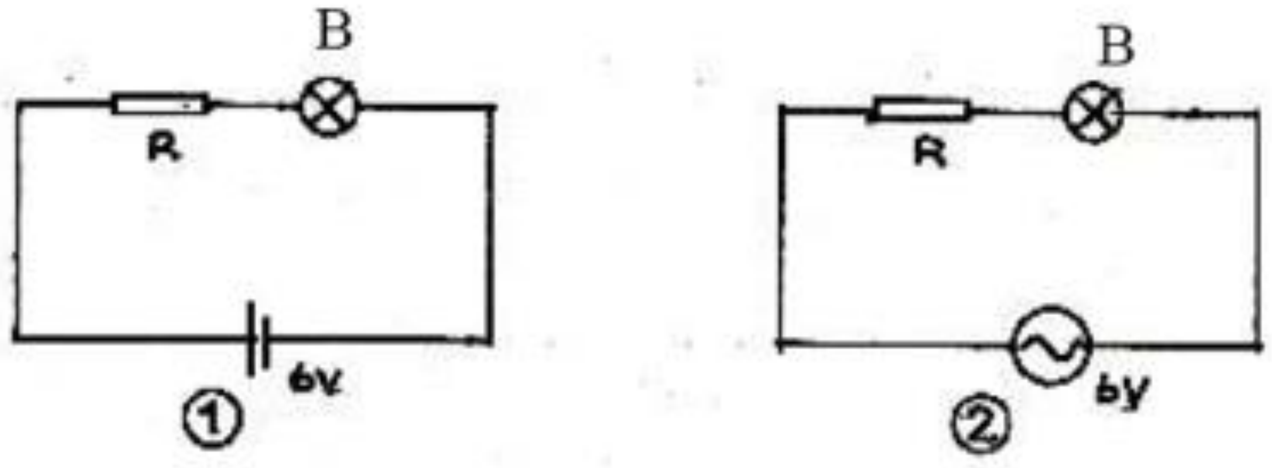
The Effect of Flowing DC/AC through Passive Electrical Devices

By Eng. Susantha Jayasinghe

DC / AC over Resistive Circuits

- Experiment:



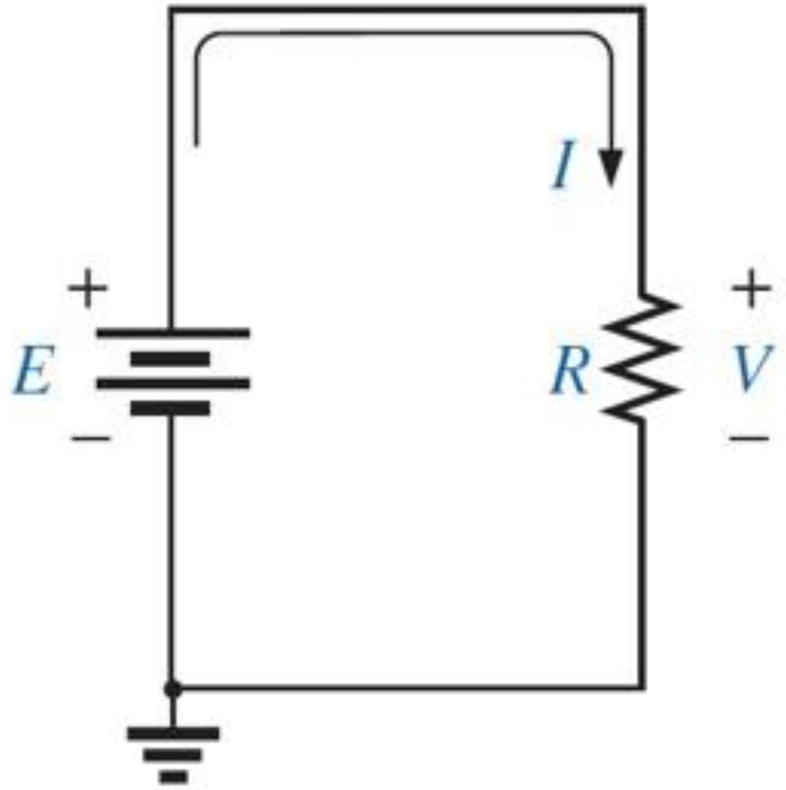
Observations and Conclusions..

- Bulb in both circuits Illuminated .
- Illumination level of the two bulbs equal.
- Therefore it is concluded that both AC and DC equally responds for resistors.

Resisters in DC Circuits….

- DC circuit is a linear circuit. Resistor is a linear device. Therefore following circuit theorems can be applied to solve DC resistive circuits.
- Ohms law
- Kirchhoff’s law
- Thevenin theorem
- Superposition theorem
- Norton’s theorem

Ohm's law for DC circuits…



$$I = \frac{V}{R} \text{ (amps)}$$

$$V = IR \text{ (volts)}$$

$$R = \frac{V}{I} \text{ (ohms)}$$

Kirchhoff’s law for DC circuits…..

Many of the electrical circuits are complex in nature and the computations required to find the unknown quantities in such circuits, using simple ohm’s law and series/parallel combination simplifying methods is not possible. Therefore, in order to simplify these circuits Kirchhoff’s laws are used.

These laws are the fundamental analytical tools that are used to find the solutions of voltages and currents in an electric circuit whether it can be AC or DC. Elements in an electric circuit are connected in numerous possible ways, thus to find the parameters in an electrical circuit these laws are very helpful.

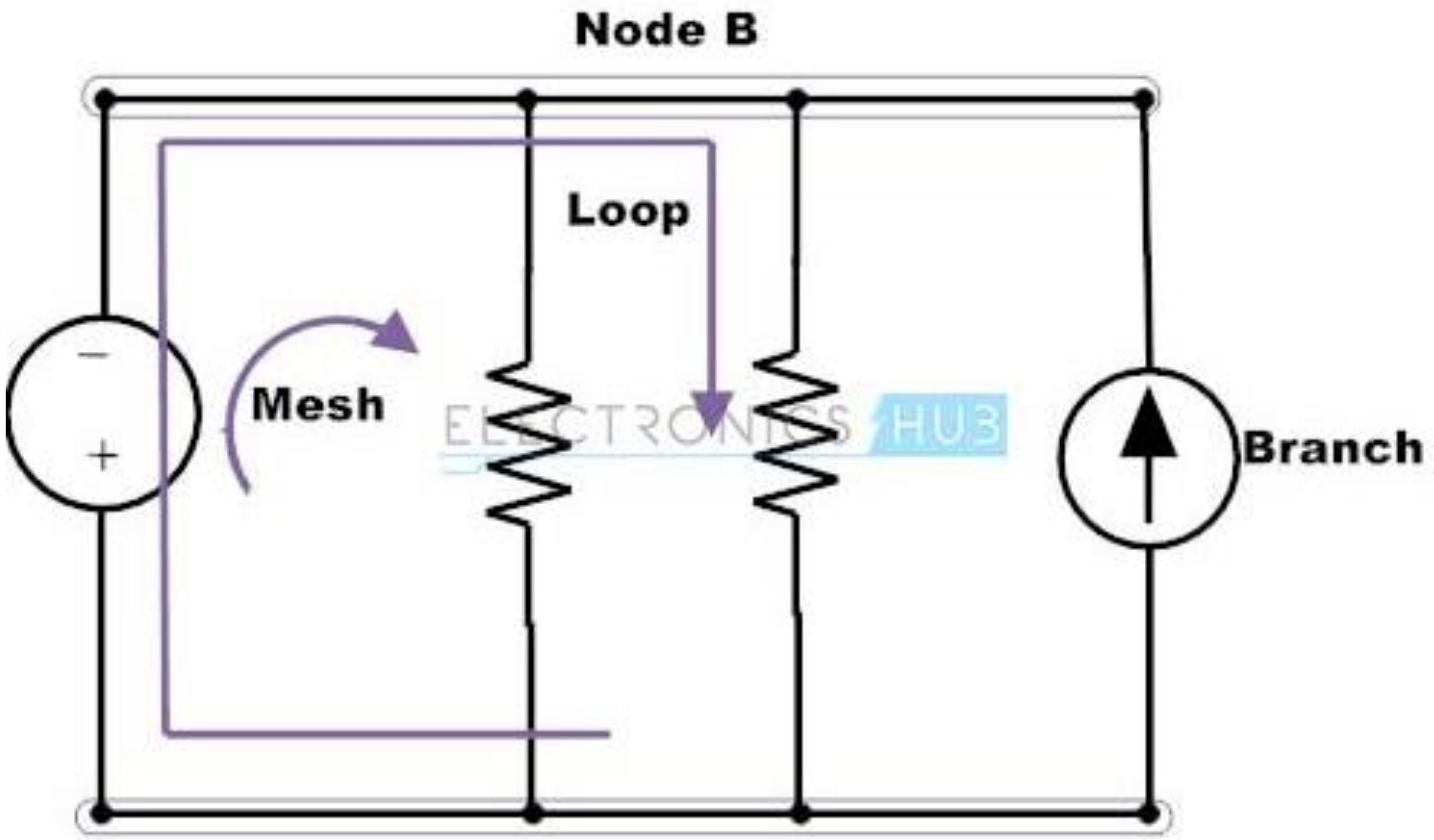
Before going to know more about Kirchhoff's law, we have to consider some of the terms related to electric circuits.

Node: Node or junction is a point in the circuit where two or more electrical elements are connected. This specifies a voltage level with a reference node in a circuit.

Branch: The continuous conducting path between two junctions which contains electrical element in a circuit is referred as branch.

Loop: In an electrical circuit a loop is an independent closed path in a circuit that follows the sequence of branches in such a way that it must start and ends with same node and it shouldn't touch any other junction or node more than once.

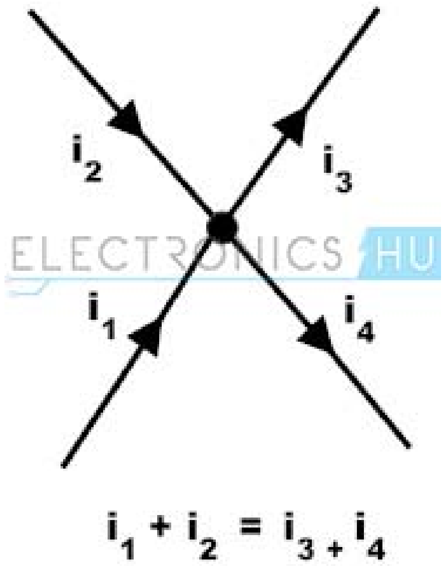
Mesh: In an electrical circuit mesh is a loop that doesn't contain any other loop in its interior.

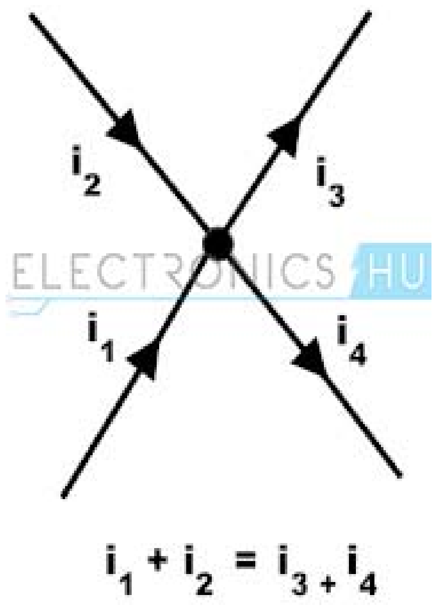


Node B
Loop
Mesh
Branch
ELECTRONICS HUB

Kirchhoff's Current Law (KCL)

This is also called as the law of conservation of charge because charge or current cannot be created or destroyed at the junction or node. It states that the algebraic sum of currents at any node is zero. Thus the current entering at a node must be equal to sum of current out of the node.





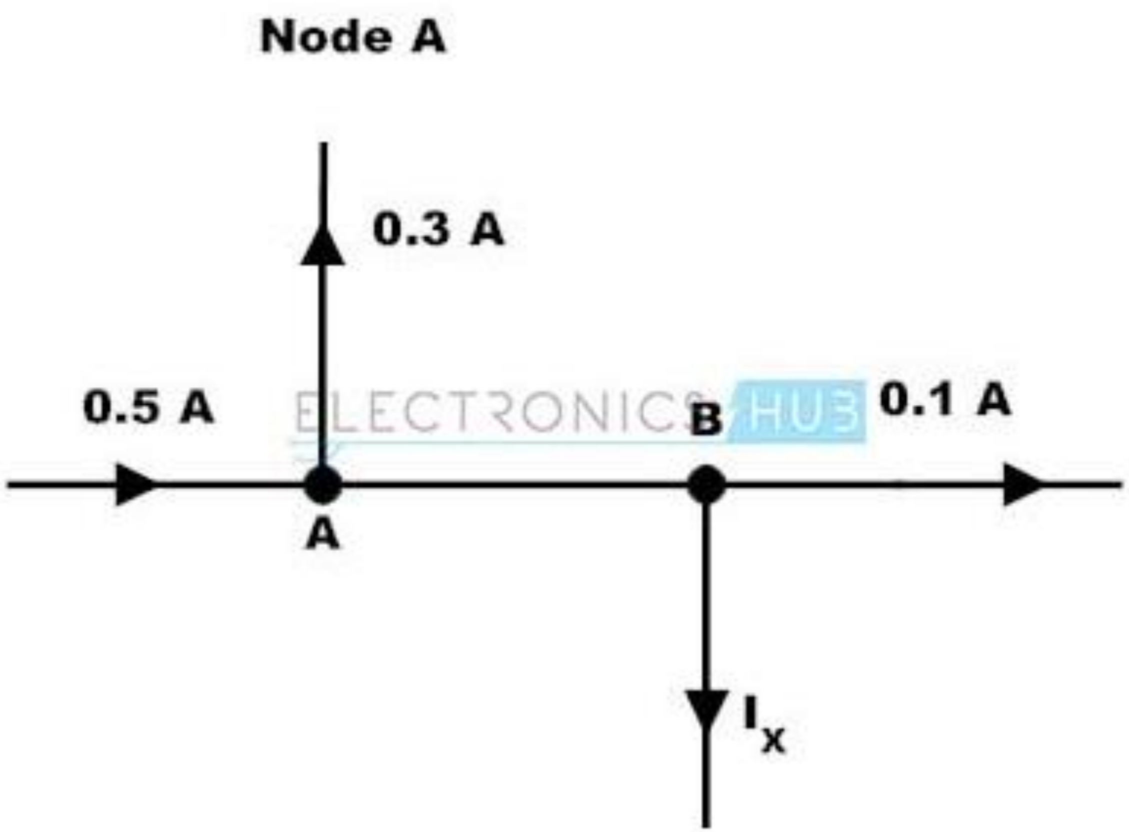
In the above figure, currents I1 and I2 are entering to the node while the currents I3 and I4 are leaving from the node. By applying KCL at the node , assume that entering currents are positive and leaving currents are negative ,we can write as

$$I1 + I2 + (-I3) + (-I4) = 0$$

$$I1 + I2 = I3 + I4$$

Example Problem of KCL

Consider the below figure where we have to determine the currents IAB and Ix by using KCL .



By applying Kirchhoff's Current Law at point A, we get

$$IAB = 0.5 – 0.3$$

$$IAB = 0.2 \text{ Amps}$$

Similarly by applying KCL at point B, we get

$$IAB = 0.1 + Ix$$

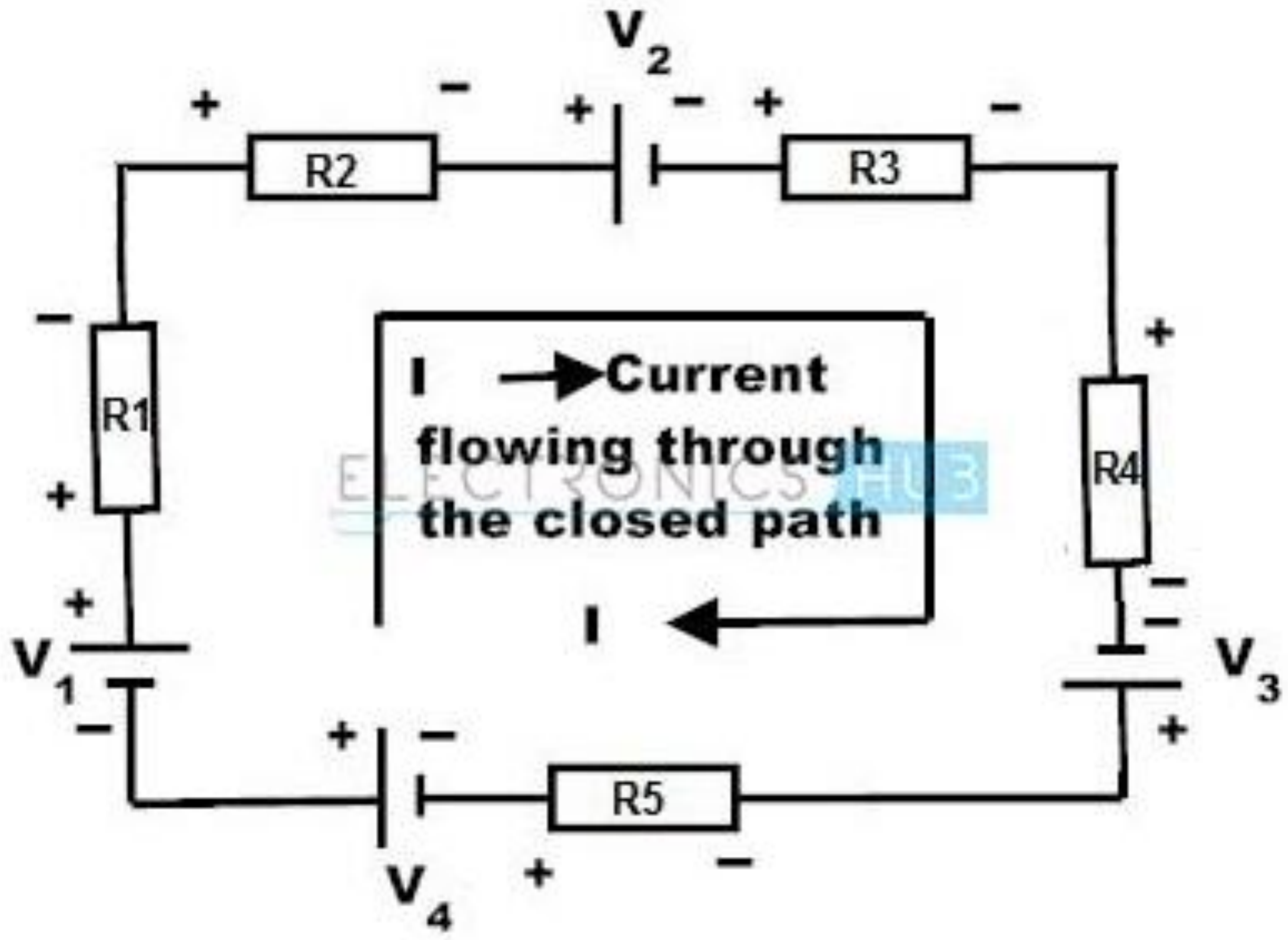
$$0.2 = 0.1 + Ix$$

$$Ix = 0.2 – 0.1 = 0.1 \text{ Amps}$$

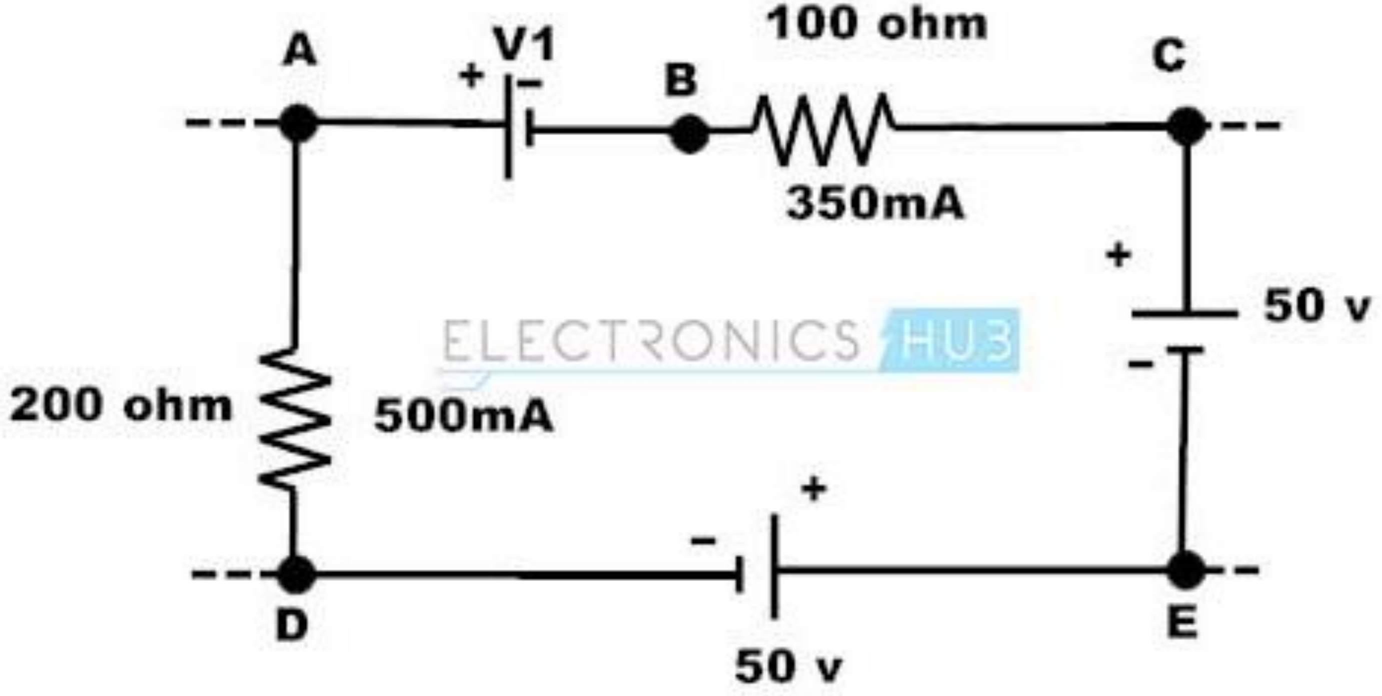
Kirchhoff’s Voltage Law (KVL)

Kirchhoff’s Voltage Law states that the algebraic sum of voltages in a closed path is equal to zero that is the sum of source voltages is equal to the sum of voltage drops in a circuit. If the current flows from higher potential to lower in an element, then we consider it as a voltage drop.

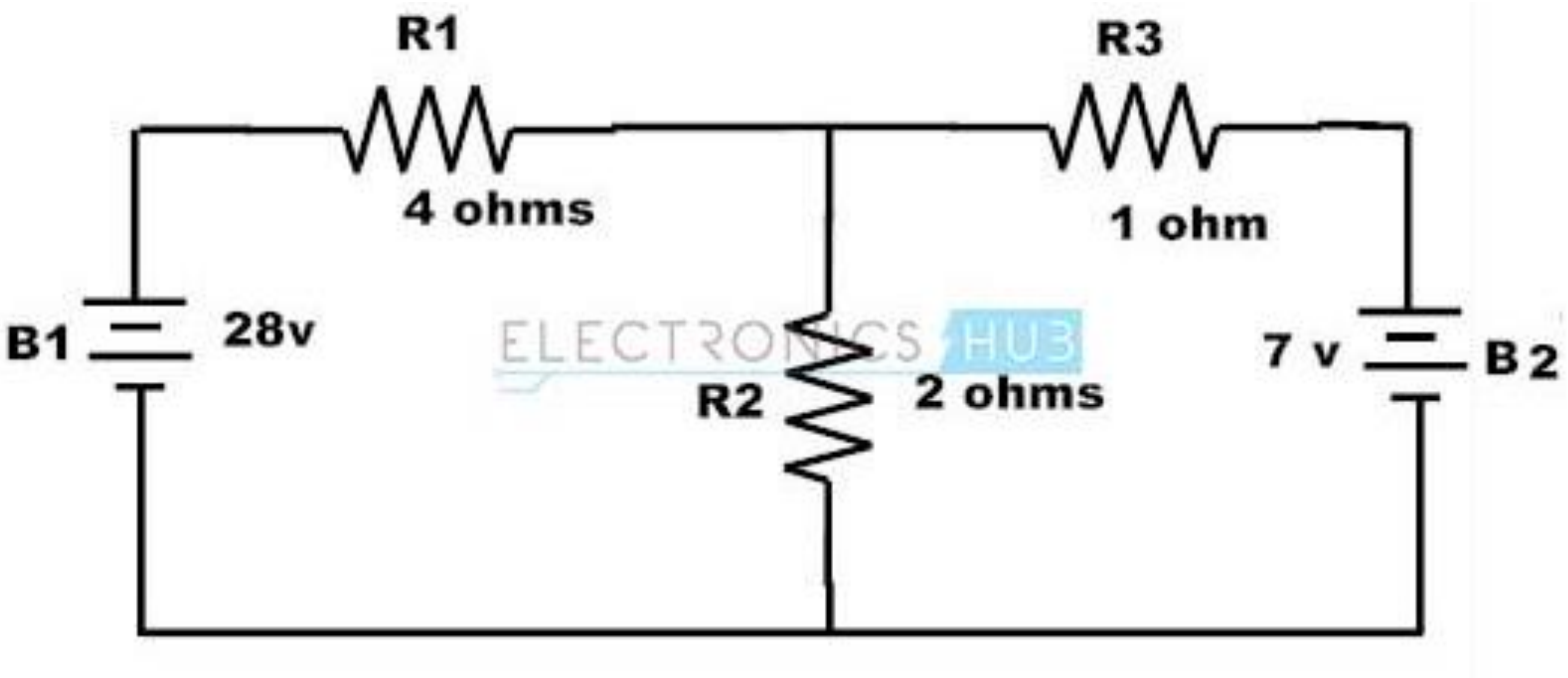
If the current flows from lower potential to higher potential, then we consider it as a voltage rise. Thus, the energy dissipated by the current must be equal to the energy given by the power supply in an electric circuit.


V2
R2
R3
R1
R4
I
Current flowing through the closed path
I
V1
V3
R5
V4
ELECTRONICS HUB

Eg.2 Find V1



Eg. 3   Find branch currents of the network

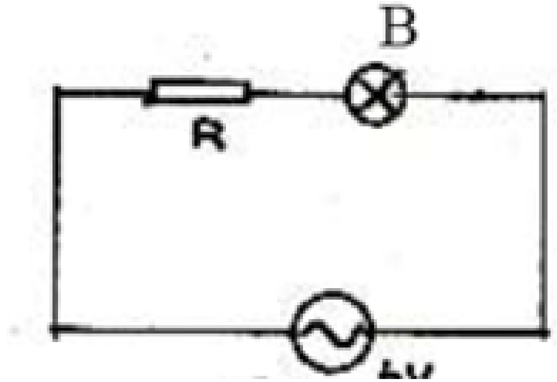


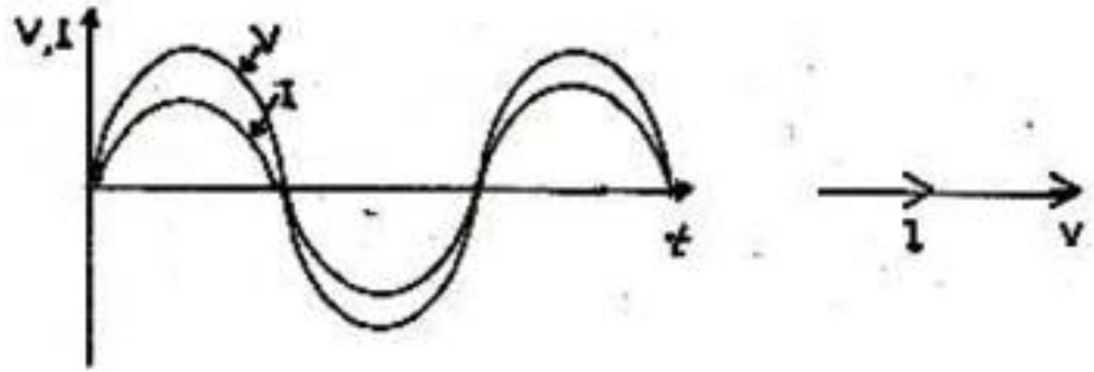
Voltage Divider Rule

Reactance

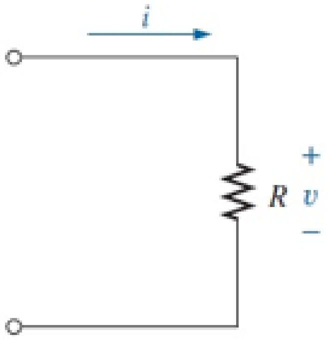
- The resistance to flow the AC current over Resistors, Capacitors and Inductors is called Reactance.
- Denoted by ‘ X ‘ .
- Unit is ‘ Ohm ‘ .

AC Pass through Resistive Circuits…..



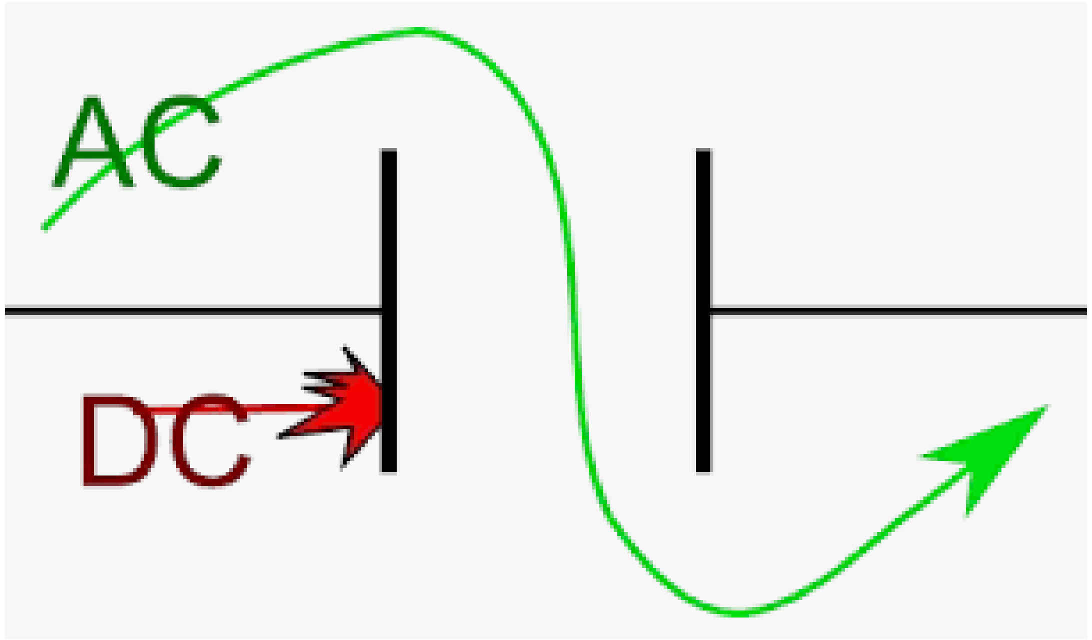


AC Reactance over Resistive Circuits…

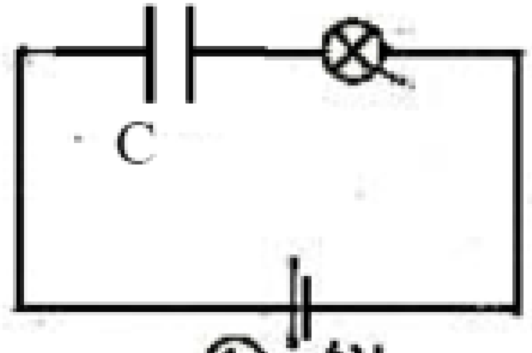


$$\boxed{X_R = R}$$

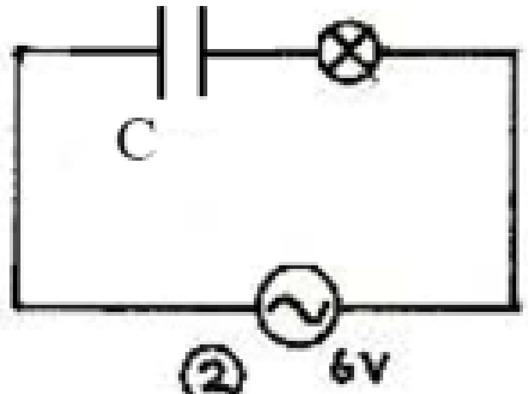
DC/AC pass over Capacitors



Experiment....

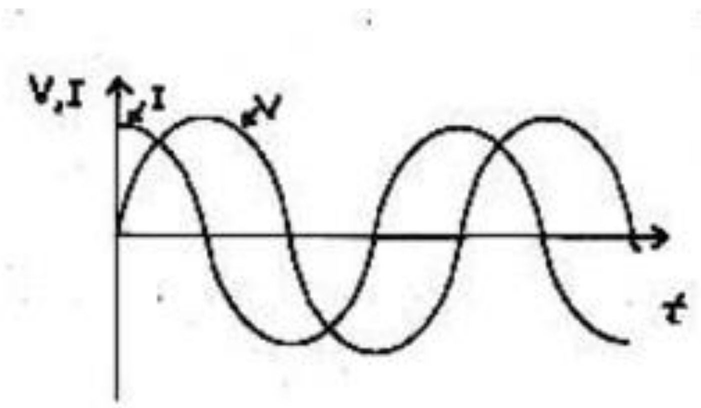


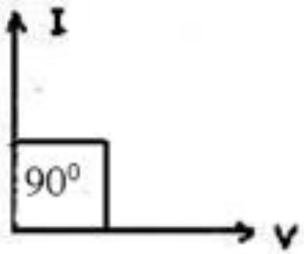
1



2

Observations…

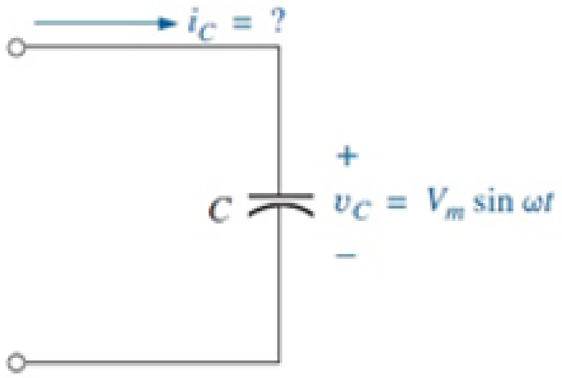




Capacitive Reactance

The flow of electrons through a capacitor is directly proportional to the rate of change of voltage across the capacitor. Capacitive reactance in a purely capacitive circuit is the opposition to current flow in AC circuits. Reactance is given by the symbol X to distinguish it from a purely resistive value as it, like resistance, is also measured in ohms. The capacitive reactance is given by the equation below as it depends on the value of the capacitor in farads as well as the frequency of the AC waveform.

Capacitive Reactance…..

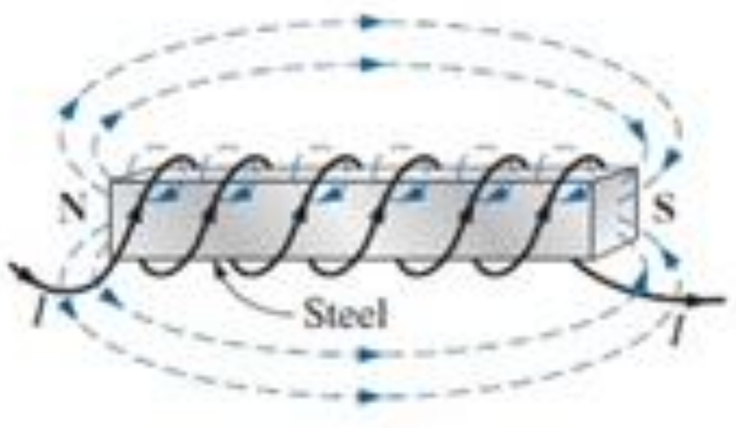


$$\boxed{X_C = \frac{1}{\omega C}}$$

$\omega = 2\pi f$

DC through an Inductor

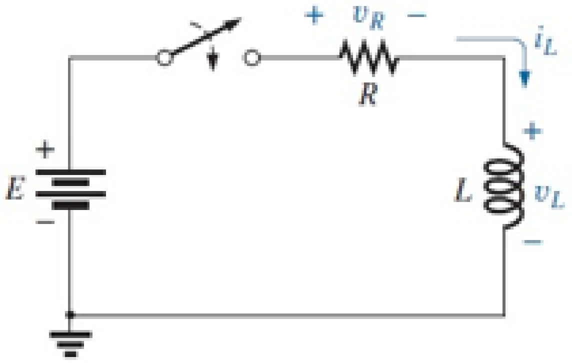
- For DC is concerned, inductor act as an electromagnet.
- When give DC supply, the resistance only comes in to the effect.

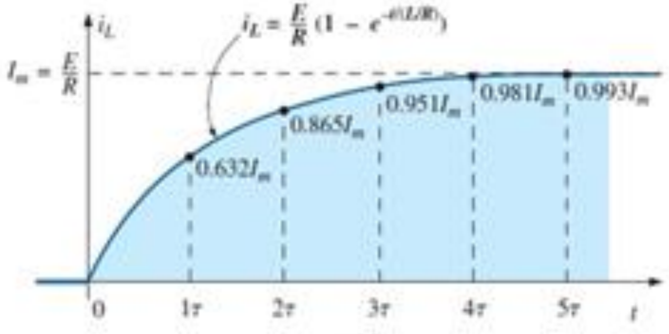


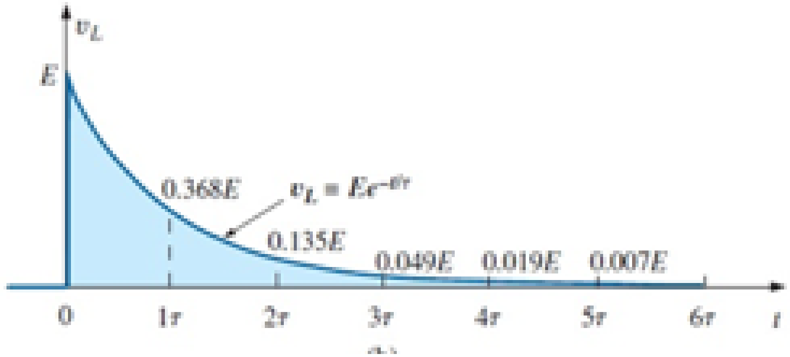
Electromagnet.

Contd.....

- When an inductor is connected to a DC source, two processes , which are called , “storing” and “decaying” energy will happen.

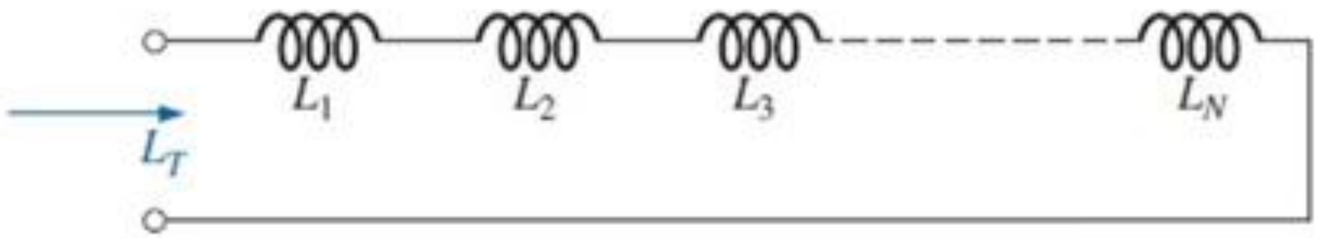






$$\boxed{W_{\text{stored}} = \frac{1}{2} L I_m^2} \qquad \text{(joules, J)}$$

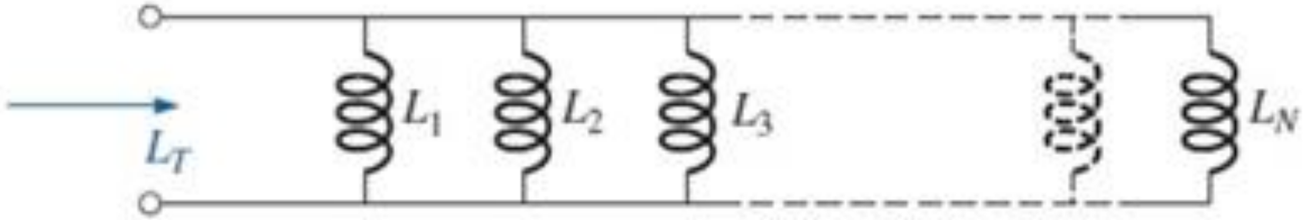
Inductors in series connection…..



Inductors in series.

$$\boxed{L_T = L_1 + L_2 + L_3 + \ \dots \ + L_N}$$

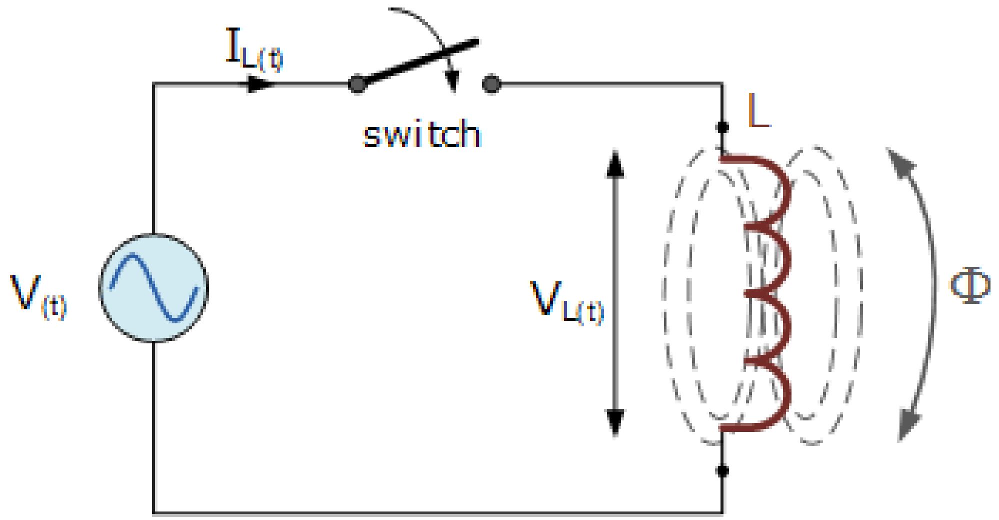
Inductors in Parallel connection….



$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \cdots + \frac{1}{L_N}$$

AC through an Inductors……

For AC, the behavior is different.
In AC, current is not constant. Current keeps changing. So does the magnetic field changes, due to change in current. And since this changing magnetic flux is linking with the coil itself, it induces an emf - and if the circuit is closed, the current flows through it. (This is in opposition with the cause producing it - Lenz law.)
So there is an opposition to AC.
More the frequency, more is the change in flux and more is the opposition.



This simple circuit above consists of a pure inductance of L Henries (H), connected across a sinusoidal voltage given by the expression: $V(t) = V_{max} \sin \omega t$. When the switch is closed this sinusoidal voltage will cause a current to flow and rise from zero to its maximum value. This rise or change in the current will induce a magnetic field within the coil which in turn will oppose or restrict this change in the current.

Inductive Reactance….

The actual opposition to the current flowing through a coil in an AC circuit is determined by the AC Resistance of the coil with this AC resistance being represented by a complex number. But to distinguish a DC resistance value from an AC resistance value, which is also known as Impedance, the term **Reactance** is used.

Like resistance, reactance is measured in Ohm's but is given the symbol "X" to distinguish it from a purely resistive "R" value and as the component in question is an inductor, the reactance of an inductor is called **Inductive Reactance**, (X_L) and is measured in Ohms. Its value can be found from the formula.

Inductive Reactance

$$X_L = 2\pi f L$$

Where:

X_L = Inductive Reactance in Ohms, (Ω)

π (pi) = a numeric constant of 3.142

f = Frequency in Hertz, (Hz)

L = Inductance in Henries, (H)

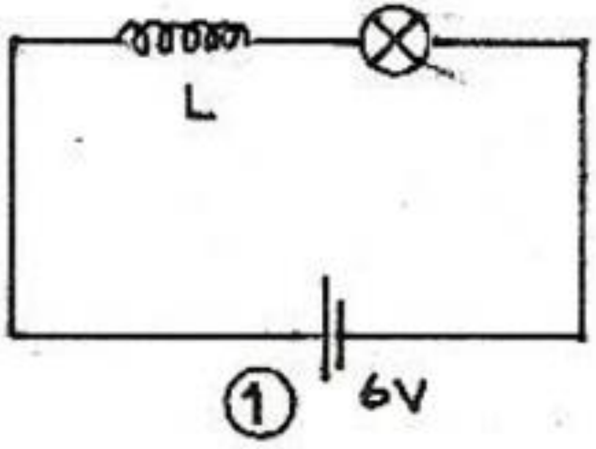
We can also define inductive reactance in radians, where Omega, ω equals $2\pi f$.

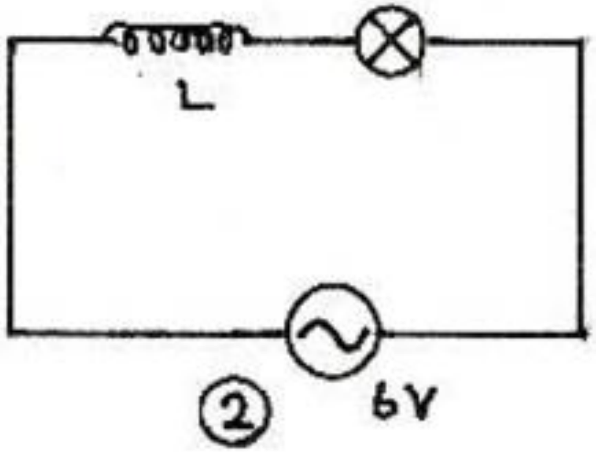
$$X_L = \omega L$$

Impedance

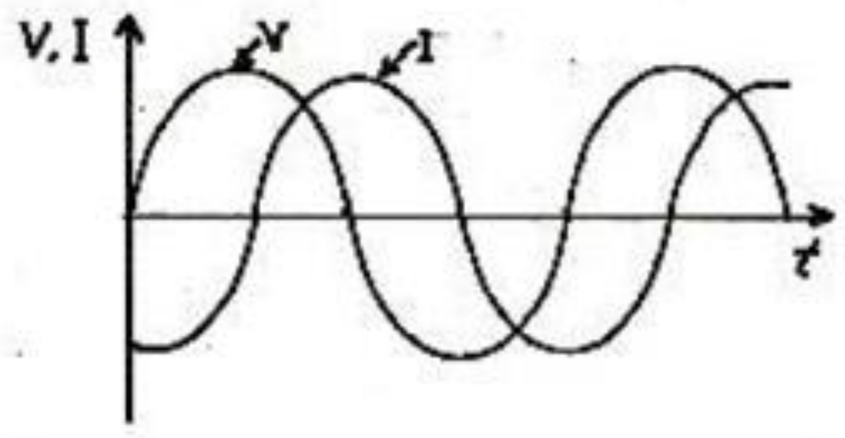
Electrical impedance, measure of the total opposition that a circuit or a part of a circuit presents to electric current.

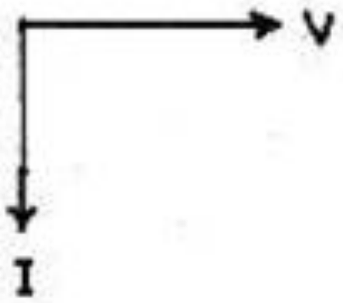
Experiment ....





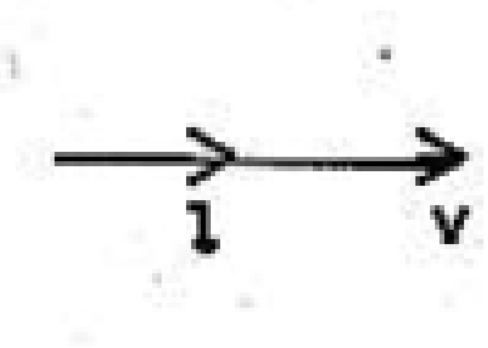
Observations….



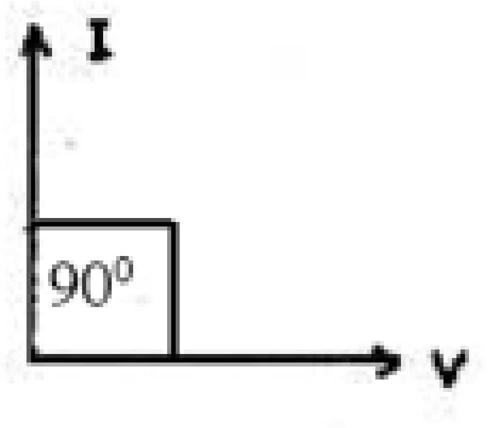


Summary….

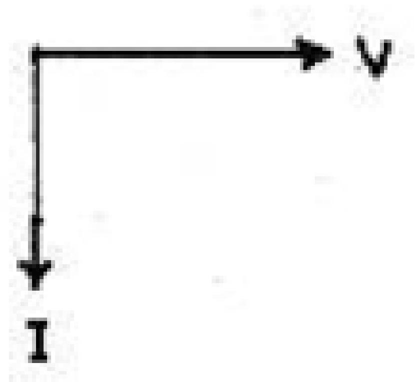
- Phasor diagram for Resistor



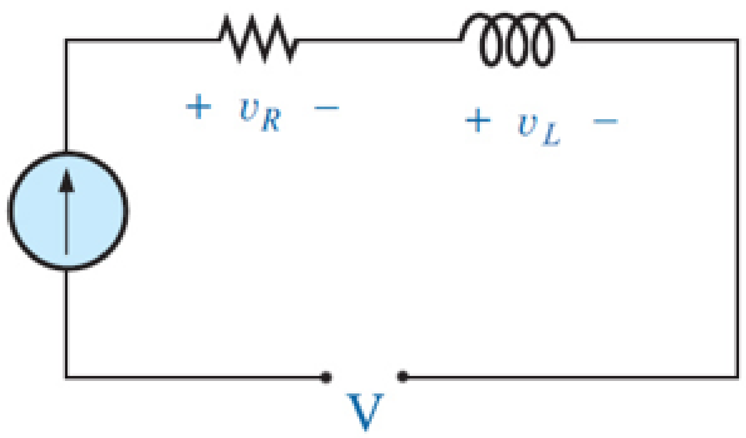
- Phasor diagram for Capacitor.

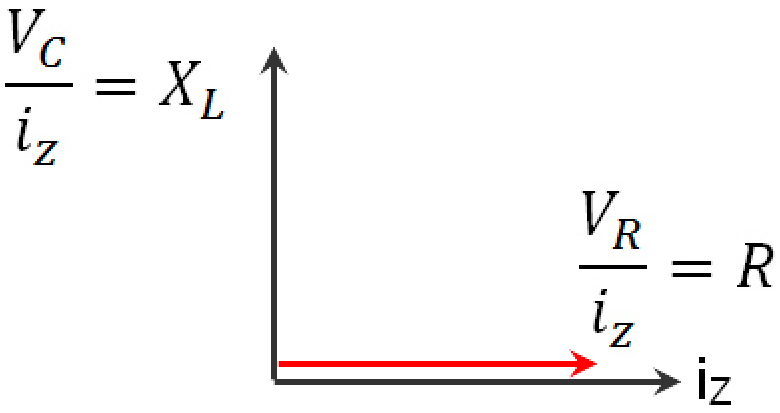


- Phasor diagram for Inductor.

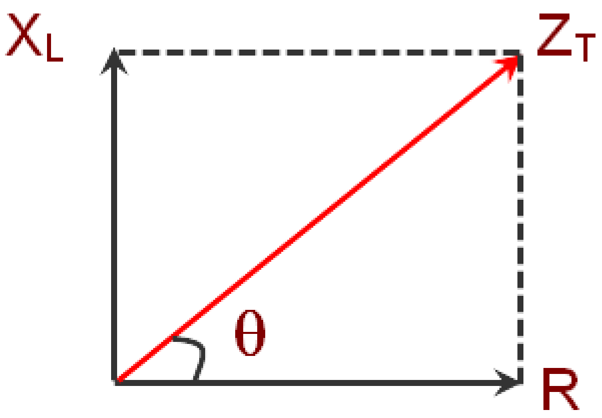


Resistor & Inductor (LR) series circuit.





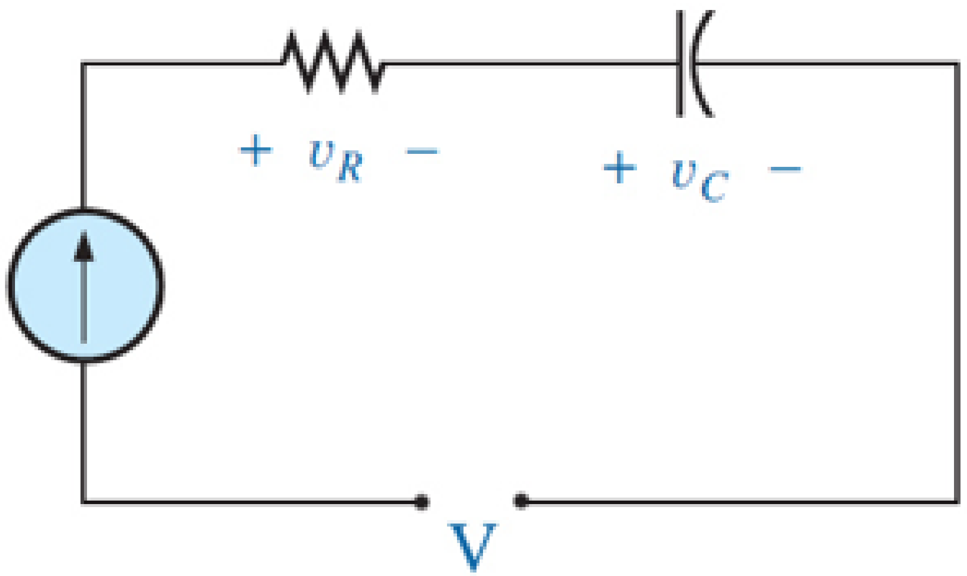
ප්‍රතිබාධන කලා සටහන

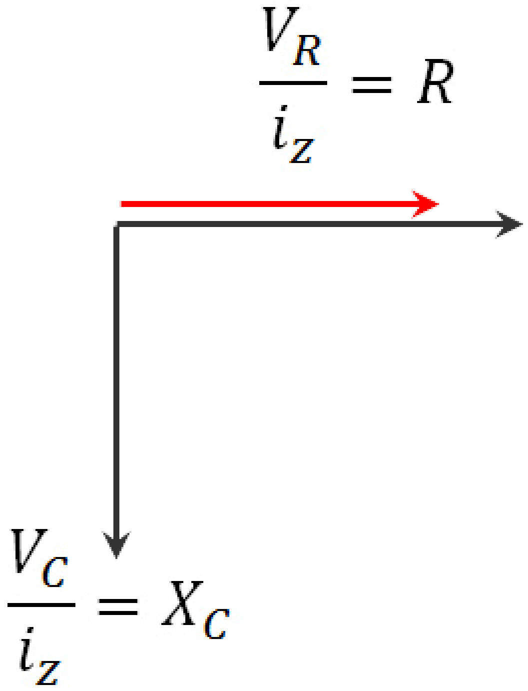


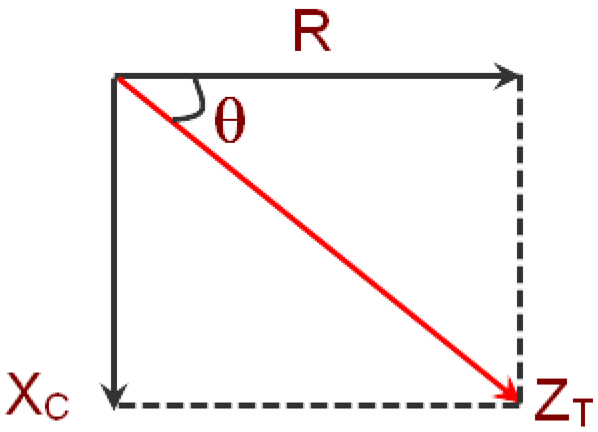
$$Z_T = \sqrt{R^2 + {X_L}^2}$$

$$\theta = \tan^{-1}\left(\frac{X_L}{R}\right)$$

Resistor & Capacitor (RC) Series Circuit





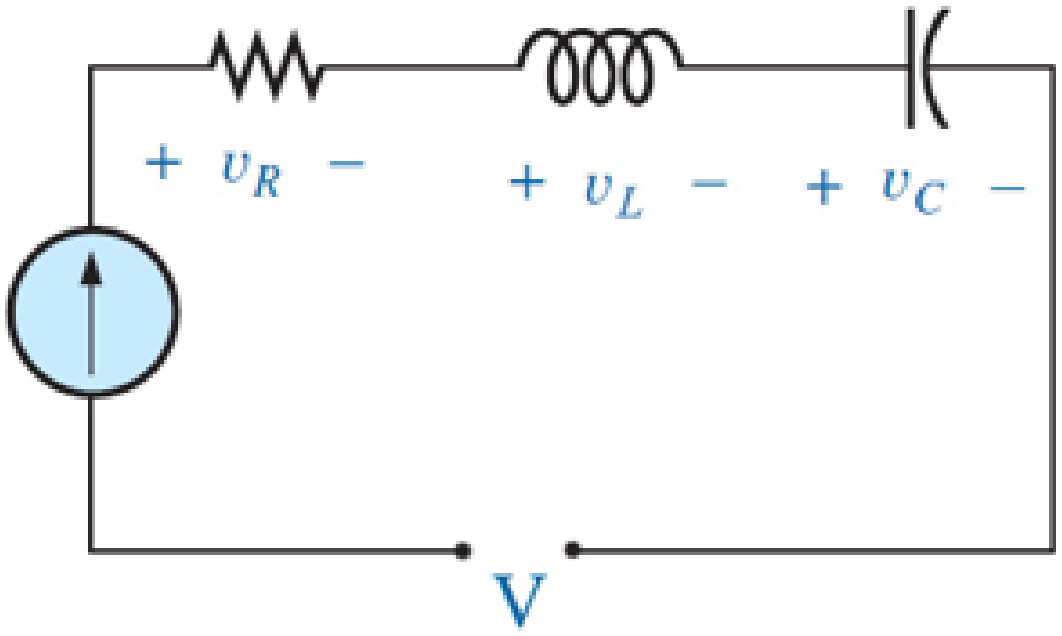


ප්‍රතිබාධන කලා සටහන

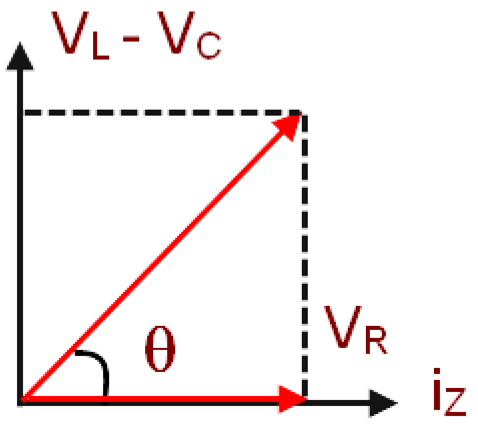
$$Z_T = \sqrt{R^2 + {X_C}^2}$$

$$\theta \ = \tan^{-1}\left(\frac{X_C}{R}\right)$$

RLC Series Circuit



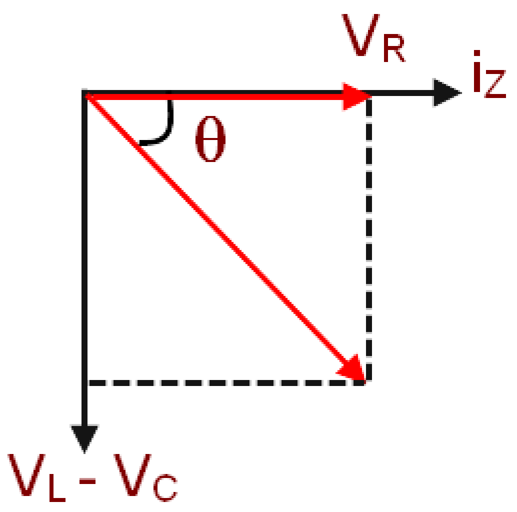
$V_L > V_C$ නම්,



$$V = \sqrt{{V_R}^2 + (V_L - V_C)^2}$$

$$\theta = \tan^{-1}\left(\frac{V_L - V_C}{V_R}\right)$$

$V_C > V_L$ නම්,

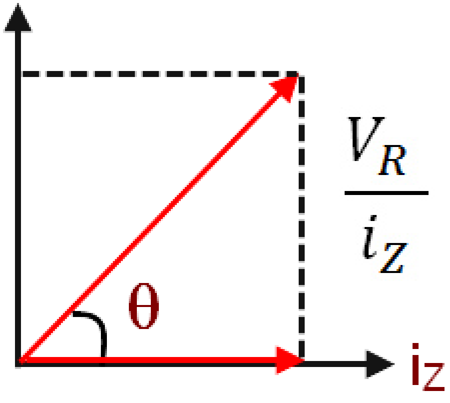


$$V = \sqrt{{V_R}^2 + (V_C - V_L)^2}$$

$$\theta = \tan^{-1}\left(\frac{V_C - V_L}{V_R}\right)$$

$V_L > V_C$ නම්,

$$\frac{V_L - V_C}{i_Z} = X_L - X_C$$



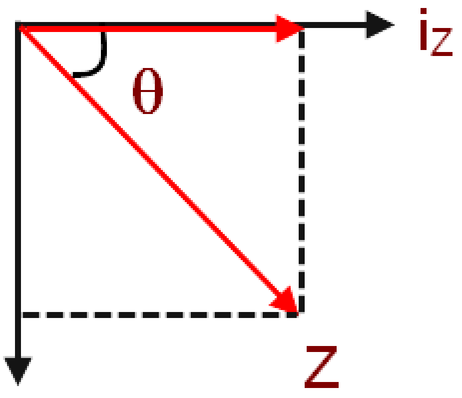
$$\frac{V_R}{i_Z} = R$$

ප්‍රතිබාධන කලා සටහන

$$Z_T = \sqrt{R^2 + (X_L - X_C)^2}$$

$$\theta = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$$

$V_C > V_L$ නම්,

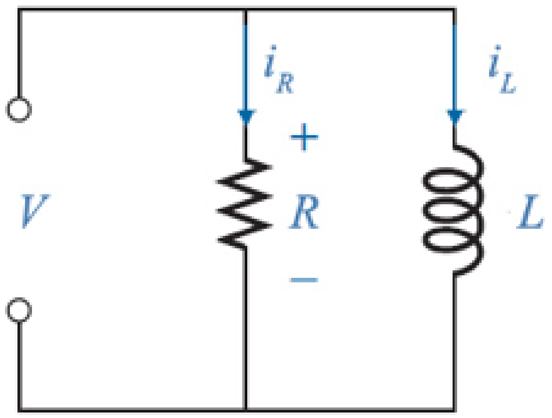


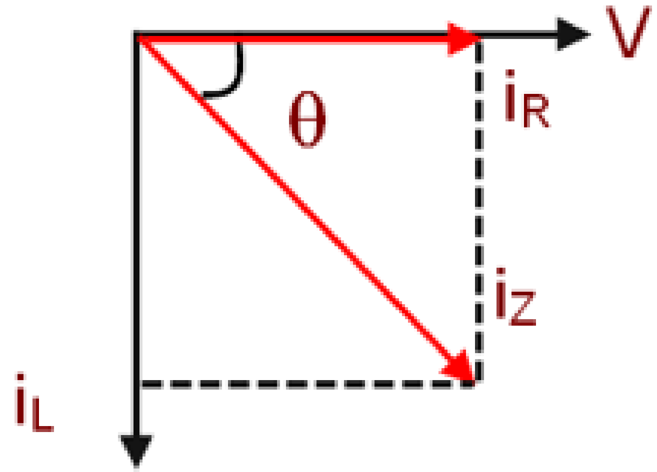
$$\frac{V_C - V_L}{i_Z} = X_C - X_L$$

$$Z_T = \sqrt{R^2 + (X_C - X_L)^2}$$

$$\theta = \tan^{-1}\left(\frac{X_C - X_L}{R}\right)$$

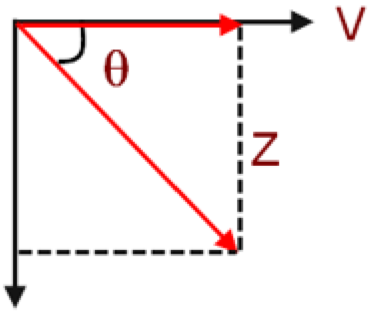
RL Parallel Circuit





$$\frac{i_R}{V} = \frac{1}{R}$$

$$\frac{i_L}{V} = \frac{1}{X_L}$$

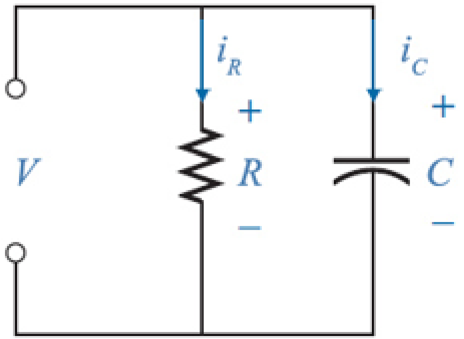


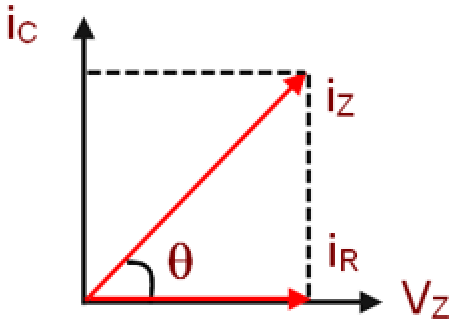
$$Z = \frac{1}{\sqrt{\frac{1}{R^2} + \frac{1}{{X_L}^2}}}$$

$$\theta = \tan^{-1}\left(\frac{R}{X_L}\right)$$

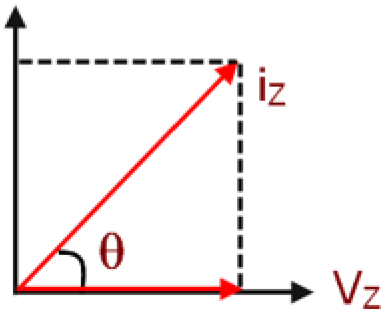
$$X_L = \omega L$$

RC Parallel circuit.....





$$\frac{i_L}{V_Z} = \frac{1}{X_C}$$



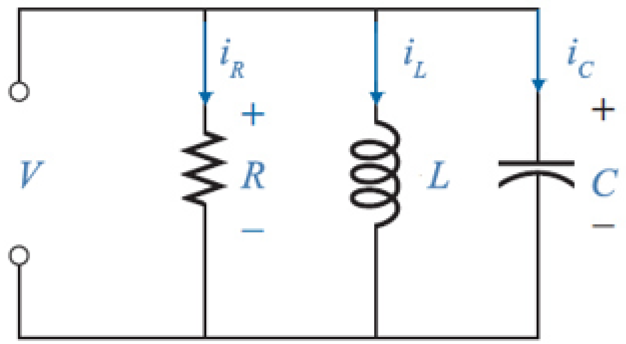
$$\frac{i_R}{V_Z} = \frac{1}{R}$$

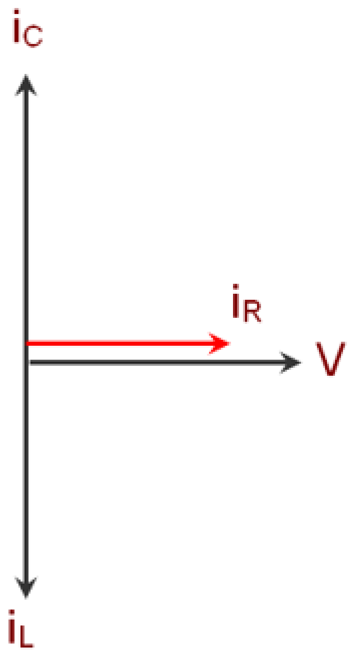
$$Z = \frac{1}{\sqrt{\frac{1}{R^2} + \frac{1}{{X_C}^2}}}$$

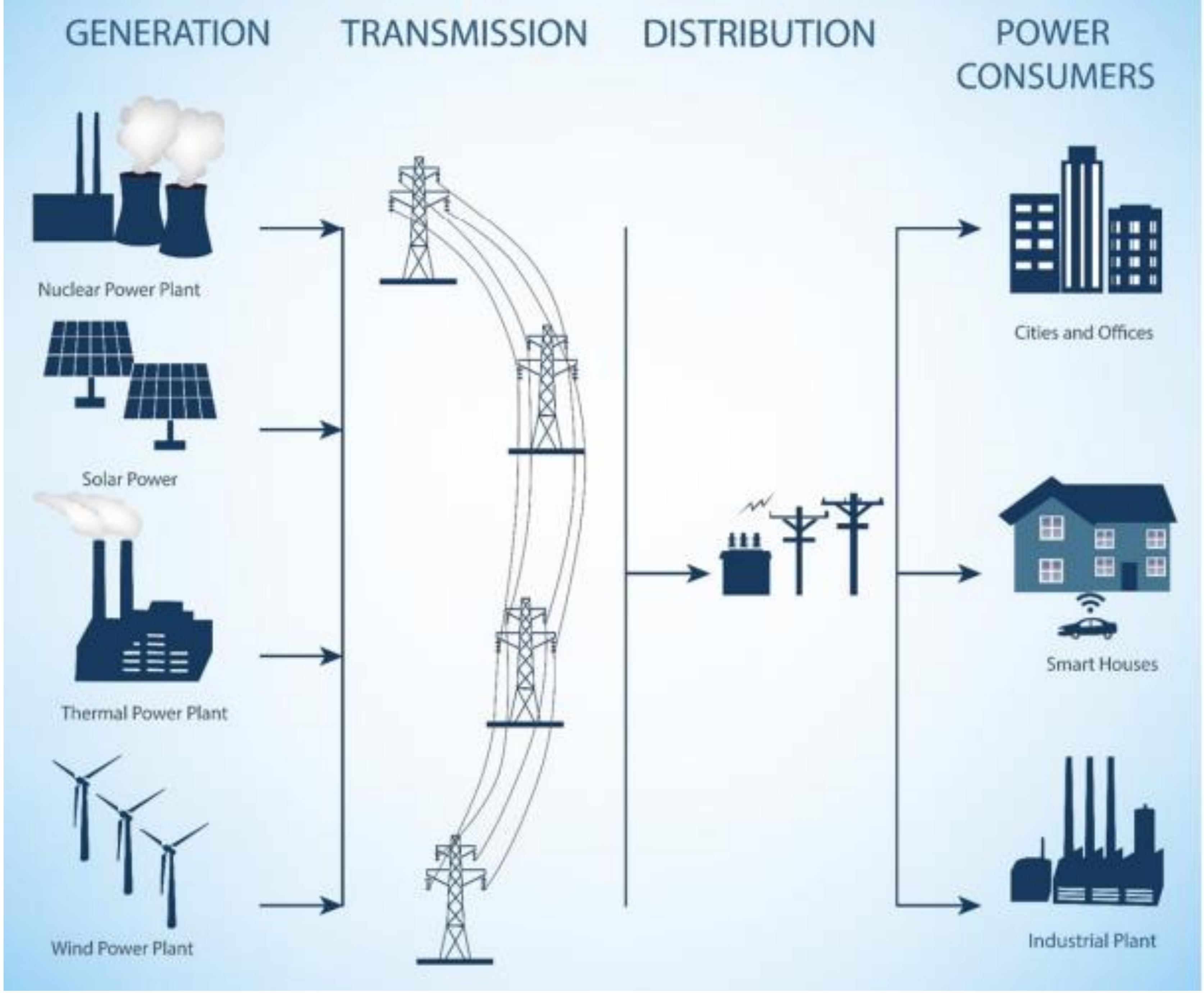
$$\theta = \tan^{-1}\left(\frac{i_C}{i_R}\right)$$

$$\boxed{X = \frac{1}{\omega C}}$$

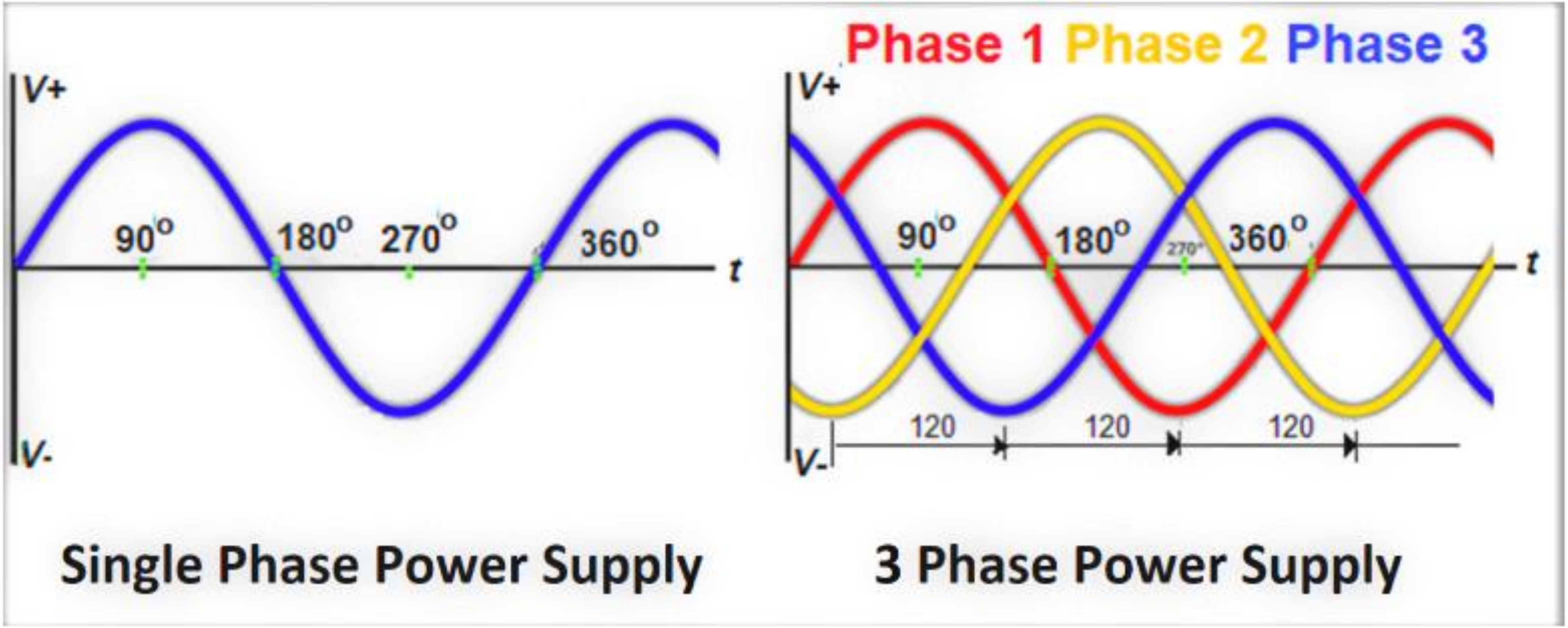
RLC Parallel Circuit



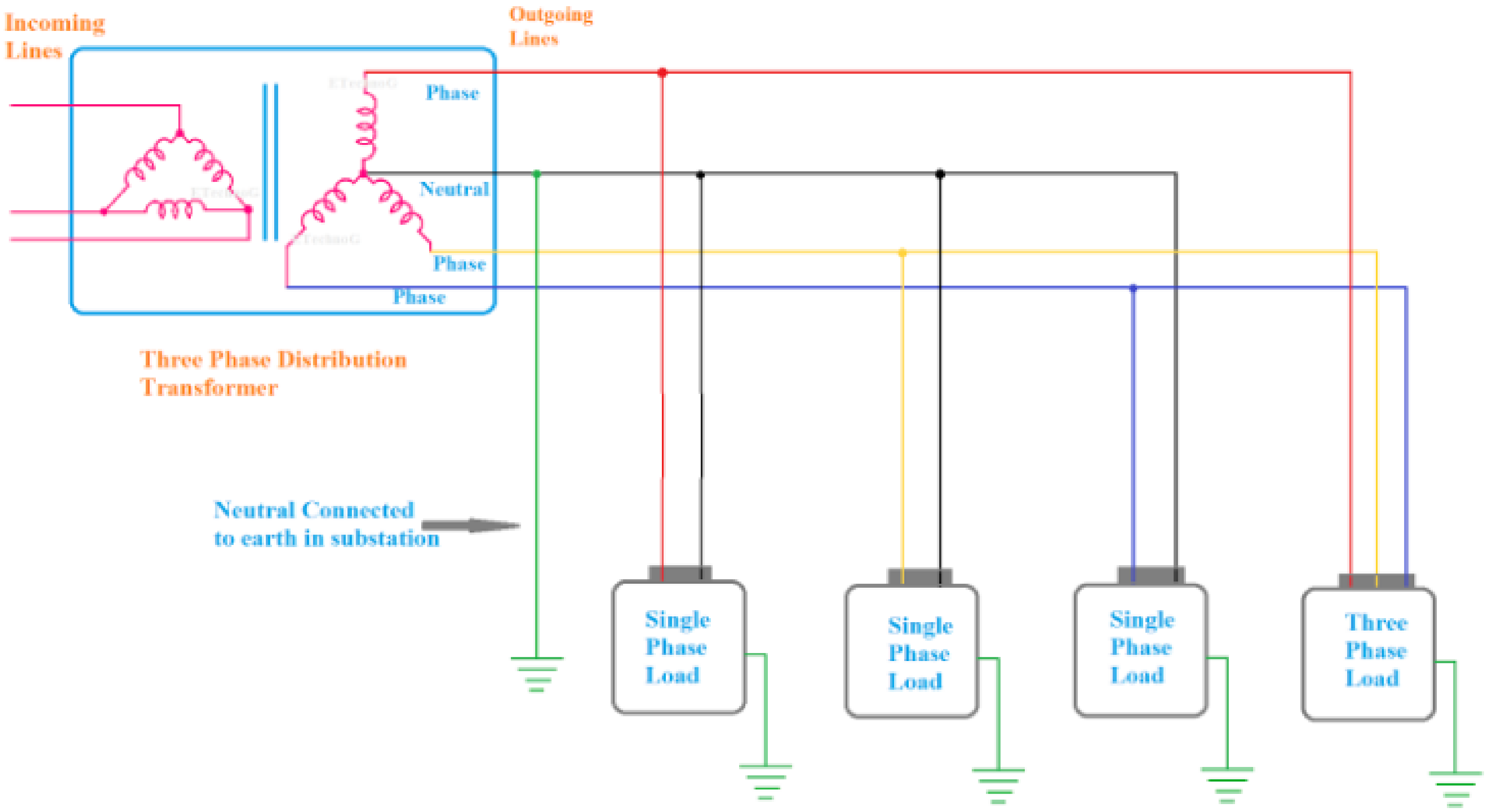



GENERATION
TRANSMISSION
DISTRIBUTION
POWER CONSUMERS
Nuclear Power Plant
Solar Power
Thermal Power Plant
Wind Power Plant
Cities and Offices
Smart Houses
Industrial Plant

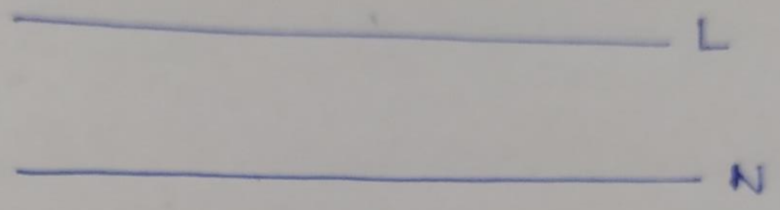
Single Phase Power…..



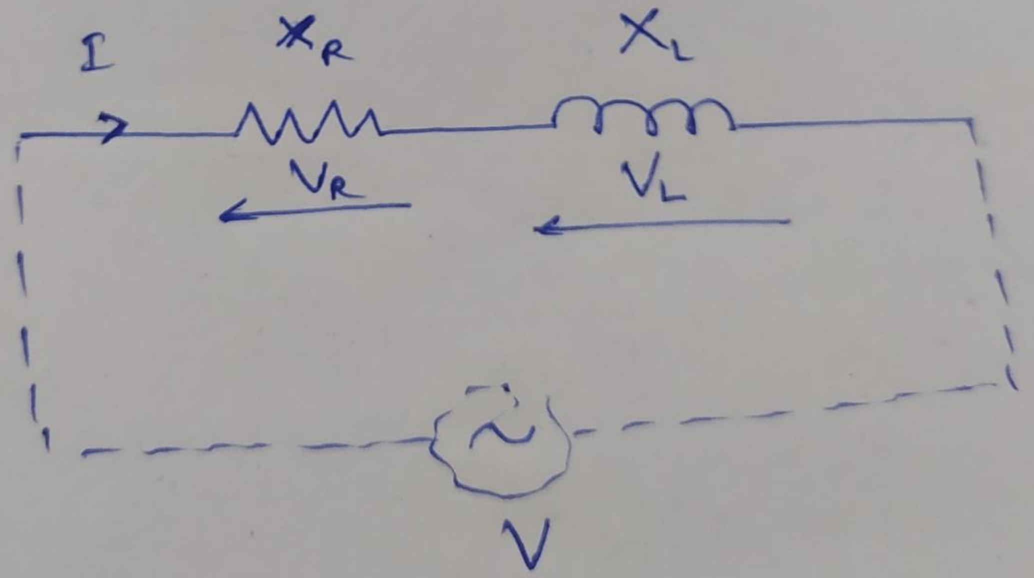
Single Phase power supply



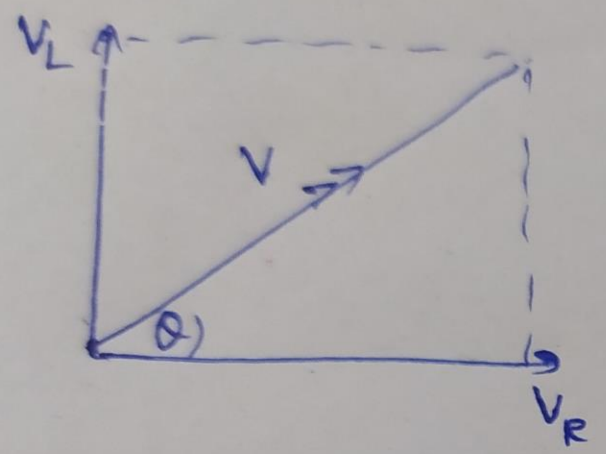
Single Phase Power Supply

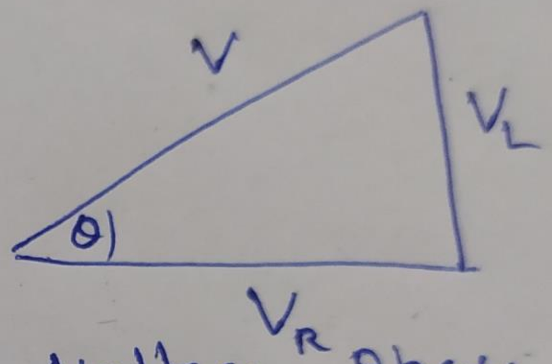


Considering live wire; its electrical equivalent circuit is;

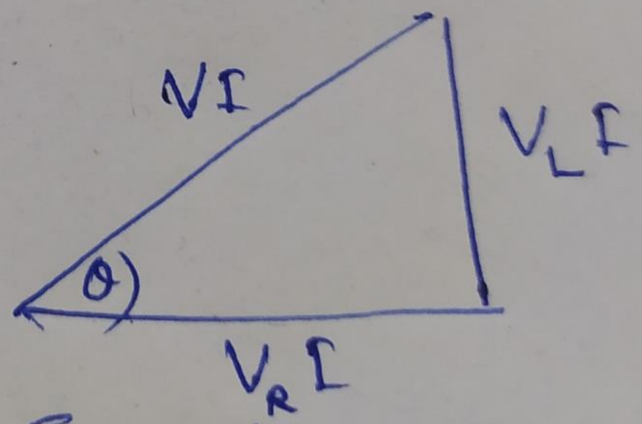


Voltage Phasor diagram:





Voltage phase triangle

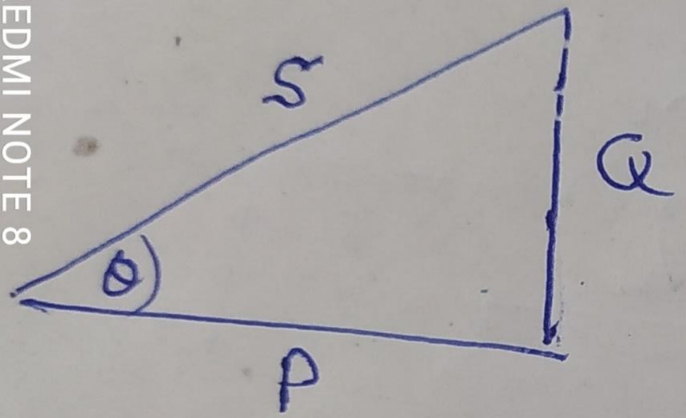


Power Triangle.

VI – Apparent Power – (S)

$V_R I$ – Real Power – (P)

$V_L I$ – Reactive Power – (Q)



$$\cos\theta = \frac{P}{S}$$

$$P = S\cos\theta$$

$$= VI\cos\theta$$

$$\boxed{P = VI\cos\theta}$$

$$\sin\theta = \frac{Q}{S}$$

$$\therefore Q = S\cdot\sin\theta$$

$$\therefore \boxed{Q = VI\sin\theta}$$

$$\boxed{S = VI}$$

Power factor $= \cos\theta = \frac{P}{S}$

when $\theta \longrightarrow 0$ $\cos\theta \longrightarrow 1$

i.e; maximum Power factor.

when $\theta \longrightarrow 90^\circ$ $\cos\theta \longrightarrow 0$

i.e; minimum Power factor.

Theoritically maximum Power factor $= 1$
Practically " " " $= 0.8$

About the Power Factor…..

The electrical energy is almost exclusively generated, transmitted and distributed in the form of alternating current. Therefore, the question of power factor immediately comes into picture. Most of the loads (*e.g.* induction motors, arc lamps) are inductive in nature and hence have low lagging power factor. The low power factor is highly undesirable as it causes an increase in current, resulting in additional losses of active power in all the elements of power system from power station generator down to the utilisation devices. In order to ensure most favourable conditions for a supply system from engineering and economical standpoint, it is important to have power factor as close to unity as

Power Factor Definition

6.1 Power Factor

The cosine of angle between voltage and current in an a.c. circuit is known as **power factor.**

In an a.c. circuit, there is generally a phase difference ϕ between voltage and current. The term $\cos \phi$ is called the power factor of the circuit. ~~If the circuit is inductive, the current lags~~

The power factor of a circuit can be defined in one of the following three ways :

(*a*) Power factor $= \cos\phi$ = cosine of angle between V and I

(*b*) Power factor $= \dfrac{R}{Z} = \dfrac{\text{Resistance}}{\text{Impedance}}$

(*c*) Power factor $= \dfrac{VI\cos\phi}{VI} = \dfrac{\text{Active power}}{\text{Apparent Power}}$

The reactive power is neither consumed in the circuit nor it does any useful work. It merely flows back and forth in both directions in the circuit. A wattmeter does not measure reactive power.

Illustration. Let us illustrate the power relations in an a.c. circuit with an example. Suppose a circuit draws a current of 10 A at a voltage of 200 V and its p.f. is 0·8 lagging. Then,

$$\text{Apparent power} = VI = 200 \times 10 = 2000 \text{ VA}$$

$$\text{Active power} = VI \cos\phi = 200 \times 10 \times 0{\cdot}8 = 1600 \text{ W}$$

$$\text{Reactive power} = VI \sin\phi = 200 \times 10 \times 0{\cdot}6 = 1200 \text{ VAR}$$

The circuit receives an apparent power of 2000 VA and is able to convert only 1600 watts into active power. The reactive power is 1200 VAR and does no useful work. It merely flows into and out of the circuit periodically. In fact, reactive power is a liability on the source because the source has to supply the additional current (*i.e.*, $I \sin\phi$).

Disadvantages of Low Power Factor

The power factor plays an importance role in a.c. circuits since power consumed depends upon this factor.

$$P = V_L I_L \cos \phi \qquad \text{(For single phase supply)}$$

$$\therefore \quad I_L = \frac{P}{V_L \cos \phi} \qquad ...(i)$$

$$P = \sqrt{3}\, V_L I_L \cos \phi \qquad \text{(For 3 phase supply)}$$

$$\therefore \quad I_L = \frac{P}{\sqrt{3}\, V_L \cos \phi} \qquad ...(ii)$$

It is clear from above that for fixed power and voltage, the load current is inversely proportional to the power factor. Lower the power factor, higher is the load current and *vice-versa*. A power factor less than unity results in the following disadvantages :

(*i*) **Large kVA rating of equipment.** The electrical machinery (*e.g.*, alternators, transformers, switchgear) is always rated in *kVA.

Now,
$$\text{kVA} = \frac{\text{kW}}{\cos \phi}$$

It is clear that kVA rating of the equipment is inversely proportional to power factor. The smaller the power factor, the larger is the kVA rating. Therefore, at low power factor, the kVA rating of the equipment has to be made more, making the equipment larger and expensive.

(*ii*) **Greater conductor size.** To transmit or distribute a fixed amount of power at constant voltage, the conductor will have to carry more current at low power factor. This necessitates large conductor size. For example, take the case of a single phase a.c. motor having an input of 10 kW on full load, the terminal voltage being 250 V. At unity p.f., the input full load current would be 10,000/250 = 40 A. At 0·8 p.f; the kVA input would be 10/0·8 = 12·5 and the current input 12,500/250 = 50 A. If the motor is worked at a low power factor of 0·8, the cross-sectional area of the supply cables and motor conductors would have to be based upon a current of 50 A instead of 40 A which would be required at unity power factor.

(*iii*) **Large copper losses.** The large current at low power factor causes more I^2R losses in all the elements of the supply system. This results in poor efficiency.

(*iv*) **Poor voltage regulation.** The large current at low lagging power factor causes greater voltage drops in alternators, transformers, transmission lines and distributors. This results in the decreased voltage available at the supply end, thus impairing the performance of utilisation devices. In order to keep the receiving end voltage within permissible limits, extra equipment (*i.e.*, voltage regulators) is required.

(*v*) **Reduced handling capacity of system.** The lagging power factor reduces the handling capacity of all the elements of the system. It is because the reactive component of current prevents the full utilisation of installed capacity.

Causes of Low Power Factor

Low power factor is undesirable from economic point of view. Normally, the power factor of the whole load on the supply system in lower than 0·8. The following are the causes of low power factor:

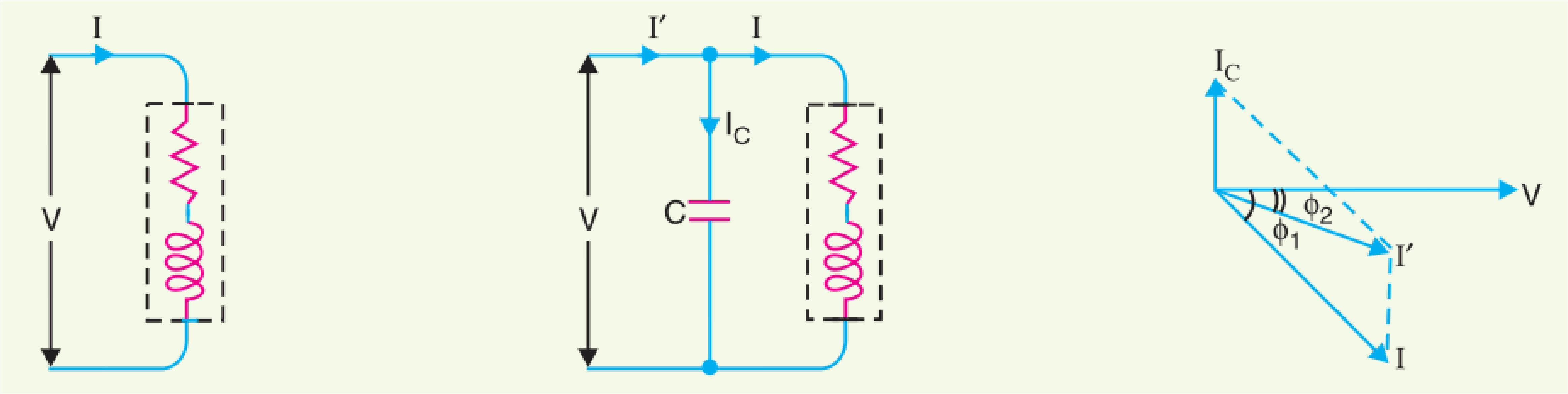
(i) Most of the a.c. motors are of induction type (1ϕ and 3ϕ induction motors) which have low lagging power factor. These motors work at a power factor which is extremely small on light load (0·2 to 0·3) and rises to 0·8 or 0·9 at full load.

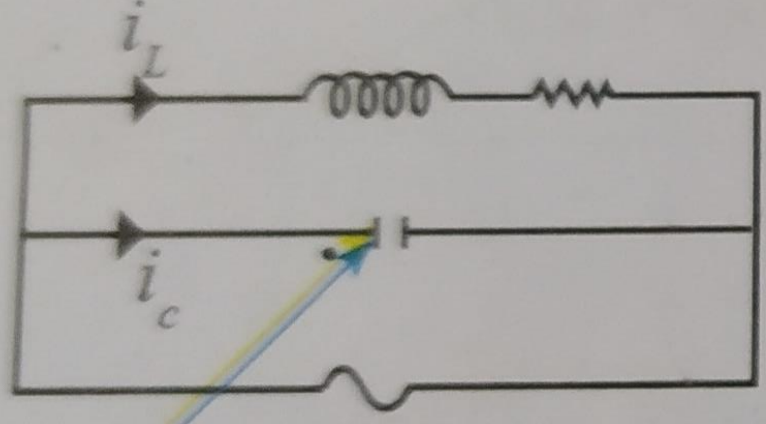
(ii) Arc lamps, electric discharge lamps and industrial heating furnaces operate at low lagging power factor.

(iii) The load on the power system is varying ; being high during morning and evening and low at other times. During low load period, supply voltage is increased which increases the magnetisation current. This results in the decreased power factor.

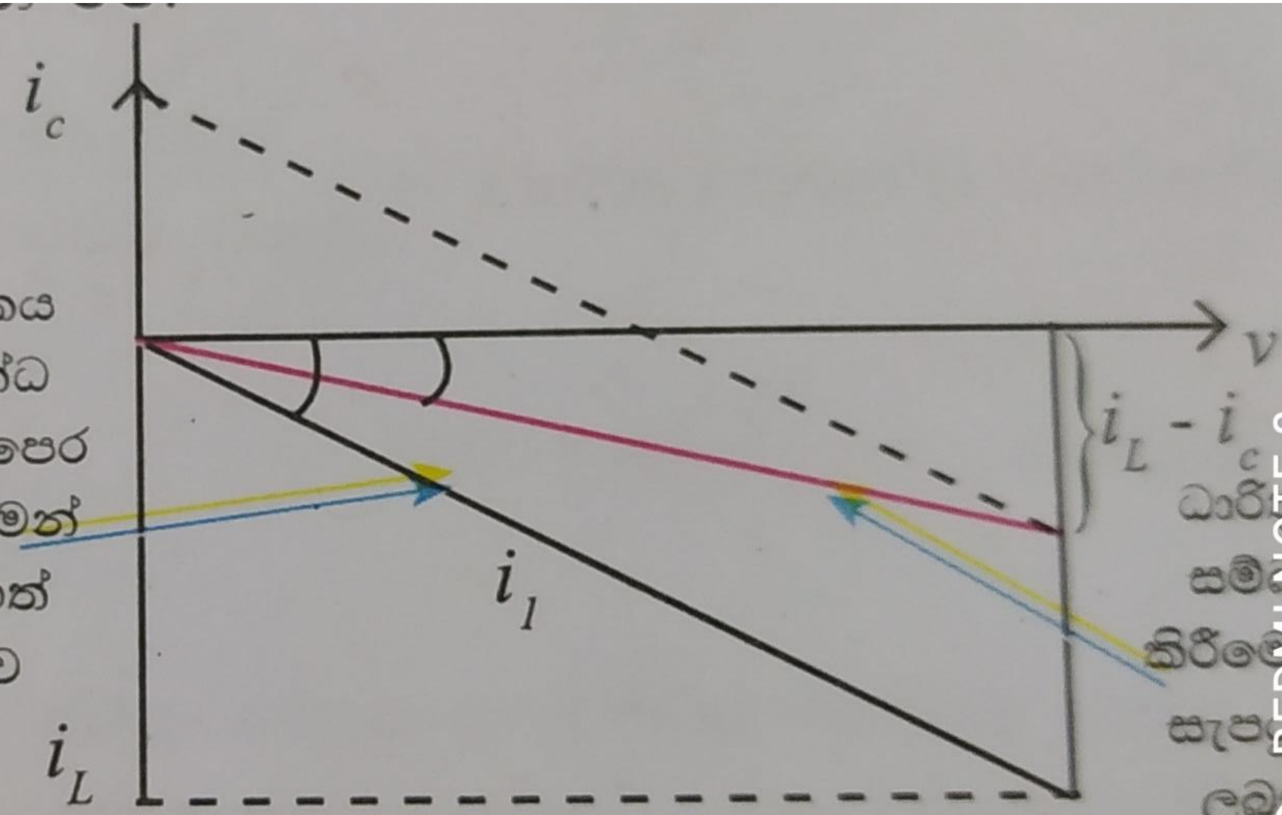
Power Factor Improvement – Single Phase system

The low power factor is mainly due to the fact that most of the power loads are inductive and, therefore, take lagging currents. In order to improve the power factor, some device taking leading power should be connected in parallel with the load. One of such devices can be a capacitor. The capacitor draws a leading current and partly or completely neutralises the lagging reactive component of load current. This raises the power factor of the load.





රූපය 2.77 (a). ප්‍රේරක විබැරක් සහිත
පරිපථයක ජව සාධකය වැඩි දියුණු කිරීම

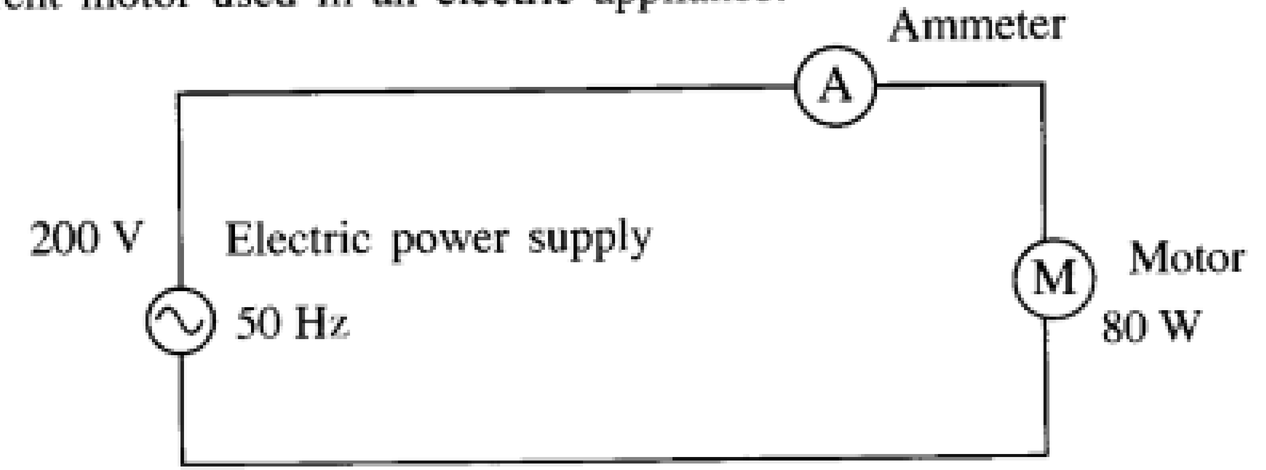


රූපය 2.77 (b). ජව සාධකය වැඩි
දියුණු කිරීමෙන් පසු අවධික සටහන

Year 2020 ET PAPER…..

(*b*) (i) In relation to an electric motor, show active power, apparent power, reactive power and power factor using a power triangle. (10 *marks*)

(ii) The circuit shown below was designed to calculate the power factor of a single-phase alternating current motor used in an electric appliance.



When the electric power supply was 200 V, the ammeter reading was seen as 0.5 A. Assume that the power loss in the ammeter is zero.

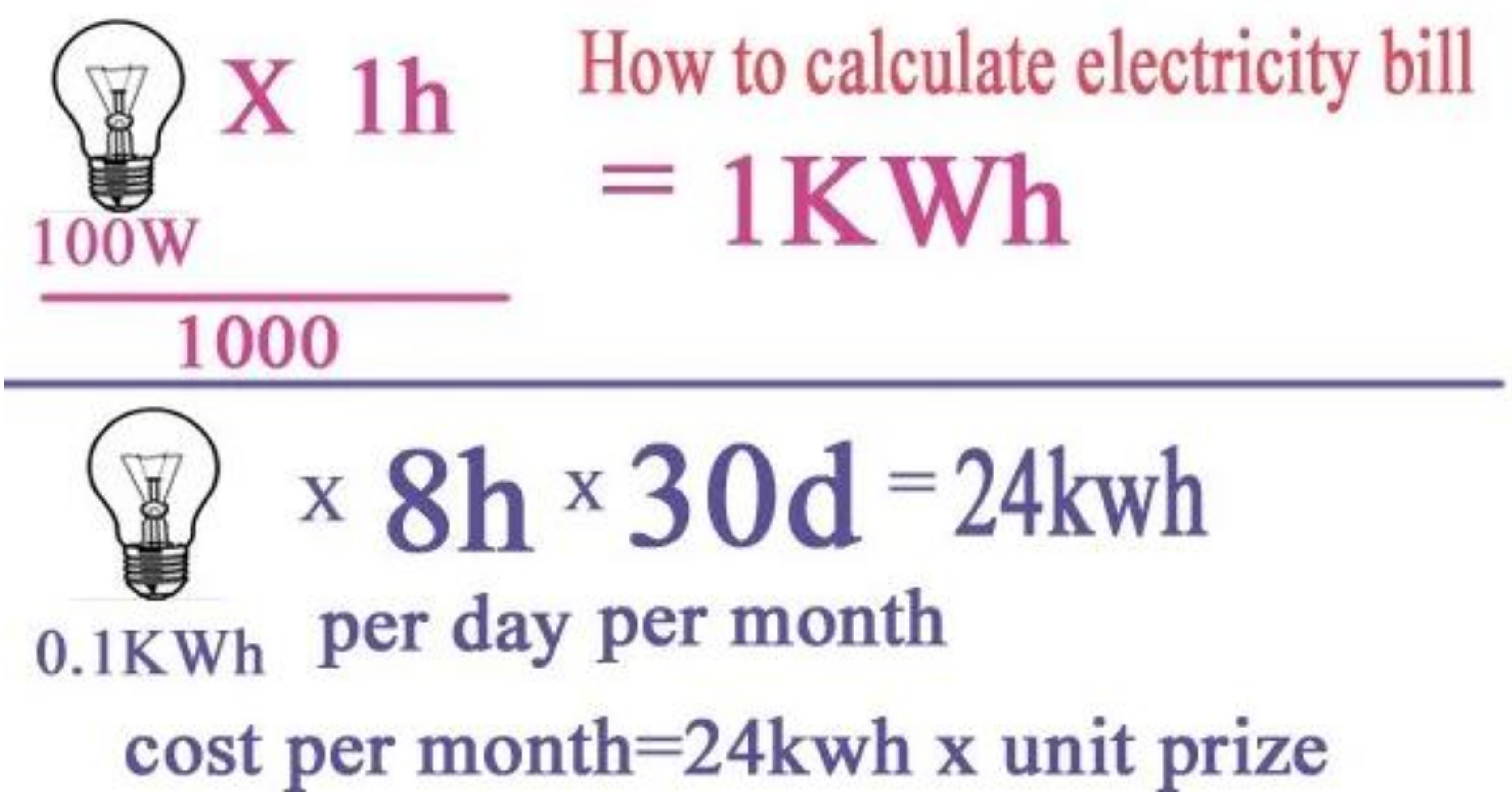
(I) Calculate the apparent power drawn by the motor. (10 *marks*)

(II) How much is the active power of the motor? (10 *marks*)

(III) Calculate the power factor of the motor. (10 *marks*)

(IV) Calculate the reactive power drawn by the motor. (10 *marks*)

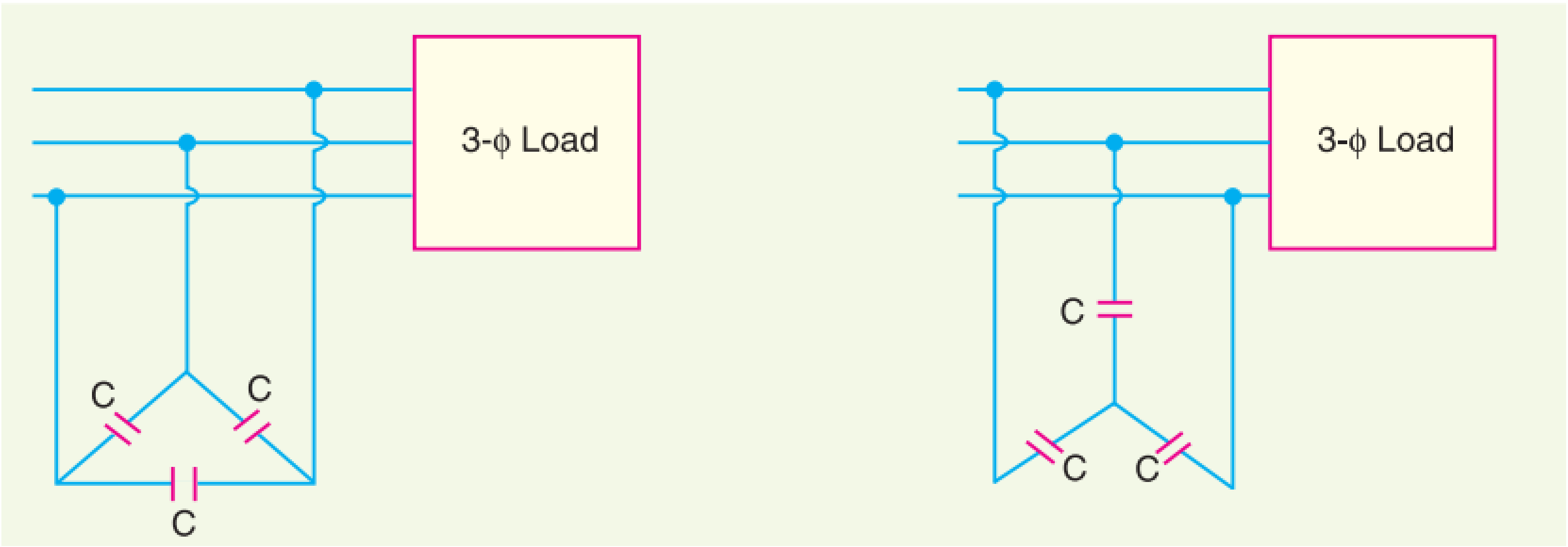
CALCULATION OF DOMESTIC ELECTRICITY BILL



Power Factor Improvement Equipment - Three Phase systems

Normally, the power factor of the whole load on a large generating station is in the region of 0·8 to 0·9. However, sometimes it is lower and in such cases it is generally desirable to take special steps to improve the power factor. This can be achieved by the following equipment :

1. Static capacitors.
2. Synchronous condenser.



1. Static capacitor. The power factor can be improved by connecting capacitors in parallel with the equipment operating at lagging power factor. The capacitor (generally known as static** capacitor) draws a leading current and partly or completely neutralises the lagging reactive component of load current. This raises the power factor of the load. For three-phase loads, the capacitors can be connected in delta or star as shown in Fig. 6.4. Static capacitors are invariably used for power factor improvement in factories.

Advantages

(*i*) They have low losses.

(*ii*) They require little maintenance as there are no rotating parts.

(*iii*) They can be easily installed as they are light and require no foundation.

(*iv*) They can work under ordinary atmospheric conditions.

Disadvantages

(*i*) They have short service life ranging from 8 to 10 years.

(*ii*) They are easily damaged if the voltage exceeds the rated value.

(*iii*) Once the capacitors are damaged, their repair is uneconomical.

** To distinguish from the so called *synchronous condenser* which is a synchrnous motor running at no load and taking leading current.

2. Synchronous condenser. A synchronous motor takes a leading current when over-excited and, therefore, behaves as a capacitor. An over-excited synchronous motor running on no load is known as *synchronous condenser.* When such a machine is connected in parallel with the supply, it takes a leading current which partly neutralises the lagging reactive component of the load. Thus the power factor is improved.

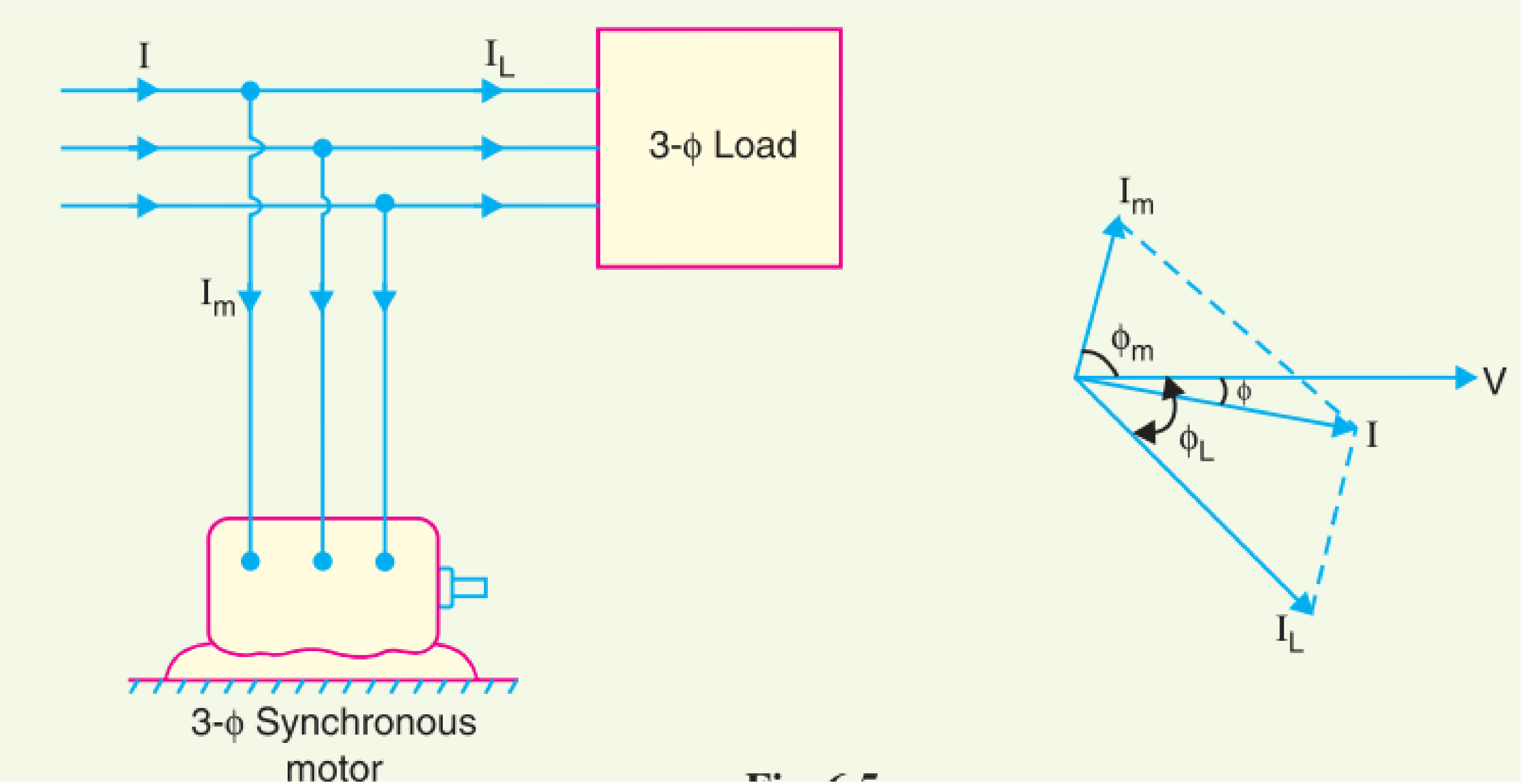


Fig 6.5 shows the power factor improvement by synchronous condenser method. The 3ϕ load takes current I_L at low lagging power factor cos ϕ_L. The synchronous condenser takes a current I_m which leads the voltage by an angle ϕ_m*. The resultant current I is the phasor sum of I_m and I_L and lags behind the voltage by an angle ϕ. It is clear that ϕ is less than ϕ_L so that cos ϕ is greater than cos ϕ_L. Thus the power factor is increased from cos ϕ_L to cos ϕ. Synchronous condensers are generally used at major bulk supply substations for power factor improvement.

Advantages

(*i*) By varying the field excitation, the magnitude of current drawn by the motor can be changed by any amount. This helps in achieving stepless † control of power factor.

---

* If the motor is ideal *i.e.*, there are no losses, then $\phi_m = 90^o$. However, in actual practice, losses do occur in the motor even at no load. Therefore, the currents I_m leads the voltage by an angle less than 90^o.

† The *p.f.* improvement with capacitors can only be done in steps by switching on the capacitors in various groupings. However, with synchronous motor, any amount of capacitive reactance can be provided by changing the field excitation.

(*ii*) The motor windings have high thermal stability to short circuit currents.

(*iii*) The faults can be removed easily.

Disadvantages

(*i*) There are considerable losses in the motor.

(*ii*) The maintenance cost is high.

(*iii*) It produces noise.

(*iv*) Except in sizes above 500 kVA, the cost is greater than that of static capacitors of the same rating.

(*v*) As a synchronous motor has no self-starting torque, therefore, an auxiliary equipment has to be provided for this purpose.

Note. The reactive power taken by a synchronous motor depends upon two factors, the d.c. field excitation and the mechanical load delivered by the motor. Maximum leading power is taken by a synchronous motor with maximum excitation and zero load.