network elements may be classified into four groups

(1) Active (or) Passive

(2) Unilateral (or) bilateral

(3) Linear (or) nonlinear

(4) Lumped (or) distributed

(1) Active and Passive:-

→ Energy sources (V & I sources) are active elements, capable of delivering power to some external device. → Passive elements are those which are capable only of receiving power. Inductors & capacitors are capable of storing a finite amount of energy, and return it later to an external element.

(2) Bilateral and Unilateral:-

In the bilateral element, the V/g - I (curr) relation is the same for current flowing in either direction. In contrast, a unilateral element has different relations b/w V/g & current for the two possible directions of current.

Example of unilateral element:- Vacuum diodes, silicon diodes & metal rectifiers.

Bilateral ele → R, L, C

(3) Linear & Nonlinear Elements:-

An element is said to be linear, If its v-i characteristic is at all times a straight line through the origin. $V \propto I$ (or) $V = IR$.

The linear element (or) network is one which satisfies the principle of superposition. i.e the principle of homogeneity and additivity.

→ An element which does not satisfy the above principle is called a non linear element.

(4) Lumped and distributed:-

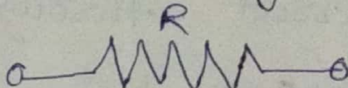
Lumped elements are those elements which are very small in size and in which simultaneous actions takes place for any given cause at the same instant of time. Typical lumped elements are capacitors, resistors, inductors and transformers. Generally the elements are considered as lumped when their size is very small compared to the wave length of the applied signal. Distributed elements on ~~the other hand~~, are those which are not electrically seperable for analytical purposes:

Ex:- a t/m line which has distributed resistance inductance & capacitance along its length may extend for hundreds of miles.

Resistance Parameters:-

When a current flows in a material, the free electrons move through the material and collide with other atoms. these collisions cause the electrons to lose some of their energy. this loss of energy per unit charge is the drop in potential across the material.

→ the property of a material to restrict the flow of electrons is called resistance, denoted by R.

the Symbol for the resistor is 

the unit of resistance is ohm (Ω).

ohm:- It is defined as the resistance offered by the material when a current of one ampere flows b/w terminals with one volt applied across it.

According to ohm's law, $I \propto V$, $I \propto \frac{1}{R}$

$$I = \frac{V}{R} \Rightarrow \boxed{V = IR} \Rightarrow \boxed{V = R\frac{dq}{dt}}$$

$$\text{Power } (P) = Vi = (iR)i = i^2R$$

$$\text{Energy } W = \int_0^t P\,dt = Pt = i^2Rt = \frac{V^2}{R}t$$

Example:- A 10 Ω resistor is connected across a 12V battery. How much current flows through the resistor

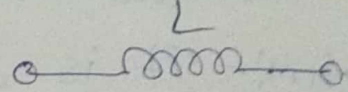
$$V = IR$$

$$I = \frac{V}{R} = \frac{12}{10} = 1.2\,A$$

Inductance Parameter:-

A wire of certain length, when twisted into a coil becomes a basic inductor. If current is made to pass through an inductor, an electromagnetic feild is formed. A change in the magnitude of the current, changes the electromagnetic field.

The unit of inductance is henry, denoted by H. By definition, the inductance is one henry when current through the coil. changing at the rate of one ampere per second, induced one volt across the coil. the Symbol for inductance is



$$v = L\frac{di}{dt} \Rightarrow di = \frac{1}{L}v\,dt$$

$$\int_0^t di = \frac{1}{L}\int_0^t v\,dt \Rightarrow i(t) - i(0) = \frac{1}{L}\int_0^t v\,dt$$

$$\boxed{i(t) = \frac{1}{L}\int_0^t v\,dt + i(0)}$$

The current in an inductor is dependent upon the integral of the v/g across its terminals and the initial current in the coil, i(0)

$$P = vi = L\,i\frac{di}{dt} \text{ watts}$$

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

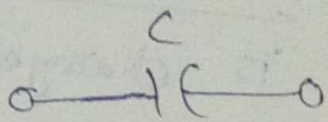
Example:- the current in a 2H inductor varies at a rate of 2 A/s. Find the v/g across the inductor and the energy stored in the magnetic field after 2S.

Sol:-

$$v = L\frac{di}{dt} = 2\times 4 = 8V \qquad W = \frac{1}{2}Li^2 = \frac{1}{2}\times 2\times(4)^2 = 16J.$$

Capacitance Parameter:-

Any two conducting surfaces separated by an insulating medium exhibit the property of a capacitor. The conducting surfaces are called electrodes, and the insulating medium is called dielectric. A capacitor stores energy in the form of an electric field that is established by the opposite charges on the two electrodes. the electric field is represented by lines of force b/w the positive and -ve charges, and is concentrated within the dielectric. the amount of charge per unit voltage that is capacitor can store is its capacitance denoted by C. the unit of capacitance is Farad. By def^n on Farad is the amount of capacitance when one coulomb of charge is stored with one volt across the plates.

The symbol for capacitance is 

A capacitor is said to have greater capacitance if it can store more charge per unit voltage & the capacitance is given by

$$C=\frac{Q}{V} \Rightarrow q=CV \Rightarrow \frac{dq}{dt}=C\frac{dv}{dt} \Rightarrow \boxed{i=C\frac{dv}{dt}}$$

$$dv=\frac{1}{C}\,i\,dt$$

$$\int_0^t dv = \frac{1}{C}\int_0^t i\,dt$$

$$v(t) - V(0) = \frac{1}{C}\int_0^t i\,dt$$

$$\boxed{V(t) = \frac{1}{C}\int_0^t i\,dt + V(0)}$$

the voltage in a capacitor is dependent upon the integral of the current through it. and initial voltage across it.

Power $P = Vi = VC\frac{dV}{dt}$

Energy $W = \int_0^t P\,dt = \int_0^t VC\frac{dV}{dt}\,dt$

$$\boxed{W = \frac{1}{2}CV^2}$$

Example:- A capacitor having a capacitance $2\mu F$ is charges to a voltage of 1000V. Calculate the stored energy in joules

Solⁿ:- $W = \frac{1}{2}CV^2 = \frac{1}{2}\times 2\times 10^{-6}\times(1000)^2$

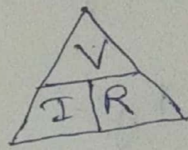
$= 1\,J.$

V-I Relation of RLC element

	Volts(V)	Ampere	Power	Energy
Resistor (R)	$V = IR$	$I = \frac{V}{R}$	$P = I^2R$ (or) $\frac{V^2}{R}$	—
Inductor (L)	$V = L\frac{di}{dt}$	$I = \frac{1}{L}\int_0^t V\,dt$	$P = Li\frac{di}{dt}$	$W = \frac{1}{2}Li^2$
Capacitor (C)	$V = \frac{1}{C}\int_0^t i\,dt$	$i = C\frac{dV}{dt}$	$P = CV\frac{dV}{dt}$	$W = \frac{1}{2}CV^2$

Ohm's law:-

Ohm's law proposed by German physics Scientist George Ohm in 1827. "Ohm's law states that the current passing through a conductor b/w two points is directly proportional to the Voltage applied across it & inversly proportional to the resistance, the temperature remains Constant.



$$I \propto V \;,\; I \propto \frac{1}{R}$$

$$I = \frac{V}{R} \;,\quad V = IR \;,\quad R = \frac{V}{I}$$

Limitations of ohm's law:

→ It is only applicable for linear elements only

→ It is not applicable for unilateral elements such as diode and transistor.

→ It is not applicable for non linear elements such as diode Thyristor, Arc furnace, Arc welding.

V-I Relation of RLC elements:-

	Volts (V)	Amperes (I)	Power	Energy
Resistor (R)	$V = IR$	$I = \frac{V}{R}$	$P = I^2R$ or $\frac{V^2}{R}$	$W = I^2Rt$
Inductor (L)	$V = L\frac{di}{dt}$	$I = \frac{1}{L}\int_0^t v\,dt$	$P = Li\frac{di}{dt}$	$W = \frac{1}{2}Li^2$
Capacitor (C)	$V = \frac{1}{C}\int_0^t i\,dt$	$I = C\frac{dv}{dt}$	$P = CV\frac{dv}{dt}$	$W = \frac{1}{2}CV^2$

Kirchoff's Laws:-

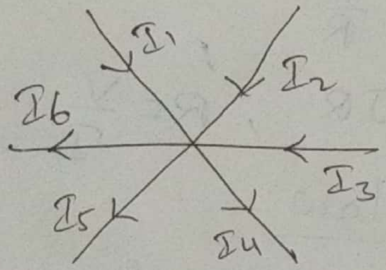
1. Kirchoff's Current law (KCl):-

KCl states that, the sum of currents entering into the node is equal to the sum of currents leaving from that node

(or)

The algebric sum of all the currents at a particular node (or) junction is equal to zero.

Eg:-



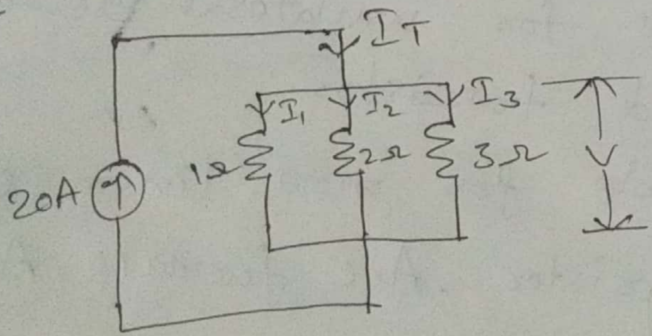
$$I_1+I_2+I_3 = I_4+I_5+I_6$$

(or)

$$I_1+I_2+I_3-I_4-I_5-I_6=0$$

$$\sum i = 0$$

Eg:-



Apply KCl at node $I_T = I_1+I_2+I_3$

$$20 = \frac{V}{1}+\frac{V}{2}+\frac{V}{3}$$

$$20 = V\left[1+\frac{1}{2}+\frac{1}{3}\right]$$

$$V = 10.9V$$

$\therefore I_1 = \frac{10.9}{1} = 10.9A$, $I_2 = \frac{10.9}{2} = 5.4A$, $I_3 = \frac{10.9}{3} = 3.6A$

$\therefore I_1+I_2+I_3 = 20A.$

Current division Rule :-

$$I = \frac{\text{opposite resistance}}{\text{Total resistance}} \times I_T$$

$$I_1 = \frac{2//3}{(2//3)+1} \times 20$$

$$= \frac{\frac{2\times3}{2+3}}{\frac{2\times3}{2+3}+1} \times 20 = 10.9A$$

$$I_2 = \frac{1//3}{(1//3)+2} \times 20 = 5.4A$$

$$I_3 = \frac{1//2}{(1//2)+3} \times 20 = 3.6A.$$

Kirchoff's Voltage law (KVL) :-

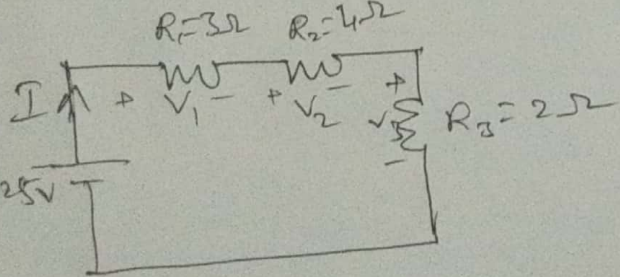
KVL states that algebric sum of all branch voltages around any closed path in a circuit at any instant of time is equal to zero.

(or)

The total voltage is equal to the sum of voltage drops at individual resistance elements.

KVL is also called as conservation of energy.

Eg:-



$$V_T = V_1 + V_2 + V_3$$

$$I_T = \frac{V_T}{R_{eq}} = \frac{25}{9} = 2.77A$$

$V_1 = I R_1 = 2.7 \times 3 = 8.3V$

$V_2 = I R_2 = 2.7 \times 4 = 110.8V = 11.08V$

$V_3 = I R_3 = 2.7 \times 2 = 5.54V$

$\therefore V_1 + V_2 + V_3 = 8.3 + 110.8 + 5.54 = 24.93 \simeq 25V$

Voltage division Rule:-

$$V = \frac{\text{Same Resistance}}{\text{total Resistance}} \times \text{Total Voltage.}$$

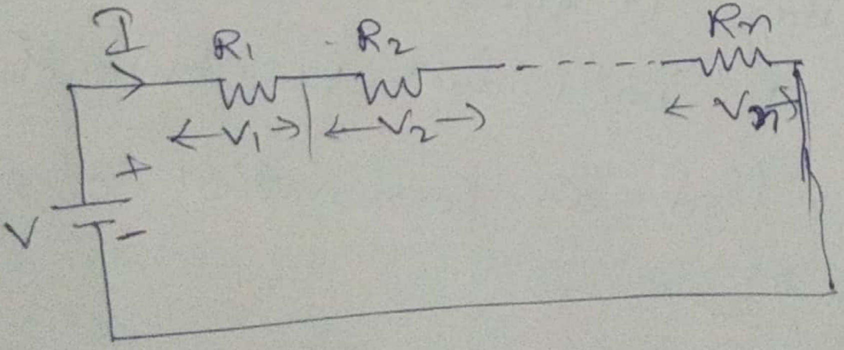
$V_1 = \frac{3}{9} \times 25 = 8.33\,V$

$V_2 = \frac{4}{9} \times 25 = 11.11\,V$

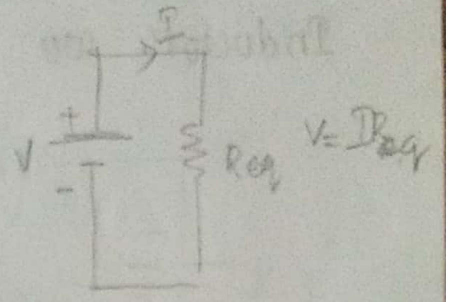
$V_3 = \frac{2}{9} \times 25 = 5.55\,V$

$\therefore V_1 + V_2 + V_3 = 24.99 \simeq 25V = V_T$

Resistors are connected in Series:-



Apply KVL,



$$V_S = V_1 + V_2 + \cdots + V_n$$

WKT,

$$V_S = IR_{eq}$$

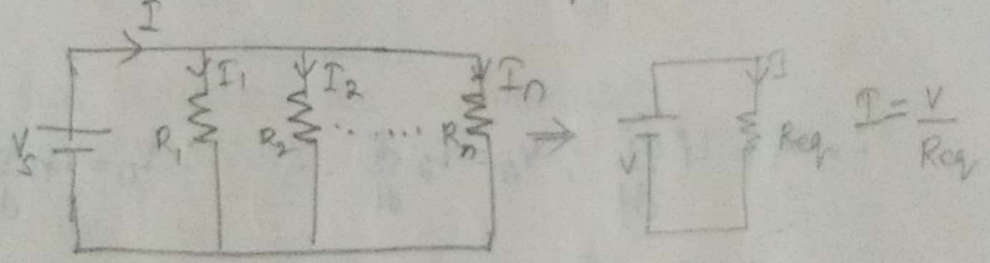
$$\therefore V_1 = IR_1 \; ; \; V_2 = IR_2 \; ; \; V_3 = IR_3 \cdots V_n = IR_n.$$

$$IR_{eq} = IR_1 + IR_2 + \cdots + IR_n$$

$$IR_{eq} = I(R_1 + R_2 + \cdots + R_n)$$

$$R_{eq} = R_1 + R_2 + \cdots R_n.$$

Resistor are connected in parallel:



Apply KCL,

$$I = I_1 + I_2 + \cdots + I_n$$

$$I_1 = \frac{V}{R_1} \; ; \; I_2 = \frac{V}{R_2} \; ; \cdots \; I_n = \frac{V}{R_n}$$

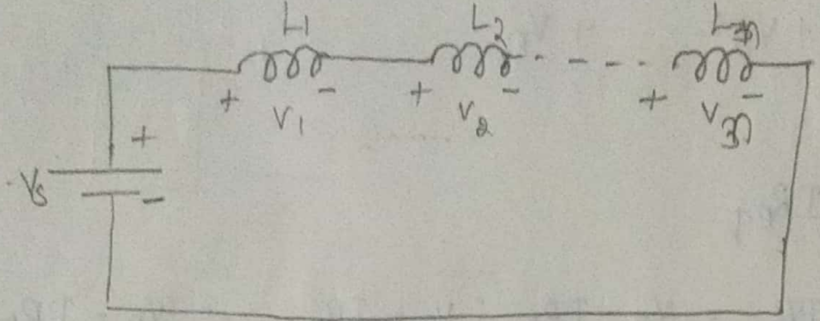
$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \cdots + \frac{V}{R_n}$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots \frac{1}{R_n}.$$

Resistor of two connected in parallel

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

Inductors are connected in series:

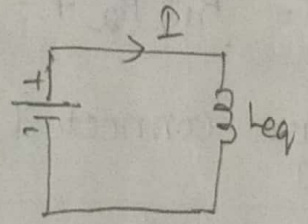


Apply KVL

$$V = V_1 + V_2 + \cdots V_n$$

WKT,

$$V_s = L_{eq}\frac{di}{dt}$$



$$\therefore V_1 = L_1\frac{di}{dt} \; ; \; V_2 = L_2\frac{di}{dt} \cdots\cdots ; V_n = L_n\frac{di}{dt}$$

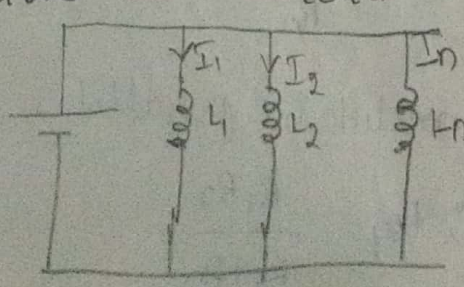
$$i_1 = i_2 = i_3 \cdots = i_n = I$$

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

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

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

Inductors are connected in parallel:

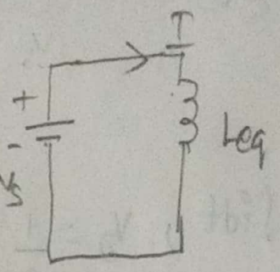


Apply KCL,

$$I = I_1 + I_2 + \cdots + I_n$$

WKT,

$$I = \frac{1}{L_{eq}} \int V_s \, dt$$



$$\frac{1}{L_{eq}} \int V_s \, dt = \frac{1}{L_1} \int V dt + \frac{1}{L_2} \int V dt + \cdots + \frac{1}{L_n} \int V dt$$

$$\frac{1}{L_{eq}} \int V dt = \int V dt \left[\frac{1}{L_1} + \frac{1}{L_2} + \cdots + \frac{1}{L_n} \right]$$

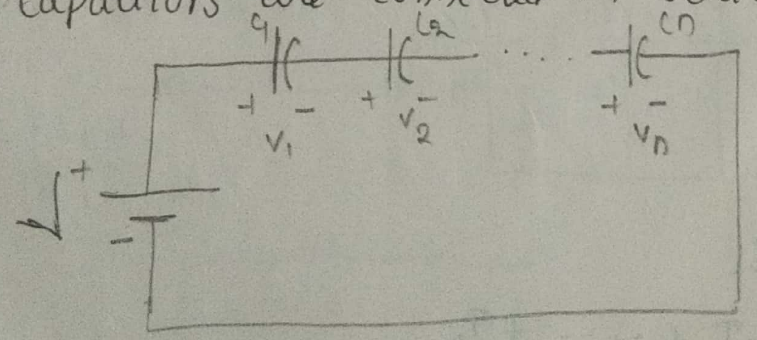
$$\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2} + \cdots + \frac{1}{L_n}$$

If two inductors are in parallel:

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

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

Capacitors are connected in series:

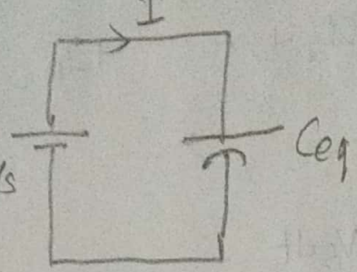


Apply KVL,

$$V_s = V_1 + V_2 + \cdots V_n$$

WKT,

$$V_s = \frac{1}{C_{eq}} \int i\,dt$$



$$\therefore V_1 = \frac{1}{C_1}\int i\,dt, \quad V_2 = \frac{1}{C_2}\int i\,dt \;\cdots\; ; \; V_n = \frac{1}{C_n}\int i\,dt$$

$$\frac{1}{C_{eq}}\int i\,dt = \frac{1}{C_1}\int i\,dt + \frac{1}{C_2}\int i\,dt + \cdots + \frac{1}{C_n}\int i\,dt$$

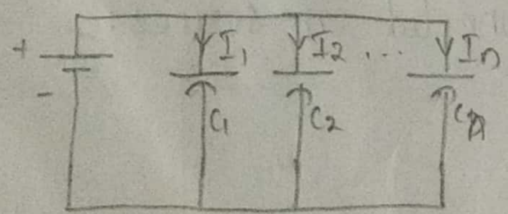
$$\frac{1}{C_{eq}}\int i\,dt = \int i\,dt \left[\frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}\right]$$

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

⇒ If two capacitors are in ~~parallel~~ series is

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

Capacitor are connected in parallel:

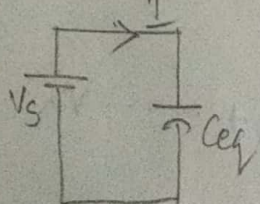


Apply KCL

$$I = I_1 + I_2 + \cdots + I_n$$

WKT,

$$I = C\frac{dV_s}{dt}$$



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

$$C_{eq}\frac{dv}{dt} = \frac{dv}{dt}(C_1 + C_2 + \cdots + C_n)$$

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