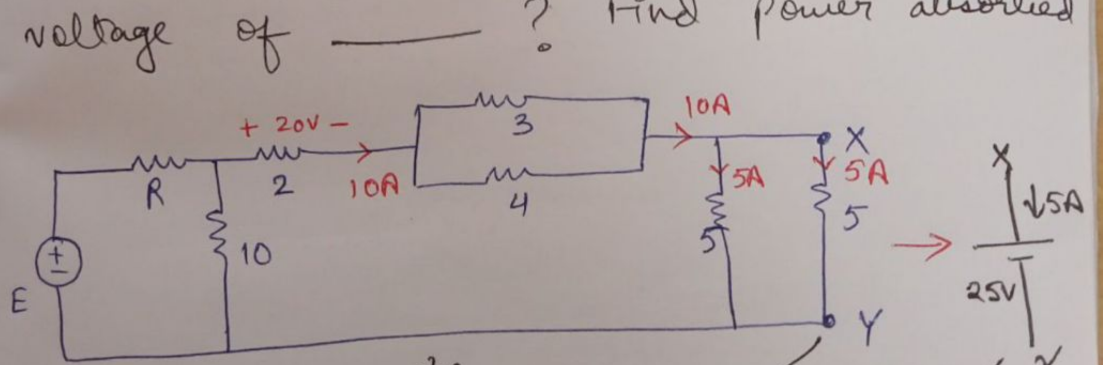
sink (passive)

NOTE

We can model a semiconductor device as a passive element while conducting, in terms of its on state voltage drop for further analysis using substitution theorem.



Q| If the voltage drop across 2Ω resistance is 20V, the 5Ω resistance branch b/w X and Y can be substituted by an equivalent voltage of ______? Find power absorbed



$$P_{absorbed} = \overset{I^2R}{(5)^2 \times 5} = 125\,W$$

$$P_{abs} = 25 \times 5 \ (VI) = 125\,W$$