Electronic Circuit Components:

(a) Passive Components: Resistors, capacitors and inductors which cannot amplify or rectify a.c. power are called Passive Components.

These are also called Linear Circuit Elements because the current-voltage relationship is linear in these elements.

(b) Active components:

Diodes, transistors, tube devices etc. which can amplify or rectify a.c. power are called Active Components.

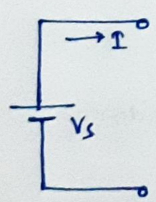
In diodes and transistors the current-voltage relationship is not linear and they are called Nonlinear Circuit Elements.

Ohm's Law or Kirchhoff's Laws are not applicable to circuits involving nonlinear elements.

Voltage Source:

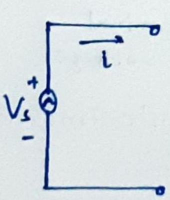
An ideal voltage source is a voltage generator whose output voltage is independent of the current delivered by the generator.

An ideal voltage source must have zero internal impedance.



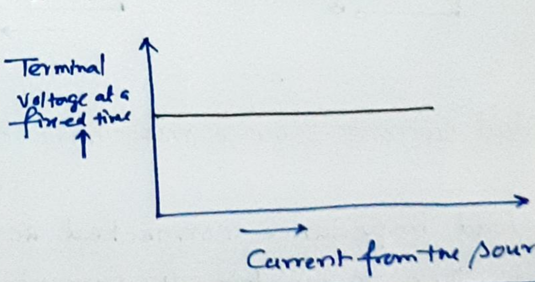
ideal

d.c. source.



ideal

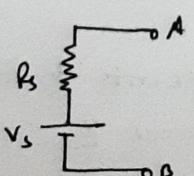
a.c. source

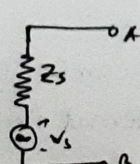


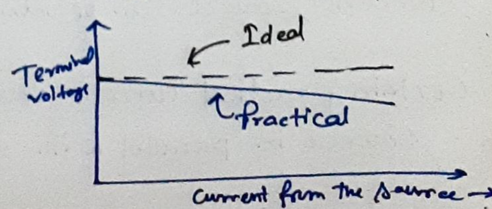
Current-voltage characteristics

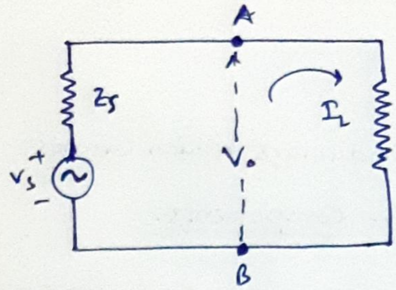
So the load current approaches infinity when the load resistance connected across it approaches zero. Thus no practical source can be ideal voltage source. A practical voltage source always has some internal impedance.

Practical voltage source









If a load impedance Z_L is connected across the terminals A, B of a voltage source, then the terminal voltage across AB is given by →

$$V_o = \frac{V_s \cdot Z_L}{(Z_s + Z_L)} = \frac{V_s}{1 + \frac{Z_s}{Z_L}}$$

$$\Downarrow$$

$\frac{Z_s}{Z_L}$ must be smaller than unity (at least $Z_s/Z_L < 0.01$) in order that a practical source can be considered as a good voltage source.

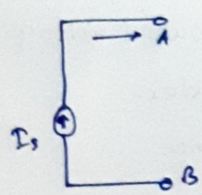
$V_o = V_s - Z_s \cdot I_L$

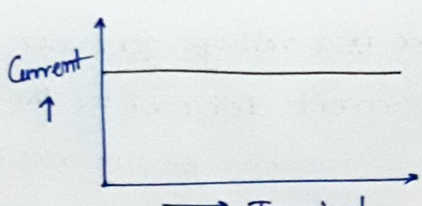
↳ The output voltage decreases with increase in load current.

↳ Load Regulation Characteristic

Current Source:

An ideal current source is a current generator which supplies a current independent of the voltage across the terminals of the current generator.





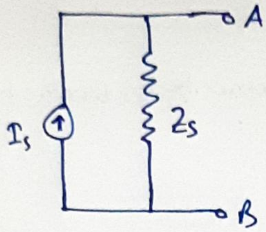
An ideal current source must have infinite internal impedance.

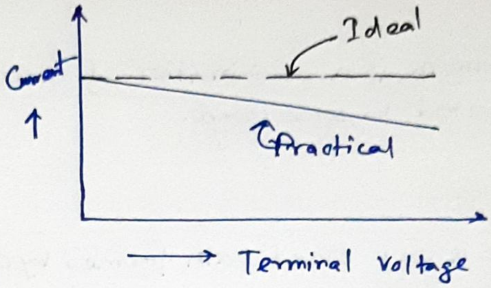
If the load impedance connected across the terminals A, B is made infinite then to maintain the current I_s constant the voltage across A, B must be infinite.

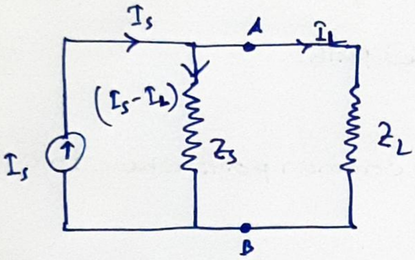
↳ This is a physical impossibility.

Thus the ideal current source is a theoretical concept and no practical current source can be ideal.

Certain practical current sources can be represented by an ideal current source in parallel with an internal impedance Z_s.







Practical Current source connected to a load impedance.

$$(I_s - I_L) \cdot Z_s = I_L \cdot Z_L$$

or, $$I_L = \frac{I_s}{1 + \frac{Z_L}{Z_s}} \Rightarrow$$ if $Z_s >> Z_L$, $I_L \approx$ Constant

if $Z_s >> 100 Z_L$ → Practical current source can be considered as a good current source.

$$V_o = I_L \cdot Z_L$$

$$\therefore I_L = I_s - \frac{1}{Z_s} V_o$$

→ load current decreases with the increase in load voltage.

Note:

→ if the load impedance is very large compared to the internal impedance of a source, then it can be considered as a voltage source.

→ if the load impedance is very small compared to the internal impedance of the source, then it may be concidered as a current source.

→ if necessary, a voltage source can be replaced by its equivalent current source and vice-versa.

(i) Circuit :⇒ A circuit may be defined as a complete path for electrical current flow.

(ii) Branch :⇒ Each individual circuit component such as resistor, inductor, Capacitor etc; is called a circuit element. A group of such elements, usually in series, and having two terminals is called a branch of the circuit.

Netwonk :⇒

A netwonk is a combination of circuit elements or branches interconnected in some ways.

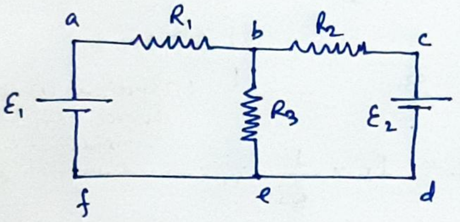
Mesh or Loop :⇒

A loop is any closed path formed by a number of branches in a netwonk.

A mesh is the simplest possible closed path.

Node :⇒

A node or junction is simply a common point where two or more circuit components meet.



abcdefa → Loop

abefa / bcdeb → Mesh

b or e → Branch point

Kirchhoff's Law :

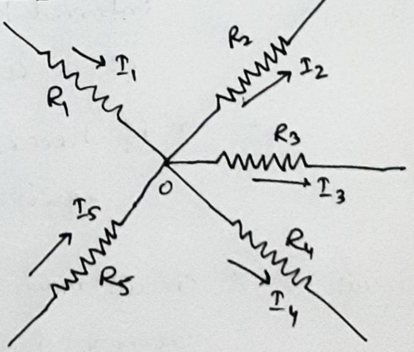
1st Law (Current Law):

This law states that the algebric sum of the currents meeting at a branch point/junction point in a mesh is always zero.

Mathematically, this is given by →
$$\boxed{\sum_{i=1}^{n} I_i = 0}$$

Thus, according to Kirchhoff's first law →

$$I_1 - I_2 - I_3 - I_4 + I_5 = 0$$



~~Thus,~~ But, we know that, $I = \frac{dQ}{dt}$

$\therefore \sum I_i = 0$

$\rightarrow \sum Q_i$ = constant

Thus, the first law of Kirchhoff's is a consequence of the conservation of charge.

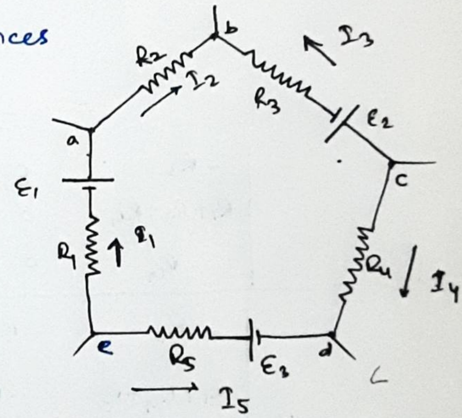
2nd Law (voltage Law):

This law States that → In any loop in a network of conductors, the algebric sum of the E.M.F's is equal to the algebric sum of the product of resistances of each link of the loop and the current flowing through them.

The algebric sum of all voltage drops around a closed path in a network is zero.

Mathematically, this is given by → $\boxed{\sum_{i=1}^{n} I_i R_i = \sum_{j=1}^{m} \mathcal{E}_j}$

Thus, if abcde is a loop consisting of 5 resistances and 3 cells $\mathcal{E}_1, \mathcal{E}_2, \mathcal{E}_3$, then for the current distribution shown in the fig., we get →



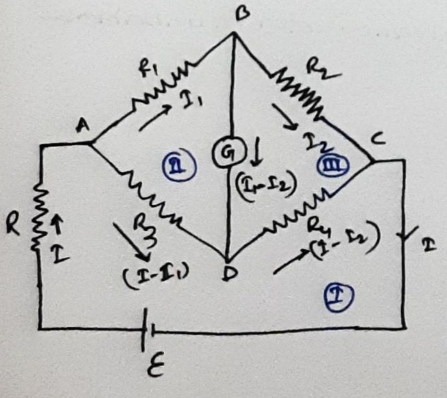
$$I_1R_1 + I_2R_2 - I_3R_3 + I_4R_4 - I_5R_5 = \mathcal{E}_1 - \mathcal{E}_2 - \mathcal{E}_3$$

Current × Resistance = E.M.F
(i) (R)

or, $i^2 \times R$ = E.M.F × i
= Power = $\frac{\text{energy}}{\text{time}}$

Thus, the 2nd law is a statement of the conservation of energy.

Determination of the Current through the Galvanometre of a Unbalanced Wheatstone Bridge: ⇒



To obtain an expression for the current through the Galvanometre in the off-balance condition, let us consider the 3 mesh equations, which are →

$$IR + R_3(I - I_1) + R_4(I - I_2) = \mathcal{E}$$

$$\text{or, } -R_3I_1 - R_4I_2 + (R + R_3 + R_4)I = \mathcal{E} \quad \text{—— (1)}$$

$$R_1I_1 + (I_1 - I_2)R_G - R_3(I - I_1) = 0$$

$$\text{or, } (R_1 + R_3 + R_G)I_1 - R_GI_2 - R_3I = 0 \quad \text{—— (2)}$$

$$I_2R_2 - (I - I_2)R_4 - (I_1 - I_2)R_G = 0$$

or, $$-R_G I_1 + (R_G + R_4 + R_2) I_2 - R_4 I = 0 \quad \text{—— (iii)}$$

Therefore,

$$I_1 = \frac{\begin{vmatrix} \varepsilon & -R_4 & R+R_3+R_4 \\ 0 & -R_G & -R_3 \\ 0 & R_G+R_4+R_2 & -R_4 \end{vmatrix}}{\begin{vmatrix} -R_3 & -R_4 & R+R_3+R_4 \\ R_1+R_3+R_G & -R_G & -R_3 \\ -R_G & R_G+R_4+R_2 & -R_4 \end{vmatrix}}$$

$$= \frac{\varepsilon\{R_G R_4 + R_3(R_2 + R_4 + R_G)\}}{\Delta}$$

$$I_2 = \frac{\begin{vmatrix} -R_3 & \varepsilon & R_1+R_3+R \\ R_1+R_3+R_G & 0 & -R_3 \\ -R_G & 0 & -R_4 \end{vmatrix}}{\begin{vmatrix} -R_3 & -R_4 & R+R_3+R_4 \\ R_1+R_G+R_3 & -R_G & -R_3 \\ -R_G & R_G+R_4+R_2 & -R_4 \end{vmatrix}} = \frac{\varepsilon\{R_4(R_1+R_G+R_3) + R_3R_G\}}{\Delta}$$

$\therefore$ Current through the Galvanometer, $I_G = I_1 - I_2$

$$= \frac{\varepsilon}{\Delta}\left\{\cancel{R_GR_4} + R_3R_2 + \cancel{R_3R_4} + \cancel{R_3R_G} - R_4R_1 - \cancel{R_4R_G} - \cancel{R_3R_4} - \cancel{R_3R_G}\right\}$$

$$= \frac{\varepsilon}{\Delta}\left(R_3R_2 - R_4R_1\right)$$

This is the current through the Galvanometer in unbalanced condition.

for balanced condition, $I_G = 0$

$$\therefore R_3R_2 - R_4R_1 = 0$$

$$\therefore R_3R_2 = R_1R_4$$

$$\therefore \boxed{\frac{R_1}{R_2} = \frac{R_3}{R_4}}$$

Superposition Theorem: ⇒

Complex networks can be solved by using the principle of Superposition, which states — "In any linear bilateral network containing linear impedances and the potential sources, the current flowing in any element is the vector sum of the current that would flow in that element by each potential source when all other sources being replaced by their internal impedances".

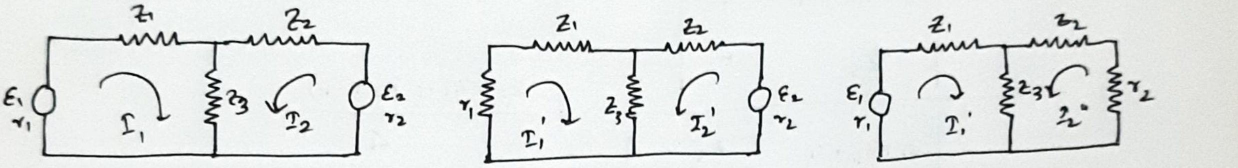


fig. 1   fig. 2   fig. 3

To explain the theorem, let us consider the fig. 1 where we have two loop equations →

$$(Z_1 + Z_3 + r_1) I_1 + Z_3 I_2 = \mathcal{E}_1$$

$$Z_3 I_1 + (Z_2 + Z_3 + r_2) I_2 = \mathcal{E}_2$$

determinant ←

Here,

$$I_1 = \frac{\begin{vmatrix} \mathcal{E}_1 & Z_3 \\ \mathcal{E}_2 & Z_2+Z_3+r_2 \end{vmatrix}}{\begin{vmatrix} Z_1+Z_3+r_1 & Z_3 \\ Z_3 & Z_2+Z_3+r_2 \end{vmatrix}} \qquad \therefore I_1 = \frac{\mathcal{E}_1 (Z_2+Z_3+r_2) - \mathcal{E}_2 Z_3}{\Delta}$$

Bilateral Network:

A circuit whose characteristics, behavior are the same irrespective of the direction of current through various elements of it, is called Bilateral Network.

⟶ Network consisting of only Resistors

$$I_2 = \frac{\begin{vmatrix} Z_1+Z_3+r_1 & \mathcal{E}_1 \\ Z_3 & \mathcal{E}_2 \end{vmatrix}}{\begin{vmatrix} Z_1+Z_3+r_1 & Z_3 \\ Z_3 & Z_2+Z_3+r_2 \end{vmatrix}} \qquad \therefore I_2 = \frac{(Z_1+Z_3+r_1)\mathcal{E}_2 - \mathcal{E}_1 (Z_3)}{\Delta}$$

Let us now consider fig. 2 where the first source is replaced by its internal impedance, then for this circuit, we get two loop equations →

$$(Z_1 + Z_3 + r_1) I_1' + Z_3 I_2' = 0$$

$$(Z_2 + Z_3 + r_2) I_2' + Z_3 I_1' = \mathcal{E}_2$$

$$I_1' = \frac{\begin{vmatrix} 0 & Z_3 \\ \mathcal{E}_2 & Z_2 + Z_3 + r_2 \end{vmatrix}}{\begin{vmatrix} Z_1 + Z_3 + r_1 & Z_3 \\ Z_3 & Z_2 + Z_3 + r_2 \end{vmatrix}} = \frac{-\mathcal{E}_2 Z_3}{\Delta}$$

$$I_2' = \frac{\begin{vmatrix} Z_1 + Z_3 + r_1 & 0 \\ Z_3 & \mathcal{E}_2 \end{vmatrix}}{\begin{vmatrix} Z_1 + Z_3 + r_1 & Z_3 \\ Z_3 & Z_2 + Z_3 + r_2 \end{vmatrix}} = \frac{\mathcal{E}_2 (Z_1 + Z_3 + r_1)}{\Delta}$$

Now consider fig. 3 where the second source is replaced by its internal impedance, so we get 2 loop equations, which are →

$$(Z_1 + Z_3 + r_1) I_1'' + Z_3 I_2'' = \mathcal{E}_1$$

$$Z_3 I_1'' + (Z_2 + Z_3 + r_2) I_2'' = 0$$

$$I_1'' = \frac{\begin{vmatrix} \mathcal{E}_1 & Z_3 \\ 0 & Z_2 + Z_3 + r_2 \end{vmatrix}}{\begin{vmatrix} Z_1 + Z_3 + r_1 & Z_3 \\ Z_3 & Z_2 + Z_3 + r_2 \end{vmatrix}} = \frac{\mathcal{E}_1 (Z_2 + Z_3 + r_2)}{\Delta}$$

$$I_2'' = \frac{\begin{vmatrix} Z_1 + Z_3 + r_1 & \mathcal{E}_1 \\ Z_3 & 0 \end{vmatrix}}{\begin{vmatrix} Z_1 + Z_3 + r_1 & Z_3 \\ Z_3 & Z_2 + Z_3 + r_2 \end{vmatrix}} = \frac{-\mathcal{E}_1 Z_3}{\Delta}$$

From these six relations, we see that →

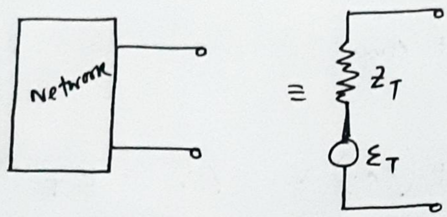
$$I_1 = I_1' + I_1''$$

$$I_2 = I_2' + I_2''$$

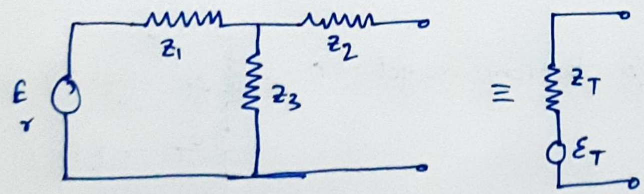
— which is the Superposition Principle.

Thevenin's Theorem: →

Any two terminal linear network containing energy sources and impedances can be replaced by an equivalent circuit consisting of a voltage source E_T in series with an impedance Z_T such that the value E_T is the open circuit voltage between the terminals of the network and Z_T is the impedance appearing across the terminals when all the energy sources replaced by their internal impedance.



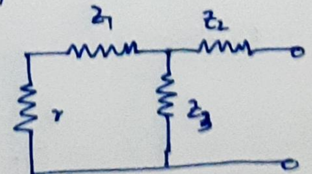
To explain this, let us consider a network which consists of a voltage source and three impedances.



Open circuit voltage $= \dfrac{E}{Z_1+Z_3+r} \times Z_3$

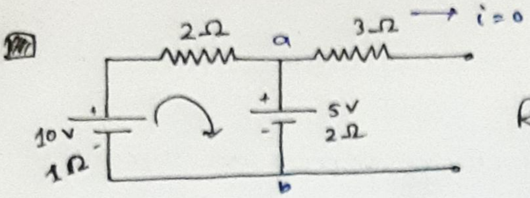
so, $\dfrac{E}{Z_1+Z_3+r} \times Z_3 = E_T$

for Z_T, the network reduces to →



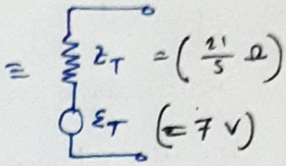
$$\therefore Z_T = Z_2 + \left\{ Z_3 \parallel (r+Z_1) \right\}$$

$$= Z_2 + \frac{Z_3(r+Z_1)}{Z_1+Z_3+r}$$

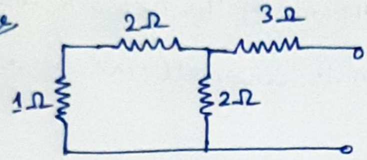


Replace this by Thevenin's Theorem.

Replacing this by Thevenin's theorem, we get →



for Resistance

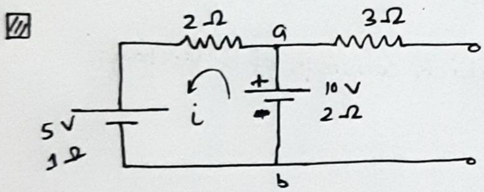


$$Z_T = 3 + \frac{3\times 2}{5} = \frac{21}{5}\,\Omega$$

for $\mathcal{E}_T$

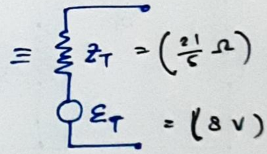
$$i = \frac{10-5}{1+2+2} = 1 \text{ Amp}$$

$$\therefore V_{ab} = 5\text{V} + (2\times 1)\text{ V} = 7\text{ V.} = \mathcal{E}_T$$

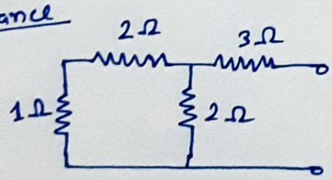


Replace this by Thevenin's Equivalent Circuit.

Replacing this by Thevenin's theorem, we get →



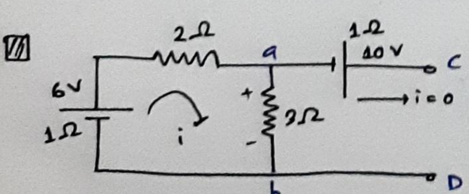
for resistance



$$Z_T = 3 + \frac{2(2+1)}{5} = \frac{21}{5}\,\Omega$$

$$i = \frac{10-5}{5} = 1 \text{ Amp}$$

$$V_{ab} = 10 - 2 = 8\text{ V} = \mathcal{E}_T$$



Replace this by Thevenin's Equivalence Circuit.

$$Z_T = 1 + \frac{3(2+1)}{6} = 2.5\,\Omega$$

$$i = \frac{6}{6} = 1 \text{ Amp} \qquad \therefore V_{CD} = 10 + 3 = 13 \text{ Volt} = \mathcal{E}_T$$

Current through the Galvanometer in an unbalanced Wheatstone Bridge using Thevenin's theorem: ⇒

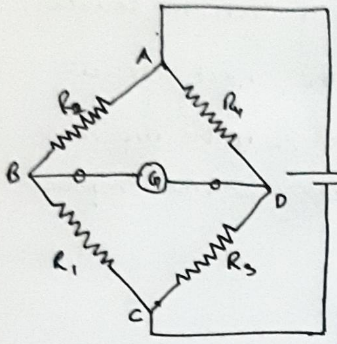


fig.1

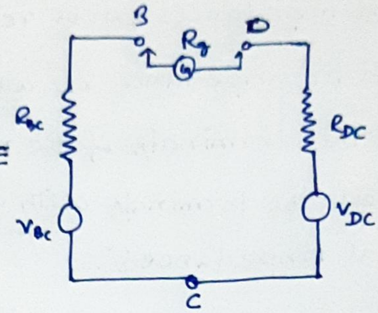


fig.2

Let us assume that, the Galvanometer has a resistance R_g then to calculate the current through it, let us replace the point B by the Thevenin's equivalent circuit, and similarly the point D is also replaced by the Thevenin's equivalent circuit so that the Wheatstone Bridge takes the form as shown in fig.2.

$$V_{BC} = \frac{E \cdot R_1}{R_1 + R_2} \quad ; \quad R_{BC} = \frac{R_1 R_2}{R_1 + R_2}$$

$$V_{DC} = \frac{E R_3}{R_3 + R_4} \quad ; \quad R_{DC} = \frac{R_3 R_4}{R_3 + R_4}$$

Thus, the current through R_g is given by →

$$I_g = \frac{V_{BC} - V_{DC}}{R_{BC} + R_{DC} + R_g} = \frac{E\left(\frac{R_1}{R_1+R_2} - \frac{R_3}{R_3+R_4}\right)}{R_{BC} + R_{DC} + R_g}$$

$$= \frac{E\left\{R_1(R_3+R_4) - R_3(R_1+R_2)\right\}}{(R_{BC} + R_{DC} + R_g)(R_1+R_2)(R_3+R_4)}$$

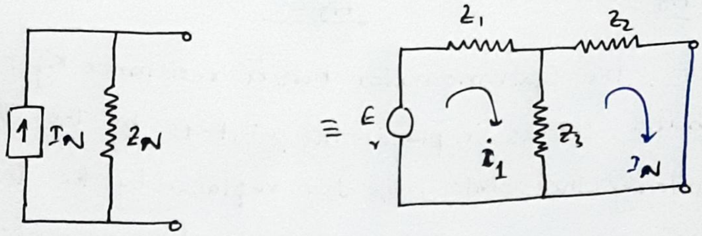
$$= \frac{E(R_1R_4 - R_2R_3)}{(R_{BC} + R_{DC} + R_g)(R_1+R_2)(R_3+R_4)}$$

In the balance condition, $I_g = 0$

$$\therefore R_1 R_4 = R_2 R_3 \quad \therefore \boxed{\frac{R_1}{R_2} = \frac{R_3}{R_4}}$$

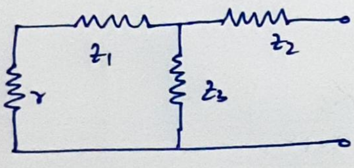
Norton's Theorem: →

This theorem states that "Any two terminal linear network containing energy sources and impedances can be replaced by a current source I_N in parallel with an impedance Z_N where I_N is the short-circuit current between the terminals of the network and Z_N is the impedance measured between the terminals with all the energy sources replaced by their internal impedances".



To explain this, let us consider the network consisting of 3 impedances Z_1, Z_2, Z_3 and a source E as shown in the figure.

Then the resistance to be connected in parallel with the current source in the Norton's Equivalent circuit will be equal to →



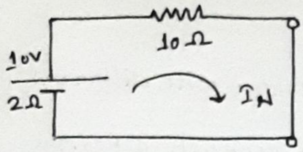
$$Z_N = Z_2 + \frac{Z_3(Z_1 + r)}{Z_1 + Z_3 + r}$$

The current source will have the current →

$$i_1(Z_1 + Z_3 + r) - I_N Z_3 = E$$

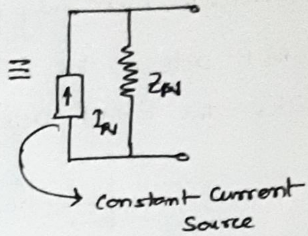
$$-i_1 Z_3 + I_N(Z_3 + Z_2) = 0 \longrightarrow i_1 = \frac{Z_3 + Z_2}{Z_3} I_N$$

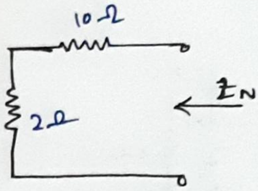
$$\therefore I_N = \frac{E}{\left[\frac{Z_3 + Z_2}{Z_3}(Z_1 + Z_3 + r) - Z_3\right]}$$



Replace this by Norton's Equivalent Circuit.

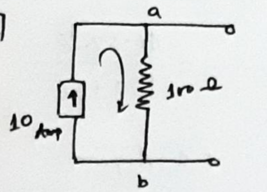
Replacing this by Norton's theorem, we get → $\equiv$





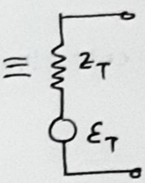
$Z_N = 12\ \Omega$

$I_N = \frac{10}{12}$ Amp



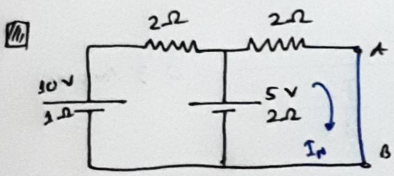
Replace this Circuit by Thevenin's Equivalence Circuit.

Replacing this circuit by Thevenin's theorem, we get → $\equiv$



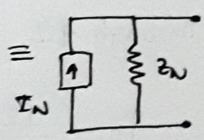
$E_T = (10 \times 100)\ V = 1000\ V$

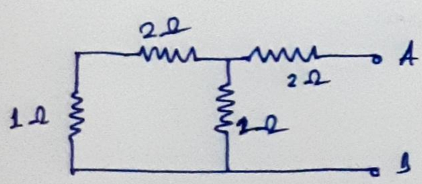
$Z_T = 100\ \Omega$



Replace this by Norton's Equivalence Circuit.

Replacing this by Norton's theorem, we get → $\equiv$





$Z_N = 2 + \frac{3 \times 2}{5} = \frac{16}{5}\ \Omega$

$$I_N = \frac{10 - 5}{\left[\frac{2+2}{2}(2+2+1) - 2\right]} = \frac{5}{8} \text{ Amp.}$$

Reciprocity Theorem:

This theorem states that — "In any linear bilateral network with different branches, but only one E.M.F., the current in the j-th branch when the E.M.F. acts in the i-th branch is the same as the current in the i-th branch when the E.M.F acts in the j-th branch".

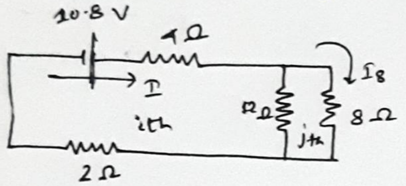


fig. 1

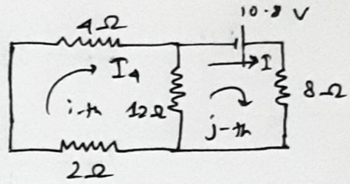


fig. 2

In the fig. 1,

$$\text{Current, } I = \frac{10.8}{4+2+(12 \parallel 8)} = \frac{10.8}{6+\frac{96}{20}} = \frac{10.8\times20}{120+96}$$

$= 1$ Ampere

Current through 8 Ω resistance in the j-th branch →

$$I_8 = \frac{1\times12}{20} = \frac{12}{20} = 0.6 \text{ Ampere}$$

In Fig. 2,

$$\text{current, } I = \frac{10.8}{8+(12 \parallel 6)} = \frac{10.8}{8+\frac{72}{18}} = 0.9 \text{ Ampere}$$

Current through 4 Ω resistance in the i-th branch

$$I_4 = \frac{12}{12+6}\times0.9 = 0.6 \text{ Ampere.}$$

∴ Reciprocity theorem is proved.

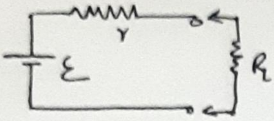
Maximum Power Transfer Theorem:

This theorem states that — "A two terminal network delivers maximum power to an external load when the internal impedance of the network is equal to the load resistance".

Electric Power $= VI = I^2R$

Unit ⇒ watt or Joule/sec

1 B.O.T ⇒ 1 Kilo watt per hour.



Let us consider the fig. beside, here the current through the load resistance is $i = \frac{E}{r+R_L}$

The power in the load is $= i^2 R_L = \frac{E^2}{(r+R_L)^2} \cdot R_L$

Now, when power is maximum, then $\frac{dP}{dR_L} = 0$

or, $E^2 \frac{d}{dR_L}\left(\frac{R_L}{(r+R_L)^2}\right) = 0$

or, $\frac{(r+R_L)^2 - 2R_L \cdot (r+R_L)}{(r+R_L)^4} = 0$

or, $r^2 + \cancel{2rR_L} + R_L^2 - \cancel{2rR_L} - 2R_L^2 = 0$

or, $r^2 - R_L^2 = 0$

or, $\boxed{r = R_L}$