1. Introduction to Electrical circits

Network :- An electric circuit or a network is the inter-connection of energy sources and passive elements like resistors, inductors and capacitors.

classification of network elements :-

Network elements
- Active element (source)
  - voltage source
  - current source
- Passive element
  - Resistors (R)
  - Inductors (L)
  - capacitors (C)

Another classification is

Network elements
- Linear or non Linear
- unilateral or Bilateral
- Time variant or Time invariant
- Lumped or distributed

Active Elements:- An element which supplies electrical energy to the circuit is known as active element.

These elements are also known as energy sources

Ex:- Voltage source and current source.

Passive elements:- An element which receives electrical energy from the energy source is known as passive elements. These elements are either absorb or stored energy

ex:- Resistance (R), Inductance (L), and capacitance (C)

Linear and non-Linear elements:- A linear element is one which is governed by a linear relationship between the excitation and responce. otherwise, it is a non-linear element.

Example:-

1. Resistor and Air cored inductor are linear elements.
2. Diodes, Transistors, etc.

Unilateral and Bilateral Elements:- conduction of current in both directions in an element with same magnetude is known as bilateral element.

ex:- Resistors, inductors and capacitors

conduction of current in one direction is known as unilateral element.

ex:- Diodes, Transistors.

Time variant and Time Invariant Elements:-

If the parameters of the network elements do not vary with time, they are called Time invariant elements, otherwise they are called Time variant.

Lumped and distributed elements:-

A lumped element is one whose size is small compared to the wavelength corresponding their normal frequency of operation. otherwise it is called a distributed element.

ex:- Resistor, inductors and capacitors are lumped elements

A long transmission line is a distributed parameter n/w

Note:- The kirchoff's laws are only applicable to circuit with lumped elements.

* Normally, we will consider networks whose elements are linear, time invariant and lumped.

Electric charge and current:-

The basic unit of charge is the charge of an electron.

The practical unit of charge is coulomb.

The charge of a particle or body may be either positive or negative.

The force of a attraction or repulsion between two charges seperated by a distance d is given by

$$F = \frac{q_1 q_2}{4\pi\epsilon d^2}$$

where the force F is in newtons, q_1 and q_2 are the point charges in coulombs and ϵ is the premitivity.

The phenomenon of transfer of charge from one point to another constitute flow of electric current.

This is mathematically expressed as

$$i = \frac{dq}{dt} \text{ coulombs/sec or Amps.}$$

Resistance parameter:-

Resistance is the property of the circuit element which opposes the flow of electric current through the material.

* The units of Resistance (R) being (Ω) ohm.
* and it is obtained from ohm's law.

ohms law:- ohms law states that, at constant temperature the current flowing through the conductor is directly propotional to the applied voltage and inversely propotional to the resistance of that conductor.

Mathematically $I = \frac{V}{R}$ (or) $V = IR$

where V = Applied voltage in volts

I = Resulting current in amperes

R = Resistance in ohms

* The reciprocal of resistance is called conductance G. and the units of conductance is Mhos or Siemens.

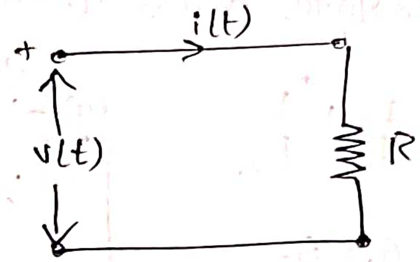
The resistor shown in bellowe figure defines a linear proportionality relationship between $v(t)$ and $i(t)$,

The volt-amp relationship is

$$v(t) = R\,i(t)$$

$$i(t) = \frac{1}{R} v(t)$$

$$= G\,v(t)$$



if R is a time variant resistance $R(t)$ then

$$v(t) = R(t) \cdot i(t)$$

The instantaneous power

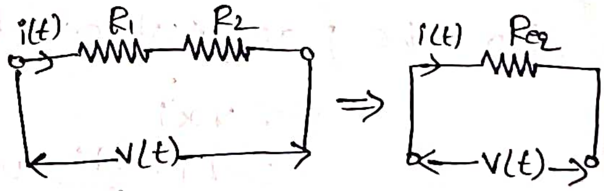
$$P(t) = v(t)\,i(t) = i^2(t)\,R$$

$$= \frac{V^2(t)}{R}$$

$$\text{Energy} = w = \int P(t)\,dt$$

Resistance in series and Parallel:-

If two resistances R_1 and R_2 are connected in series (They carry the same current), The equivalent resistance is calculated as



$$v(t) = v_1(t) + V_2(t)$$

$$= R_1 i(t) + R_2 i(t)$$

$$= (R_1 + R_2)\,i(t)$$

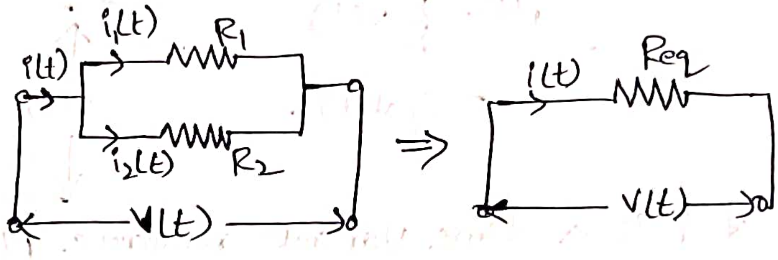
$$R_{eq} = R_1 + R_2$$

This can be extended to any number of resistances in series as $R_{eq} = R_1 + R_2 + R_3 + \cdots + R_n$.

If two resistances are connected in parallel (they have the same voltage across them) the equivalent resistance is

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

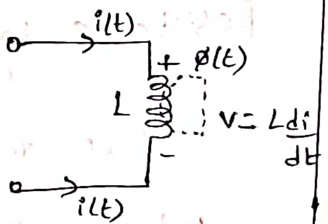
$$G_{eq} = G_1 + G_2$$



This can be extended to any number of resistances in parallel as

$$G_{eq} = G_1 + G_2 + \cdots + G_n$$

Inductance parameter:- Inductance is the property of a material by virtue of which it opposes of any change of magnitude or direction of electric current passing through the conductor.



* The units of inductance being "Henry" (L).

voltage across the coil $V = L\frac{di}{dt}$

Also, the power absorbed by the inductor is given by

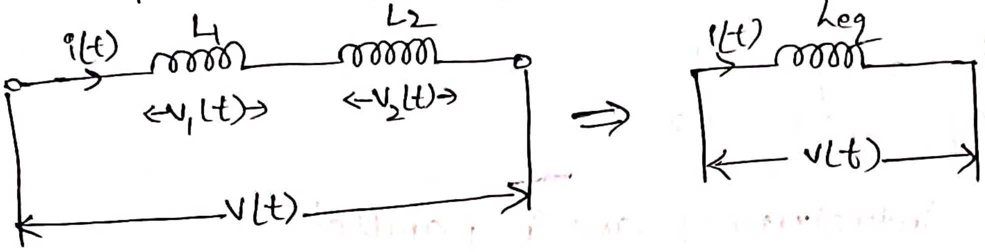
$$P = V \times i$$
$$= Li \cdot \frac{di}{dt} \text{ watts}$$

Energy absorbed by the inductor will be given by

$$W = \int_0^t P\,dt = \int_0^t Li \cdot \frac{di}{dt}\,dt = \frac{1}{2}Li^2$$

Inductance in series :-

If two Inductors L_1 and L_2 are connected in series then the equivalent inductance is calculated as



$$v(t) = v_1(t) + v_2(t)$$

$$= L_1 \frac{di}{dt} + L_2 \frac{di}{dt} = (L_1 + L_2)\frac{di}{dt} = L_{eq} \frac{di}{dt}$$

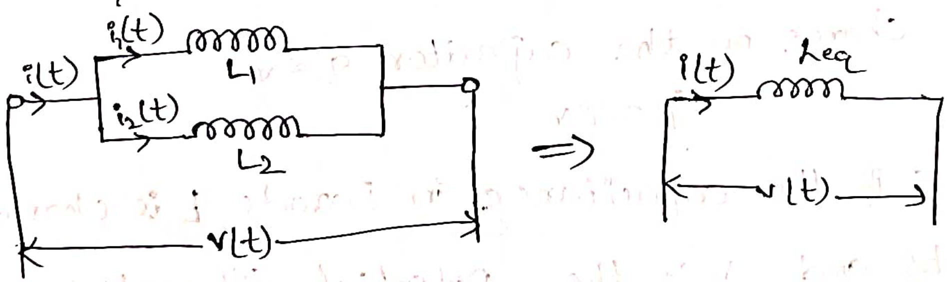
comparing the equation $L_{eq} = L_1 + L_2$

if there are n inductances in series, then the equivalent inductance

$$L_{eq} = L_1 + L_2 + L_3 + \cdots + L_n$$

Inductance in Parallel:-

If two Inductors L_1 and L_2 are connected in parallel then the equivalent inductance is calculated as



$$i(t) = i_1(t) + i_2(t)$$

$$i(t) = \frac{1}{L_1}\int v\,dt + \frac{1}{L_2}\int v\,dt = \left(\frac{1}{L_1} + \frac{1}{L_2}\right)\int v\,dt$$

From the equivalent circuit

$$i = \frac{1}{L_{eq}} \int v\,dt$$

comparing the equations for $i(t)$

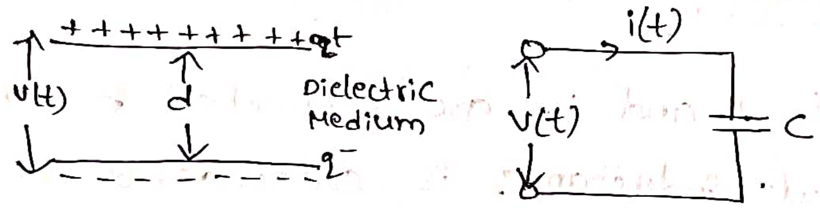
$$\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2}.$$

If n inductances are in parallel

$$\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2} + \cdots + \frac{1}{L_n}$$

Capacitance parameter:-

* A capacitor consists of two metallic surfaces or conducting surfaces seperated by a dielectric medium.
* It is a circuit element which is capable of storing electrical energy in its electric field.



Charge on the capacitor $q \propto v$

$$q = Cv$$

where C is the capacitance in Farads, q is charge in coulombs and v is the potential differential across the capacitor in volts.

The current flowing in the circuit is rate of flow of charge

$$i = \frac{dq}{dt} = \frac{C\,d(v)}{dt}$$

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

The power $p(t)$ in a capacitive circuit is $v(t)\,i(t)$

$$p(t) = v(t)\,i(t)$$

$$= v(t)\,C\frac{dv}{dt}$$

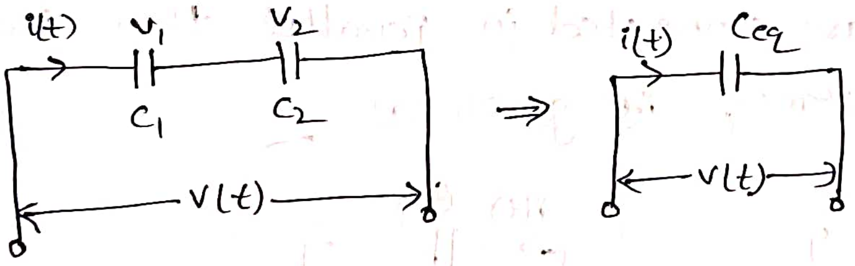
The energy w is given by

$$w = \int p\,dt = \int v i\,dt = C\int v\,dt$$

$$= \frac{1}{2}Cv^2 \text{ Joules}$$

Capacitors in series:-

Two capacitors are connected in series then the equivalent capacitance is given as



The current through the capacitors is same. Let the voltages across the capacitors C_1 and C_2 be V_1 and V_2 respectively as shown above.

$$v(t) = v_1(t) + v_2(t)$$

$$v(t) = \frac{1}{C_1}\int i\,dt + \frac{1}{C_2}\int i\,dt$$

$$v(t) = \left[\frac{1}{C_1} + \frac{1}{C_2}\right]\int i\,dt$$

From the equivalent capacitance circuit

$$v(t) = \frac{1}{C_{eq}}\int i\,dt$$

Comparing the equations for $v(t)$, we get

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$

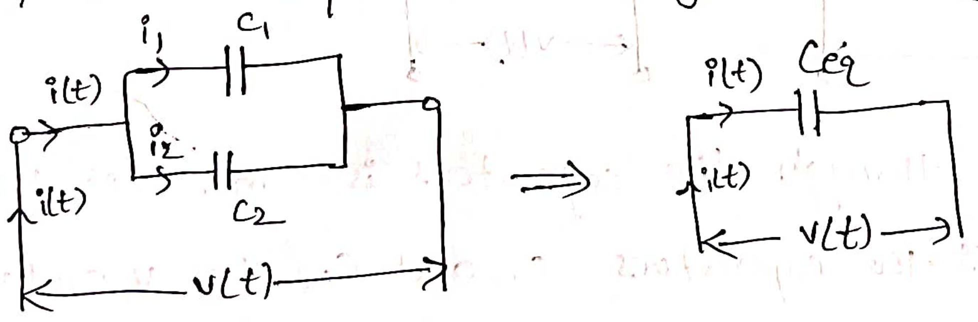
$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

If n capacitances are connected in series

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots + \frac{1}{C_n}$$

Capacitance in parallel:-

Two capacitors are connected in parallel then the equivalent capacitance is given as —



The voltage across the capacitors is same. let the current through the capacitors c_1 and C_2 be i_1 and i_2 respectively as shown above.

$$i(t) = i_1(t) + i_2(t)$$

$$i(t) = C_1 \frac{dv}{dt} + C_2 \frac{dv}{dt}$$

$$i(t) = (C_1 + C_2) \frac{dv}{dt}$$

from the equivalent circuit

$$i(t) = C_{eq} \cdot \frac{dv}{dt}$$

Comparing the equations for $i(t)$, we get

$$C_{eq} = C_1 + C_2$$

If n capacitors are connected in parallel then

$$\frac{1}{C_{eq}} = C_1 + C_2 + \cdots + C_n$$

volt-amp Relationship of circuit elements:-

Parameter	Basic Relation	Volt-current Relationship	Energy
1. Resistance (R) ohms	$v(t) = R \cdot i(t)$	$v(t) = R \cdot i(t)$ $i(t) = \frac{1}{R} v(t)$	$\int vi\,dt$ is dissipated as heat
2. Inductance (L) Henry	$\psi = Li$	$v(t) = L \frac{di}{dt}$ $i(t) = \frac{1}{L} \int_{-\infty}^{t} v\,dt$	$\frac{1}{2} Li^2$ stored in magnetic field
3. capacitance (C) Farad	$q = cv$	$v(t) = \frac{1}{C} \int_{-\infty}^{t} i\,dt$ $i(t) = C \frac{dv}{dt}$	$\frac{1}{2} cv^2$ stored in electric field

Energy Sources :-

Energy sources are devices which supplies electric energy to a circuit.

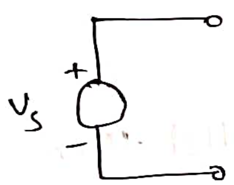
There are two types of energy sources

(i) voltage source

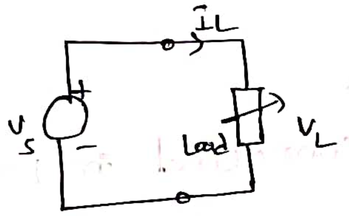
(ii) current sources

Ideal voltage source:- An ideal voltage source is defined as the energy source which delivers a constant voltage to the load connected across its terminals.

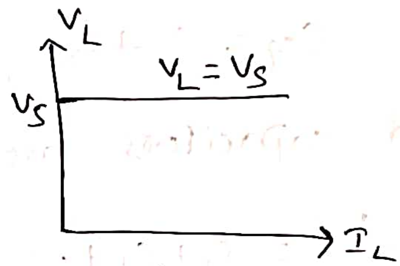
The symbol of ideal voltage source and its V-I characteristics are shown bellow



symbol

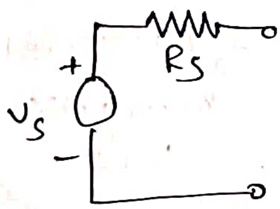


circuit

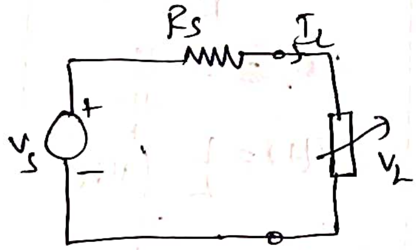


V-I characteristics

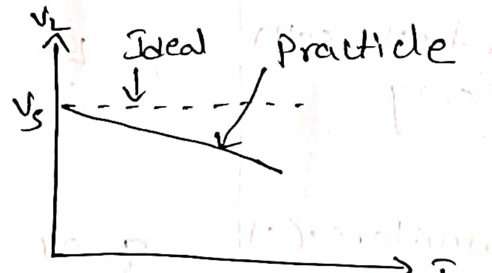
Practical or Non-Ideal voltage source:- Ideal voltage source does not have internal resistance. But practically, every voltage source has small internal resistance in series with voltage source and represented by R_s as shown bellow.



symbol



circuit

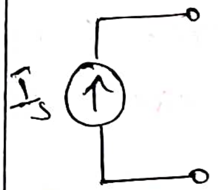


V-I-characteristics

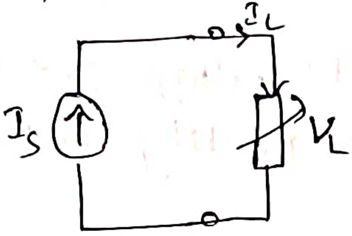
Because of internal resistance R_s, the voltage across the load terminals decrease slightly with increase in load current.

Ideal current source:- An ideal current source is defined as the energy source which delivers a constant current to the load connected to its terminals, irrespective of the load voltage variations (V_L).

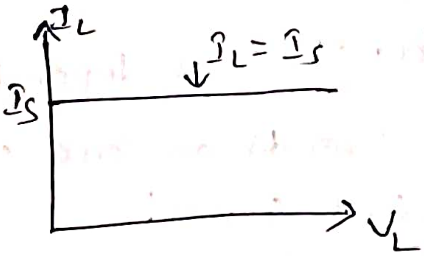
The symbol, circuit and its V-I characteristics are shown bellow



symbol

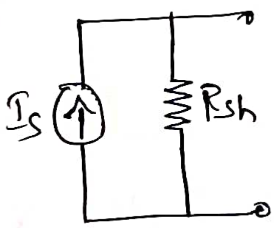


circuit

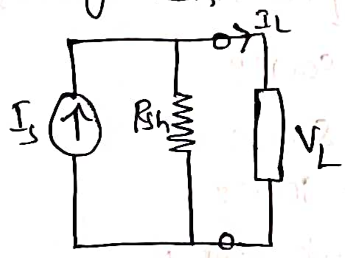


V-I characteristics

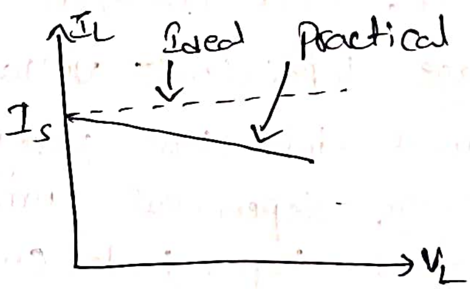
Practical current source:- An ideal current source does not have internal resistance, but practically, every current source has high internal resistance, in parallel with current source and is represented by R_{sh} as shown bellow.



symbol



circuit

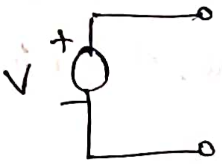


V-I characteristics

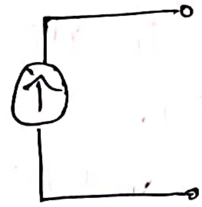
Because of internal resistance R_{sh}, the current through its terminal decrease slightly with increase in load voltage.

Independent sources:- The voltage and current source, which do not depend on any other quantity of the circuit is called "independent sources."

voltage source

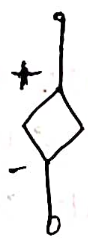


current source



Dependent sources:- A dependent voltage and current source is one which depends on some other quantity in the circuit is called "dependent sources".

Dependent voltage source

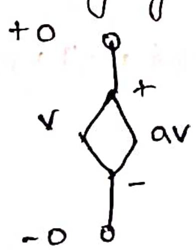


Dependent current source

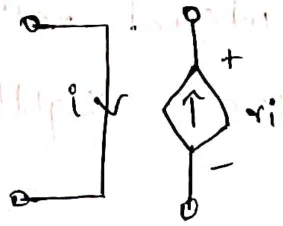
There are four possible dependent sources:

1. voltage dependent voltage source
2. current dependent voltage source
3. voltage dependent current source
4. current dependent current source

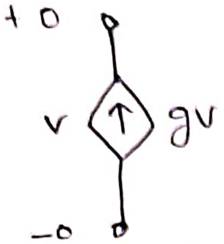
such sources can also be either constant sources or time varying sources.



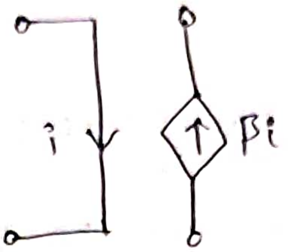
voltage dependent voltage source



current dependent voltage source.



Voltage dependent current source



current dependent current source

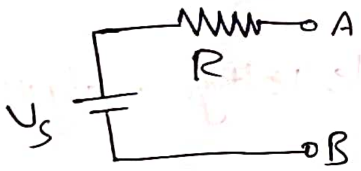
The constants of proportionality are written as a, r, g, β in which a and β has no units, r has units of ohm and g units of Mhos

Source Transformation

Conversion of voltage source to current source:-

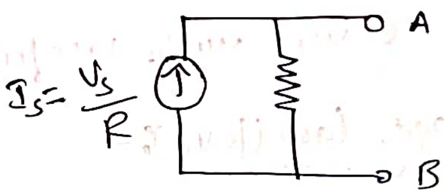
Any voltage source V_s in series with a resistance 'R' can be represented by a current source I_s in parallel with the resistance R as shown bellow.

and the magnetude of the current source, $I_s = \frac{V_s}{R}$



voltage source

$\Rightarrow$

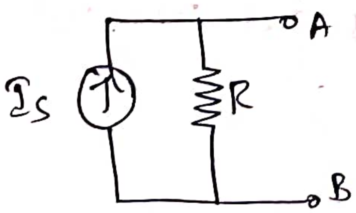


Equivalent Current Source

Conversion of current source to voltage source:-

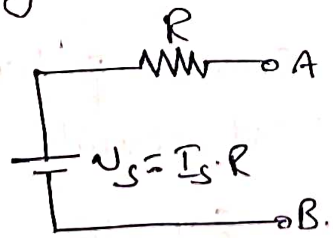
Any current source I_s in parallel with a resistance 'R' can be represented by a voltage source in series with resistance 'R' as shown and the Magnetude of the voltage source is

$V_s = I_s R$



current source

$\Rightarrow$



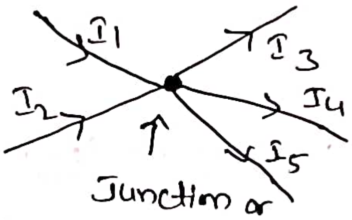
Equivalent Voltage Source

Kirchoff's Laws:-

Kirchoff's Current Law (KCL):-

In an electric network, the sum of the currents flowing towards a node is equal to the sum of the current flowing away from the node.

Mathematically ΣI at a Junction $= 0$



$$\Sigma \text{ current entering} = \Sigma \text{ currents leaving}$$

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

(or) $$I_1 + I_2 - I_3 - I_4 - I_5 = 0$$

Note:- KCL is very much useful in node voltage analysis.

Kirchoff's Voltage law (KVL):-

The sum of the potential rises around any closed circuit is equal to the sum of the potential drops in that circuit.

Mathematically, Σ potential rises $= \Sigma$ potential drops

$$\Sigma \text{ e.m.fs} = \Sigma \text{ IR drops}$$

(or)

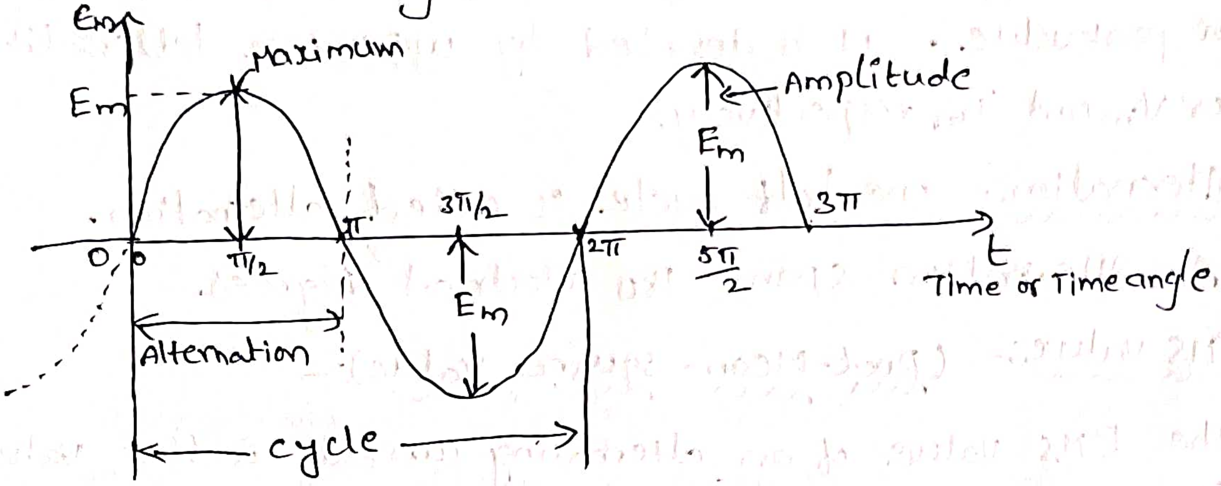
The algebraic sum of potential rises and potential drops around a closed circuit is zero.

Mathematically, $\Sigma V = 0$

Note:- KVL is very much useful in mesh current analysis.

Definitions of terms associated with periodic functions:-

Wave form:- The waveform is a graphical plot of the variation of the alternating quantity with respect to time or associated time angle.



Cycle:- one complete set of positive and negative values of an alternating quantity is known as a cycle.

Time Period:- The time taken in seconds to complete one cycle of an alternating quantity is called time period or period.

It is generally represented by T.

Angular velocity:-(ω):- It is the ~~unit~~ angle traced out per unit time. It is measured in degrees/sec or radians/sec.

$$\text{Angular velocity} = \omega = \frac{360}{T} = \frac{2\pi}{T}$$

$$\omega = 2\pi f \text{ rad/sec} \left(\because f = \frac{1}{T}\right)$$

frequency:- The number of cycles made per second by an alternating quantity is called frequency.

It is denoted by 'f'.

and is measured in cycles/sec or Hz.

The frequency of an alternating quantity is the reciprocal of time period i.e $f = 1/T$.

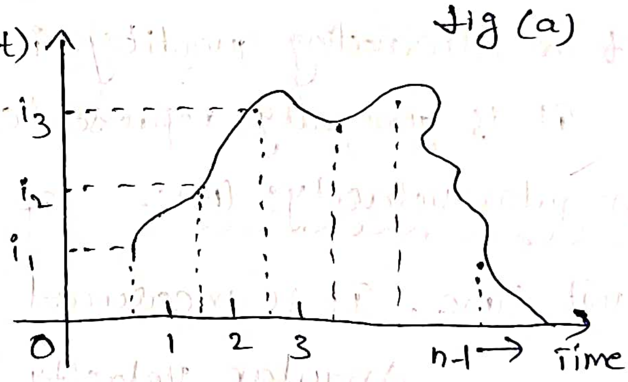
Amplitude or peak value:- The maximum value (i.e +ve or -ve) attained by an alternating quantity is called its amplitude or peak value. It is denoted by upper case letters like E_m or V_m and I_m respectively.

Alternation:- one half cycle is called alternation. An Alternation spans 180 electrical degrees.

RMS value:- (Root-Mean-Square Value):-

The RMS value of an alternating current is that value of the steady (d.c) current which when flowing through a given circuit for a given time produces the same heating effect as produced by the given alternating current flowing through the same circuit for the same time.

fig (a)



The given alternating current wave is divided into n equal time intervals.

Let the mean value of the current during the intervals be $i_1, i_2, i_3, ----, i_n$.

Let this current allowed through a circuit having resistance R.

The average power dissipated in the resistor in the interval is

$$P = \frac{(i_1^2 R + i_2^2 R + ---- + i_n^2 R)}{n}$$

If a direct current of I amps flows through the same resistance R for the same time, the power dissipated is I^2R.

If both the currents produce the same amount of heat, then

$$I^2R = \frac{(i_1^2R + i_2^2R + \cdots + i_n^2R)}{n}$$

$$I^2R = \frac{R(i_1^2 + i_2^2 + \cdots + i_n^2)}{n}$$

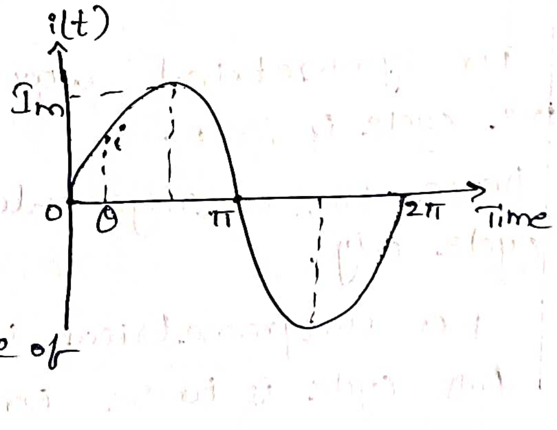
The steady current which produces the same amount of heating as the given alternating current is called RMS value and hence

$$I_{RMS} = I = \sqrt{\frac{i_1^2 + i_2^2 + \cdots + i_n^2}{n}}$$

The analytical expression for RMS value of a periodic function y(t) of a time period T is

$$Y_{RMS} = \sqrt{\frac{1}{T}\int_0^T y(t)^2 dt}$$

RMS value of sinusoidal current:-



Let the instantaneous value of the sinusoidal quantity is

$$i = I_m \sin\theta$$

From the figure the RMS value of current is

$$I_{RMS} = \sqrt{\frac{1}{T}\int_0^T i^2 dt}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{2\pi} I_m^2 \sin^2\theta \, d\theta}$$

$$= I_m \sqrt{\frac{I_m^2}{4\pi}\int_0^{2\pi}(1-\cos 2\theta)d\theta}$$

$$= I_m \sqrt{\frac{1}{4\pi}(2\pi - 0)}$$

$$= \frac{I_m}{\sqrt{2}} = 0.707 I_m$$

$$\boxed{\text{RMS value} = 0.707 \text{ max value}}$$

Average value:-

The average value of an alternating current is defined as that value of the steady current which transfers the same amount of charge across any circuit as is transferred by the given a.c current in the same circuit for the same time.

For the alternating current shown in fig (a). the average value is

$$I_{av} = \frac{(i_1 + i_2 + \cdots + i_n)}{n}$$

For symmetrical waveforms the average value over one cycle is zero.

Hence the average value is determined over one half cycle only.

For unsymmetrical waveform, to determine average value full cycle is to be considered.

The analytical expression for average value is

$$Y_{av} = \frac{1}{T}\int_0^T y(t)\,dt$$

Average value of a sinusoidal quantity:-

since sinusoidal variation is symmetrical, the Average value is calculated over one half cycle only.

The instantaneous value of the sinusoidal quantity

$$i(t) = I_m \sin\theta$$

The time period is T sec. or 2π radians.

Hence the duration of one half cycle is $\frac{T}{2}$ sec or π radians.

Sum of instantaneous value over one half cycle is

$$\int_0^{T/2} i(t)\,dt = \int_0^{\pi} I_m \sin\theta\, d\theta = 2 \times I_m$$

Mean value or average value of the sinusoidal quantity is

$$\frac{2 \times I_m}{\pi} = \frac{I_m}{1.57} = 0.636\, I_m$$

Form Factor:- It is defined as the ratio of RMS value to average value of an alternating quantity.

$$\text{Form factor} = \frac{\text{RMS value}}{\text{Average value}} = \frac{Y_{RMS}}{Y_{av}}$$

For sinusoidal alternating quantity

$$\text{Form factor} = \frac{\pi}{2\sqrt{2}} = 1.11$$

Peak factor:- It is defined as the ratio of peak value to RMS value for any alternating quantity

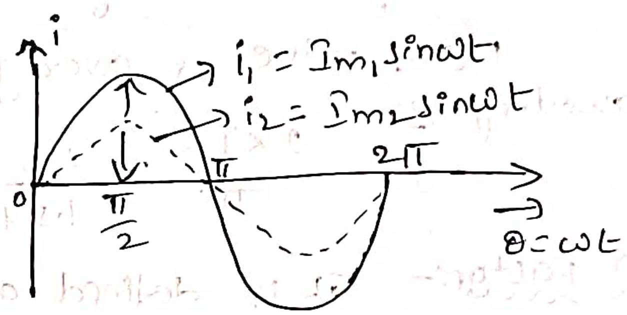
$$\text{Peak factor} = \frac{\text{Peak value}}{\text{RMS value}}$$

For a sinusoidal alternating quantity peak factor is 1.414.

phase:- The angle turned by an alternating quantity (i.e voltage or current) from a given instant is known as phase.

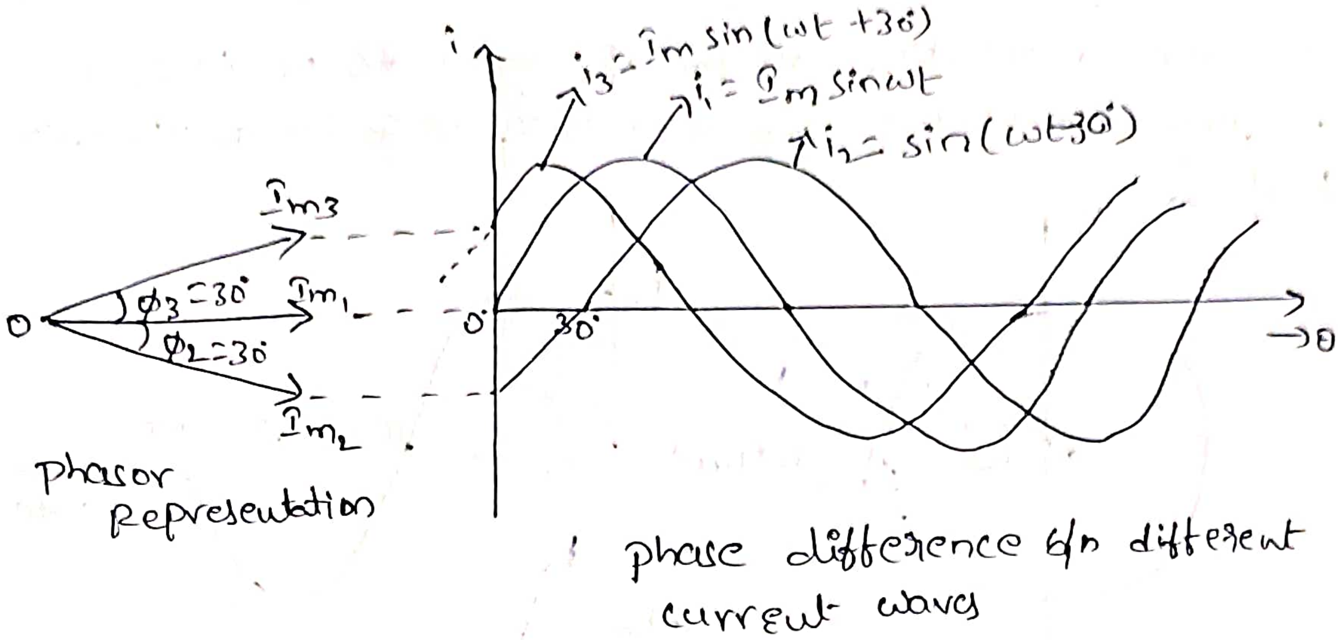
Inphase or Reference phasors:- when two alternating quantities (current or voltage) attain their maximum and zero value at the same time simultaneously, then these quantities are said to be inphase.

Phasor Representation.



Represents two alternating currents are in phase.

Phase Difference:- It is the angular displacement between two alternating quantities.



Phase angle (ϕ):- The angle between zero points of two alternating quantities is called angle of phase difference or phase angle ϕ. It is generally measured in degrees or radians.

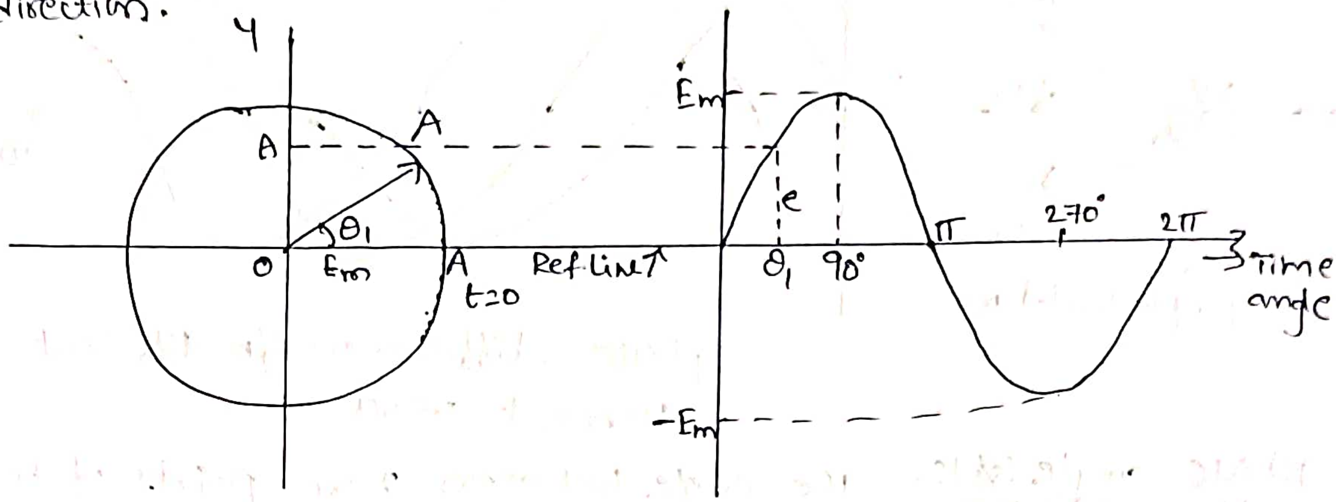
Leading Alternating quantity:- A leading alternating quantity (voltage or current) is one which attain its maximum or zero value earlier as compared to the other quantity.

Lagging Alternating quantity:- A lagging alternating quantity (voltage or current) is one which attains its maximum or zero value later than the other quantity.

phasor representation:-

Let us consider a sinusoidal alternating quantity of maximum value E_m and angular frequency ω. whose instantaneous value is $e = E_m \sin\omega t$.

* Consider a rotating vector of magnitude OA ($= E_m$) rotating at a constant angular velocity ω in the anticlockwise direction.



* At t=0, the phasor OA is along the reference line and rotates with angular velocity ω in the c.c.w direction.
* At $t = t_1$ the instantaneous value is $E_m \sin\theta_1$,
* which is given by the projection of the phasor OA on to the vertical axis.
* Hence the projection of the rotating vector at any instant along the vertical axis gives the instantaneous value of the alternating quantity.
* The phasor completes one revolution for every cycle.

Addition and subtraction of alternating quantities:-

Consider two phasor quantities as

$$v_1 = a_1 + jb_1 \text{ and } v_2 = a_2 - jb_2$$

(i) Addition:-

Resulting phasor $v = v_1 + v_2$

$$v = (a_1 + jb_1) + (a_2 - jb_2)$$
$$= (a_1 + a_2) + j(b_1 - b_2)$$

Magnetude of resultant phasor,

$$v = \sqrt{(a_1+a_2)^2 + (b_1-b_2)^2}$$

It's angle with reference to x-axis,

$$\theta = \tan^{-1}\left[\frac{(b_1-b_2)}{(a_1+a_2)}\right]$$

Subtraction:-

Resultant phasor, $v = v_1 - v_2$

$$v = (a_1 + jb_1) - (a_2 - jb_2)$$
$$= (a_1 - a_2) + j(b_1 + b_2)$$

Magnitude of resultant phasor, $v = \sqrt{(a_1-a_2)^2 + (b_1+b_2)^2}$

It's angle with reference x-axis is, $\theta = \tan^{-1}\left[\frac{(b_1+b_2)}{(a_1-a_2)}\right]$

Duality of a network:-

Two electrical networks are called duals of one another, if mesh equations of one have the same mathematical form as the nodal equations of the form.

* The advantage of duality is that there is no need to analyse both types of circuit.
* since the solution of one automatically gives the solution of the other with a suitable change of symbols for the physical quantities.

Table bellow gives the corresponding quantities for dual networks.

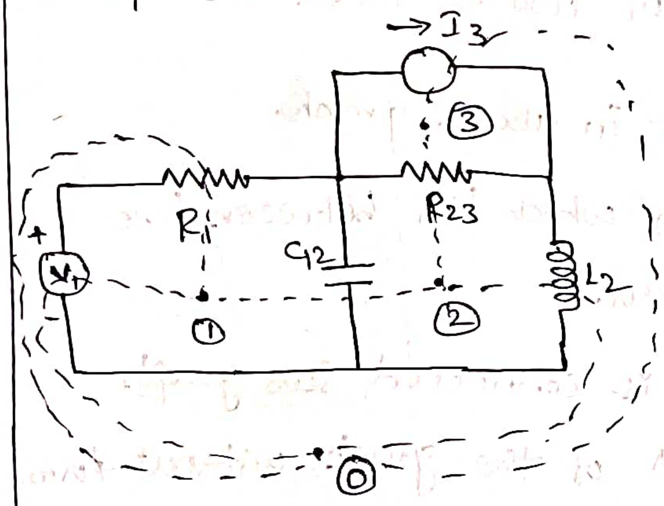
Loop Basis	Node Basis
voltage	current
Resistance	Conductance
Inductance	capacitance
Reactance	Susceptance
Impedence	Admitance
KCL	KVL
voltage source	Current source
Mesh Analysis	Node Analysis
TheVenin's Theorem	Norton's Theorem
Short circuit	open circuit
Series circuit	Parallel circuit

Procedure to obtained a dual Network:-

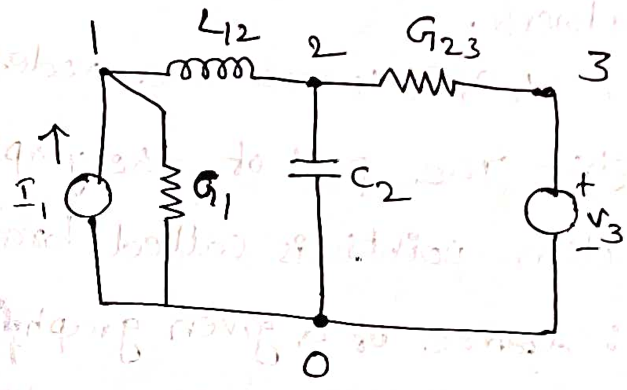
1. place a dot in each independent loop of the network. These dots correspond to independent nodes in the dual network.
2. place a dot outside the network. This dot corresponds to the reference node in the dual Network.
3. connect all internal dots in the neighbouring loops by dashed lines cutting the common branches. These branches that are cut by dashed lines will form the branches connecting the corresponding independent nodes in the dualnetwork.

4. Join all internal dots to the external dot by dashed lines cutting all external branches.
Duals of these branches cut by dashed lines will form the branches connecting the independent nodes and the reference Node.

5. Convention for sources in the dual Network:
(i) A clockwise current source in a loop corresponds to a voltage source with a positive polarity at the dual independent Node.
(ii) A voltage rise in the direction of a clockwise loop current corresponds to a current towards the dual independent node.

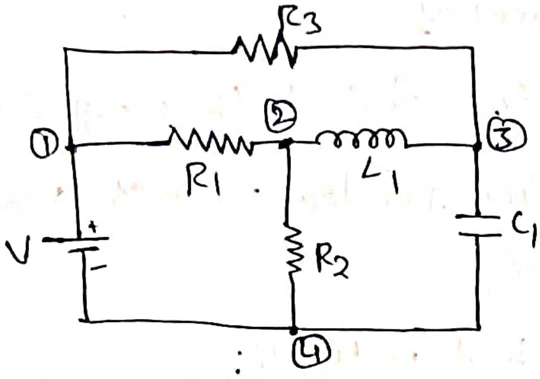


original Network

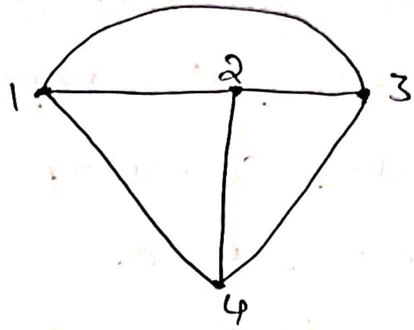


Dual Network.

Network topology:-



Network



oriented graph

No of elements in the network (e) = 6

no of nodes in the network $n_t = 4$

Edges:- The line segments in the graph replacing the elements in the network are called Edges of the graph.

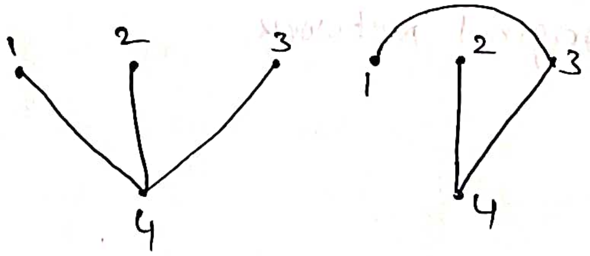
Node:- Node is the junction of two or more elements in a network.

ex:- 1, 2, 3, 4 are the Nodes in above graph.

Branch:- The part of the graph which lies between two junction points is called branch.

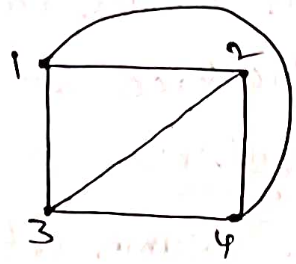
Tree:- A Tree of a given graph is connected sub graph which contains all the nodes of the graph without forming closed loop.

ex:-



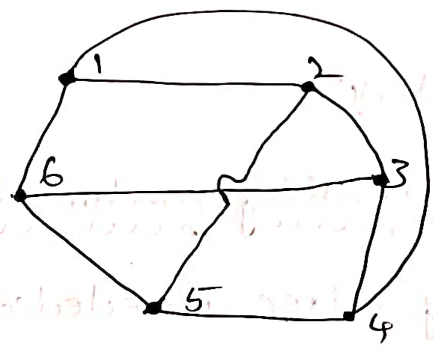
Planar Graph:- A graph is said to be planar if the graph can be drawn without cross over of edges is called planar graph.

Ex:-



Non-planar graph:- A graph is said to be non-planar if the graph can be drawn with cross the edges is known as non-planar graph

Ex:-



Formation of incidence Matrix [Ai]:-

* This matrix shows which branch is incident to which node.
* Each row of the Matrix being representing the corresponding node of the branch,
* Each column corresponds to a branch.
* If a graph does have N nodes and B branches, the complete incidence matrix [Ai] is N X B rectangular Matrix whose elements (a_{ij}) are defined by

(i) If branch j is incident at node i and is oriented away from the node, $a_{ij} = 1$

In other words, when $a_{ij} = 1$, branch j leavs away node i.

(ii) If branch j is incident at node i and is oriented towards node i, $a_{ij} = -1$
In other words branch j enters node i.

(iii) If branch j is not incidence at node i, $a_{ij} = 0$

Properties of Incidence Matrix:-

(i) Algebraic sum of the column entries of an incidence matrix is zero.

(ii) Determinant of the incidence matrix of a closed loop is zero.

Tie-set Matrix:-

Procedure of obtaining fundamental Tie-set Matrix:-

1. Arbitrarily a tree is selected in the graph.
2. Form fundamental loops with each link in the graph for the entire tree.
3. Assume directions of loop currents oriented in the same direction as that of the link.
4. Form fundamental tie-set Matrix $[b_{ij}]$ where

$b_{ij} = 1$, when branch b_j is in the fundamental loop i and their reference directions are oriented same.

$b_{ij} = -1$, when branch b_j is in the fundamental loop i but their reference direction are oriented opposite,

$b_{ij} = 0$, when branch b_j is not in the fundamental loop i.

Cut-set Matrix:-

Procedure of forming fundamental cut-set Matrix:-

1. Arbitrarily a tree is selected in the graph.
2. Form fundamental cut-sets with each twig in the graph for the entire tree.
3. Assume directions of the cut-sets oriented in the same direction of the concerned twig.
4. Form fundamental cut-set Matrix $[Q_{kj}]$

where $Q_{kj} = 1$, when branch b_j has same orientation of the cut-set k.

$Q_{kj} = -1$, when branch b_j has opposite orientation of the cutset k.

$Q_{kj} = 0$, when b_j is not in the cutset k.