NEPAL ENGINEERING COUNCIL

Concept of Basic Electrical and Electronics Engineering

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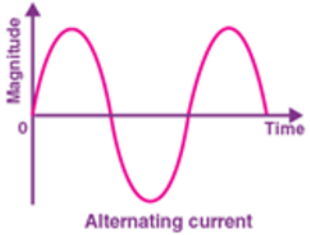
Contents

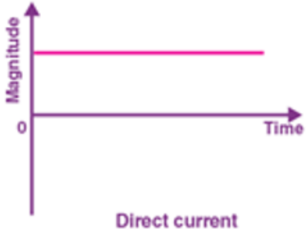
1.2 Network theorems: concept of superposition theorem, Thevenin`s theorem, Norton`s theorem, maximum power transfer theorem. R-L, R-C, R-L-C circuits, resonance in AC series and parallel circuit, active and reactive power. (AExE0102)

1.3 Alternating current fundamentals: Principle of generation of alternating voltages and currents and their equations and waveforms, average, peak and rms values, three phase system.

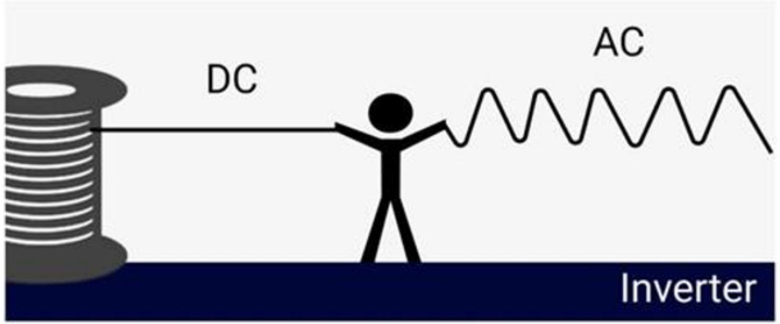
AC

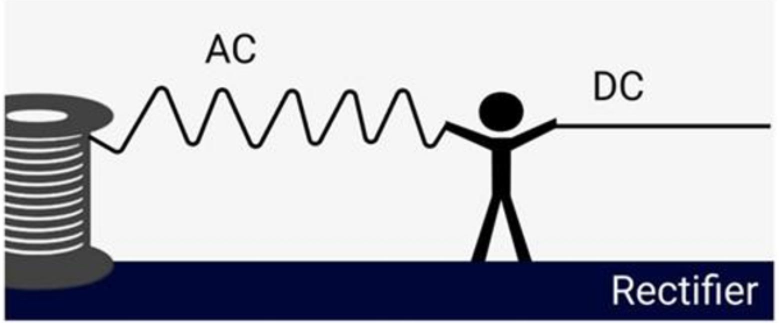


- Until now, we have discussed about D.C. supply and D.C. circuits.
- But 90 % of electrical energy used now a days is a.c. in nature.
- Electrical supply used for commercial purposes is alternating.
- The d.c. supply has constant magnitude with respect to time.
- An alternating current (a.c.) is the current which changes periodically both in magnitude and direction.
- Such change in magnitude and direction is measured in terms of cycles.
- Each cycle of a.c. consists of two half cycles namely positive cycle and negative cycle.
- Current increases in magnitude, in one particular direction, attains maximum and starts decreasing, passing through zero it increases in opposite direction and behaves similarly.



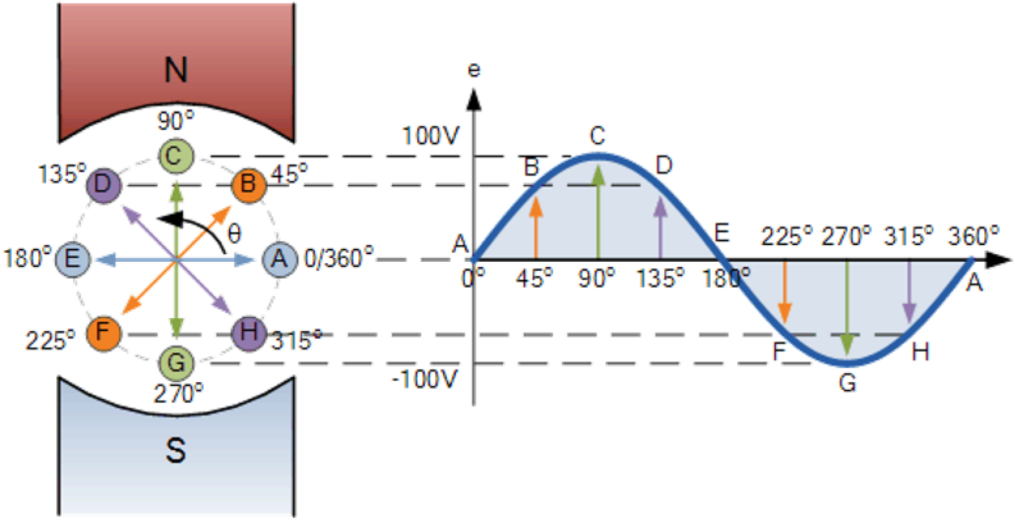
- The voltages in a.c. system can be raised or lowered with the help of a device called transformer. In d.c. system, raising and lowering of voltages is not so easy.
- As the voltages can be raised, electrical transmission at high voltages is possible. Now, higher the voltage, leaser is the current flowing through transmission line. Less the current, lesser are the copper losses and lesser is the conducting material required. This makes a.c. transmission always economical and efficient.
- A.C. electrical motors are simple in construction, are cheaper and require less attention from maintenance point of view.
- Whenever it is necessary, a.c. supply can be easily converted to obtain d.c. supply with rectifier.

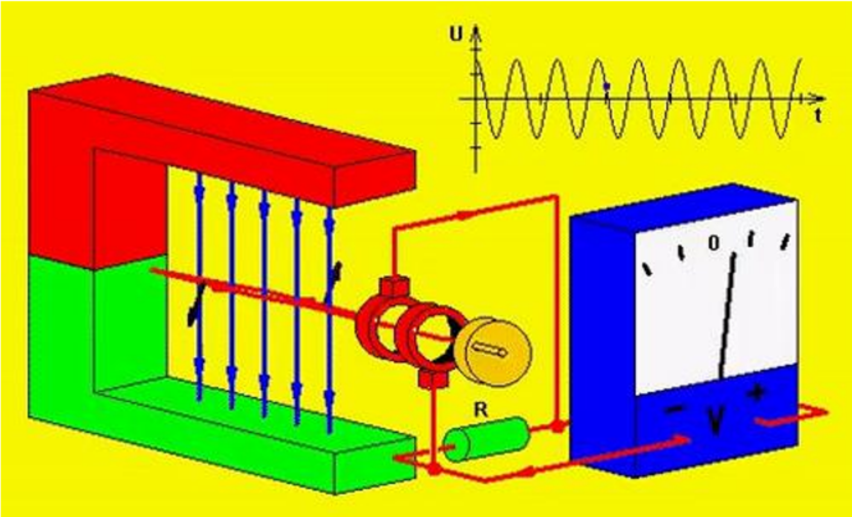




Generation of AC

- The machines which are used to generate electrical voltages are called generators.
- The generators which generate purely sinusoidal a.c. voltages are called **alternators.**
- The basic principle of an alternator is the principle of electromagnetic induction. The sine wave is generated according to Faraday's law of electromagnetic induction.





Faraday's Law of Electromagnetic Induction

- It states that whenever there is a relative motion between the conductor and the magnetic field in which it is kept, an e.m.f. gets induced in the conductor.

- Such an induced e.m.f. e then can be used to supply the electrical load.

e=-N$\frac{d\emptyset}{dt}$,

where N= number of turns of conductor and $\frac{d\emptyset}{dt}$ is rate of change of flux. And –ve sign is due to Lenz's law.

- The relative motion may exist because of movement of conductors with respect to magnetic field or movement of magnetic field with respect to conductor.
- Gives by Flemings Right hand rule

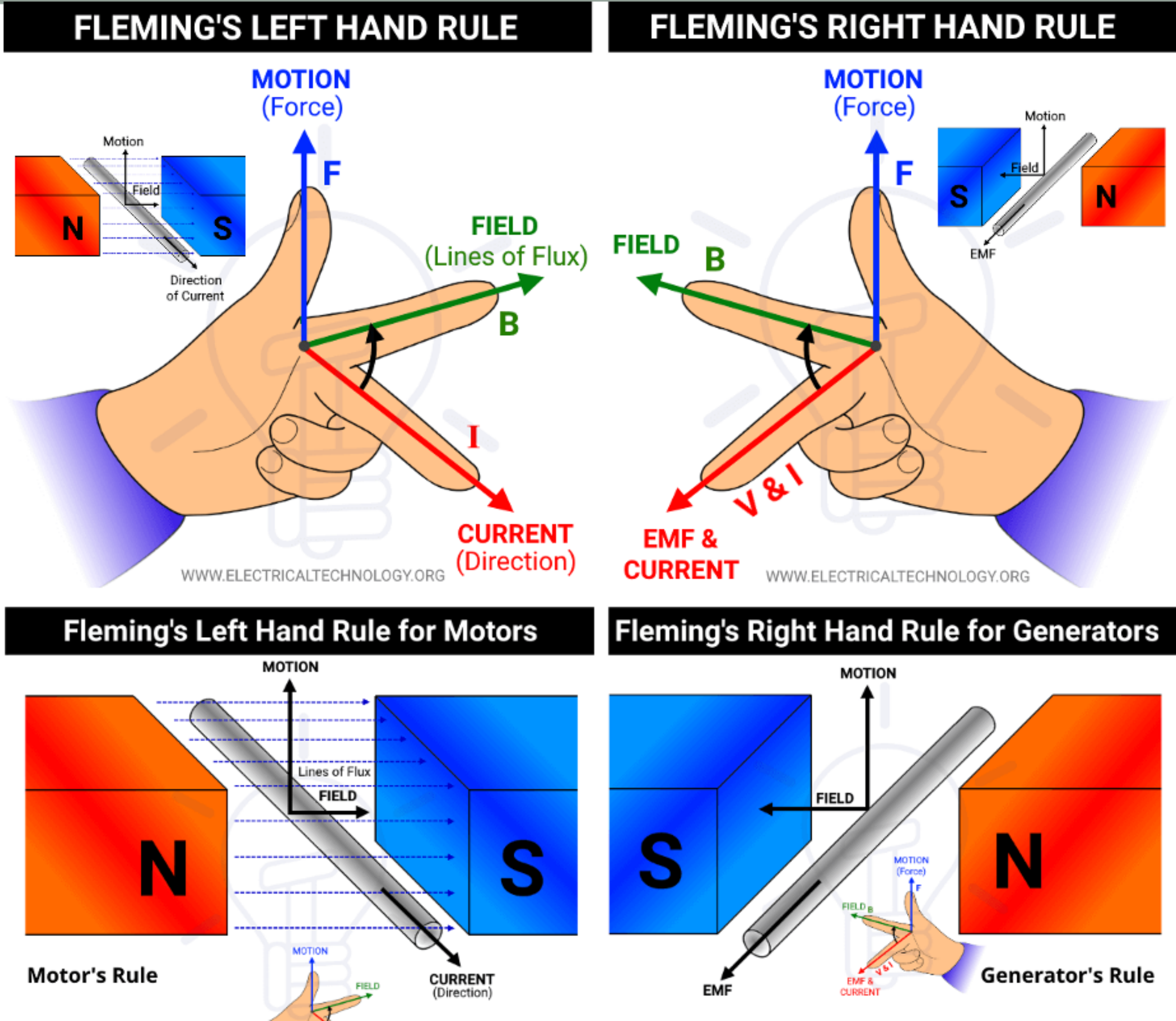
Flemings rule

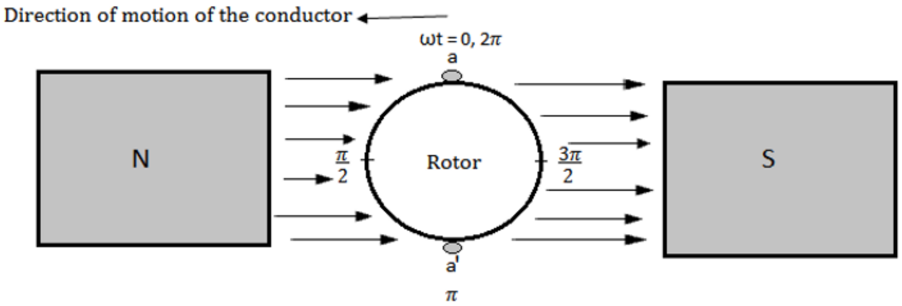
- Right hand: For generator
- Left hand: For motor

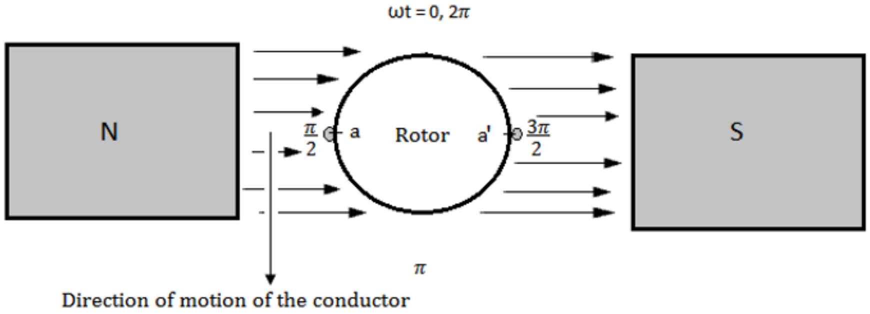
F: Force/motion

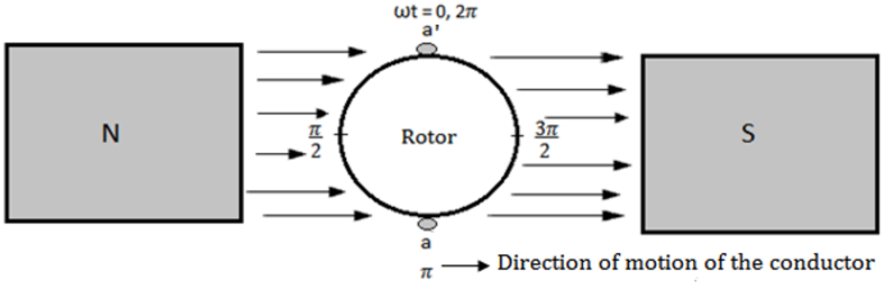
B: Magnetic flux density ($=\frac{\varphi}{A}$, Unit: Tesla or Wb/m)

I: Current

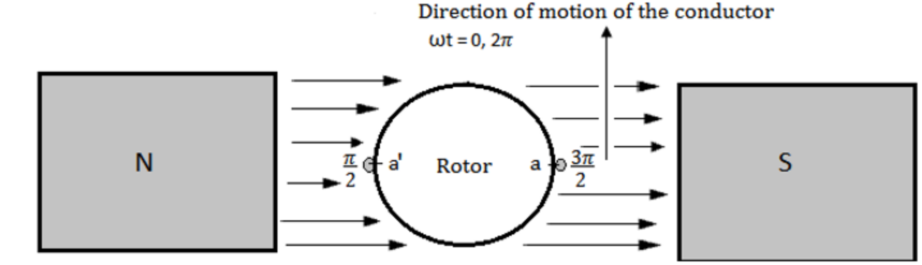


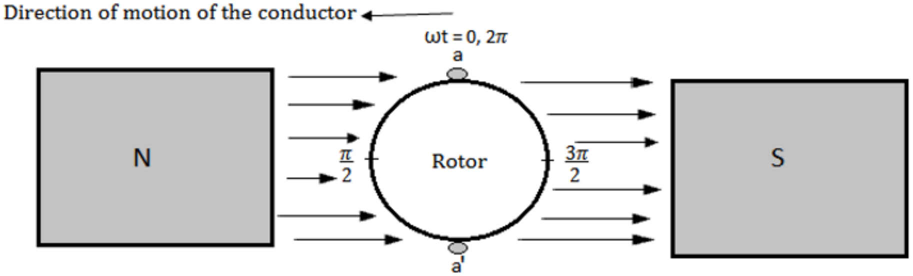






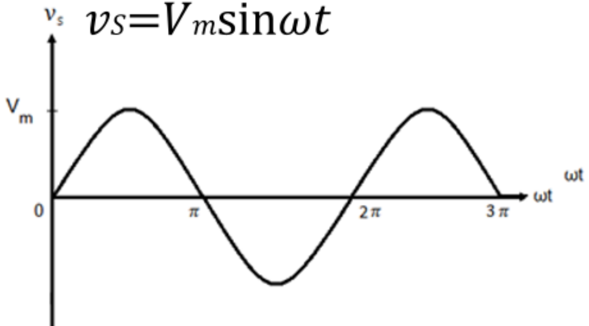
e=Blvsin(θ)





If we plot voltage v_S with respect to ωt, we get a sinusoidal waveform for this AC voltage as shown

$$v_S = V_m \sin\omega t$$



MCQ on Generation of AC voltage

- Separate file

Some terms

- Cycle

Each repetition of a set of positive and negative instantaneous values of the alternating quantity is called **a cycle**.

- Time period

The time taken by one cycle is known as time period that is denoted by T (Sec). Hence In T seconds the AC voltage attains =1 cycle.

- Frequency

The number of cycles per second is called frequency that is denoted by f (Hz). In 1 second the AC voltage attains = $1/T$ cycles.

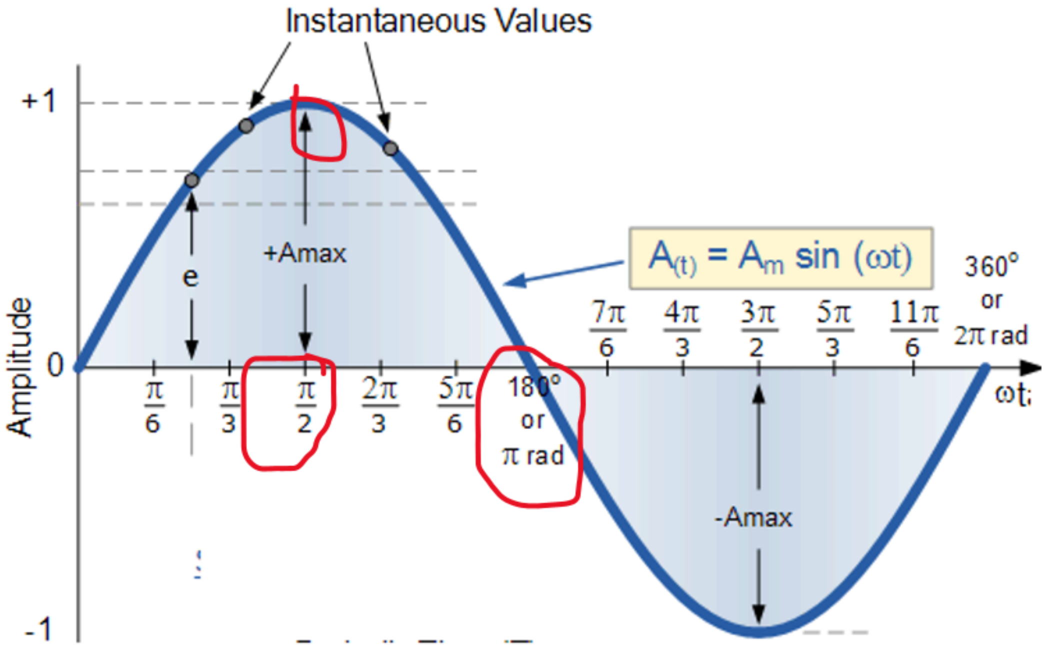
That is $f=1/T$

Instantaneous value.

- The value of an alternating quantity at a particular instant is known as its instantaneous value.

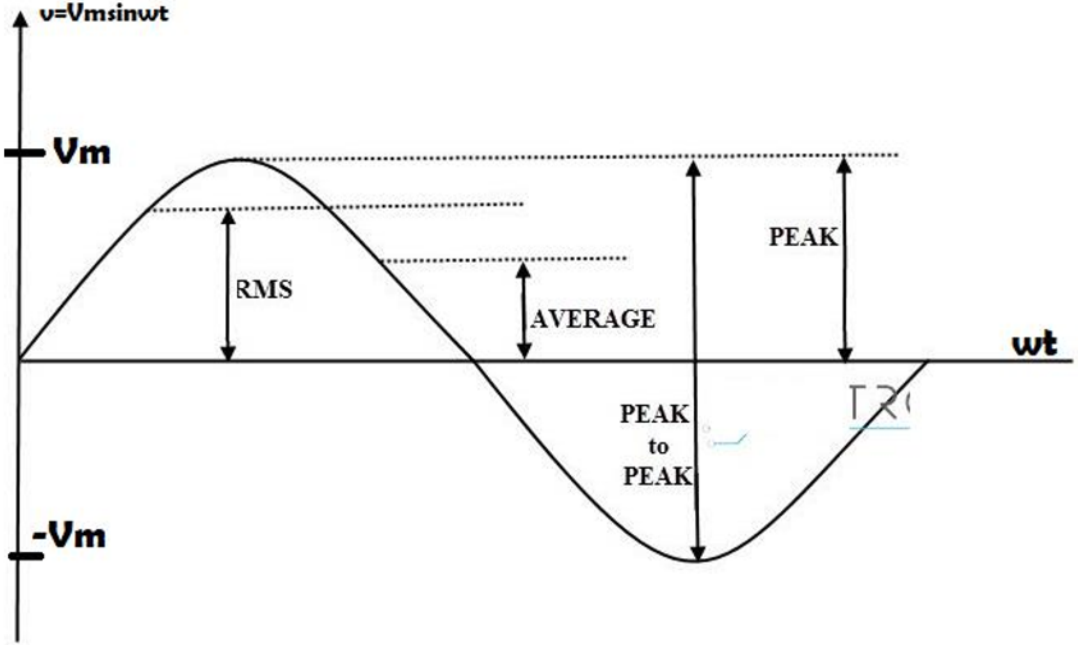
Q) The instantaneous value of the shown sinusoidal signal A at wt= pi and pi/2 are….. And …. Respectively.

a. 0, 0.5
b. 0.5, 0
c. 0, 0
d. 0, 1

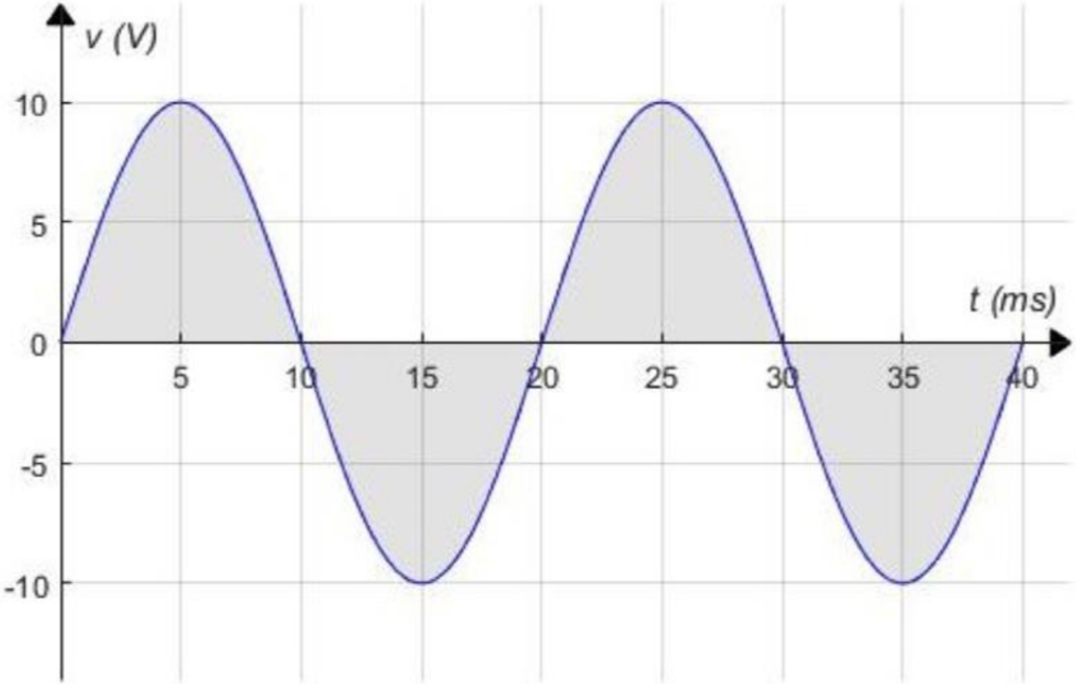


Peak Value and Peak to Peak Value

- Peak/ Maximum Value: (Vm)
- Peak to Peak value:2*Vm



1. For the sinusoidal waveform shown below,



e system

- a) 10V
- b)

At t=0.015S, -10V

At t= 0.02S…0V

- c) 20V
- d) 20 ms
- e) 2

(a) What is the peak value?
(b) What is the instantaneous value at 15 ms and at 20 ms?
(c) What is the peak-to-peak value of the waveform?
(d) What is the period of the waveform?
(e) How many cycles are shown?

Q) An alternating current of frequency 60 Hz has a maximum value of 12 A

1. Write down the equation for instantaneous values.
2. Find the value of the current after 1/360 second.
3. Time taken to reach 9.6 A for the first time.

$$i = 12 \sin 377\, t$$

$$i = 10.3924 \text{ A}$$

$$t = 2.459 \times 10^{-3} \text{ sec.}$$

Average Value

- Average value of AC is that steady current (DC) which transfers across any circuit, the **same amount of charge** as is transferred by that alternating current during the same time.
- The average value of an alternating quantity is defined as that value which is obtained by averaging all the instantaneous values over a period of half cycle.
- Mathamtically, For Sinusoidal current (i) with time period T, i=Imsinwt
- $I_{avg} = \frac{1}{T}\int_0^T idwt$

Average value ($I_{avg} = \frac{1}{T}\int_0^T i\,d\omega t$)

For full cycle,

Let i = I_m Sin θ and T=2Pi

$$I_{AV} = \frac{1}{2\pi}\int_0^{2\pi} i\,d\theta = \frac{1}{2\pi}\int_0^{2\pi} i_m \,\text{Sin}\theta\, d\theta$$

$$= \frac{I_m}{2\pi}\left[-\text{Cos}\,\theta\right]_0^{2\pi} = \frac{I_m}{2\pi}(\text{Cos}\,2\pi - \text{Cos}\,0)$$

$$= \frac{I_m}{2\pi}(1-1) = 0\ ;\quad I_{AV} = 0$$

For half cycle,

$$I_{AV} = \frac{1}{\pi}\int_0^{\pi} i\,d\theta$$

$$= \frac{1}{\pi}\int_0^{\pi} I_m \,\text{Sin}\,\theta.d\theta \qquad [\because i = I_m \,\text{Sin}\,\theta]$$

$$= \frac{I_m}{\pi}\left[-\text{Cos}\,\theta\right]_0^{\pi} = \frac{I_m}{\pi}\left[-\text{Cos}\,\pi - (-\text{Cos}\,0)\right]$$

$$= \frac{I_m}{\pi}[(+1)-(-1)] = \frac{I_m}{\pi}(+2)$$

$$I_{AV} = \frac{2}{\pi} I_m = 0.637\text{ A}$$

Key Point: For a symmetrical a.c., average value over a complete cycle is zero as both positive and negative half cycles are exactly identical. Hence, the average value is defined for half cycle only.

Root Mean Square (RMS) value

The effective or r.m.s. value of an alternating current is given by that steady current (D.C.) which, when flowing through a given circuit for a given time, produces the **same amount of heat** as produced by the alternating current, which when flowing through the same circuit for the same time.

The ammeters and voltmeters indicates the r.m.s. values of current and voltage respectively.

Mathematically, For any signal v,

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T v^2 d\omega t}$$

RMS Value of Sinusoidal quantity

The RMS value (Irms or I) of the current $i = I_m$ Sin θ is,

$$I = \sqrt{\left(\int_0^{2\pi} \frac{i^2 d\theta}{2\pi}\right)} = \sqrt{\left(\frac{I_m^2}{2\pi}\int_0^{2\pi} \sin^2\theta \, d\theta\right)}$$

We know $\cos 2\theta = 1 - 2\sin^2\theta \quad \therefore \quad \sin^2\theta = \frac{1-\cos 2\theta}{2}$

Then

$$I = \sqrt{\left(\frac{I_m^2}{4\pi}\int_0^{2\pi} (1-\cos 2\theta)\, d\theta\right)} = \sqrt{\left(\frac{I_m^2}{4\pi}\left|\theta - \frac{\sin 2\theta}{2}\right|_0^{2\pi}\right)}$$

$$= \sqrt{\frac{I_m^2}{4} \quad 2} \qquad \sqrt{\frac{I_m^2}{2}} \qquad \therefore \; \boxed{I = \frac{I_m}{\sqrt{2}} = 707 \; I_m}$$

For sinusoidal wave:

$V_{avg} = \frac{2}{\pi} Vm = 0.637Vm$

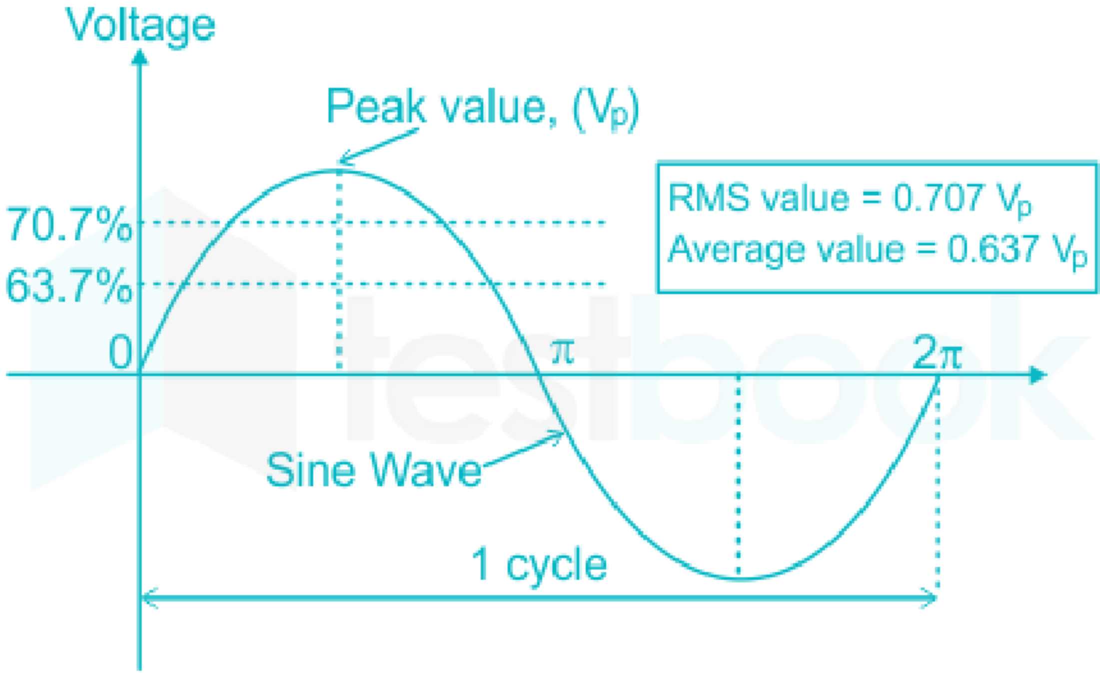
$V_{rms} = \frac{Vm}{\sqrt{2}} = 0.707Vm$

$$\textbf{Form Factor} = \frac{\text{RMS Value}}{\text{Average Value}}$$

$$= \frac{0.707\ E_M}{0.637\ E_M} \text{ Or } \frac{0.707\ I_M}{0.637\ I_M} = \mathbf{1.11}$$

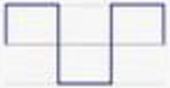
$$\textbf{Peak Factor} = \frac{\text{Maximum Value}}{\text{R.M.S Value}}$$

$$\frac{E_M}{0.707\ E_M} = \mathbf{1.414}$$



Some Popular waveform

Crest Factor/Peak factor
Form factor/ Waceform factor

Wave type	Waveform	Mean Value	RMS value	Crest factor	Waveform factor
DC		1	1	1	
Sine wave		$\frac{2}{\pi} \approx 0.637$	$\frac{1}{\sqrt{2}} \approx 0.707$	$\sqrt{2} \approx 1.414$	$\frac{\pi}{2\sqrt{2}} \approx 1.11$
Full-wave rectified sine		$\frac{2}{\pi} \approx 0.637$	$\frac{1}{\sqrt{2}} \approx 0.707$	$\sqrt{2} \approx 1.414$	$\frac{\pi}{2\sqrt{2}} \approx 1.11$
Half-wave rectified sine		$\frac{1}{\pi} \approx 0.318$	$\frac{1}{2} = 0.5$	2	$\frac{\pi}{2} \approx 1.571$
Triangle wave		$\frac{1}{2} = 0.5$	$\frac{1}{\sqrt{3}} \approx 0.577$	$\sqrt{3} \approx 1.732$	$\frac{2}{\sqrt{3}} \approx 1.155$
Square wave		1	1	1	1

MCQ

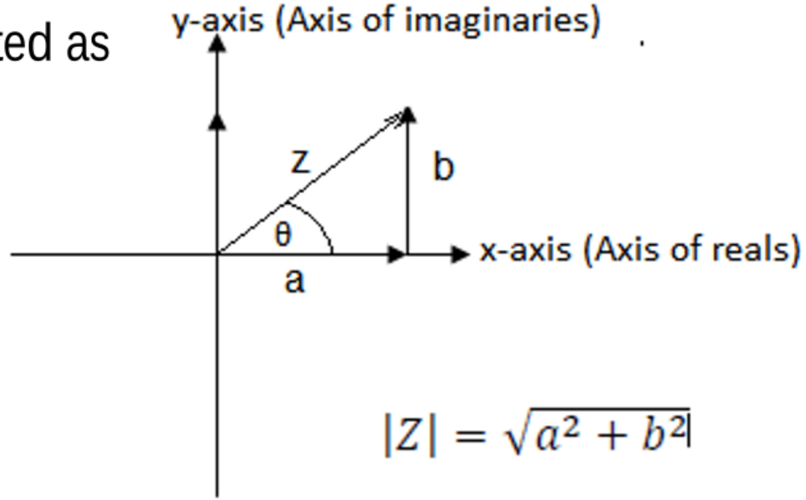
- Separate files

Complex no.

Mathematically a phasor quantity is represented as

- Rectangular form: $Z=a+jb$
- Trigonometric form: $Z=|Z|(\cos\theta+j\sin\theta)$
- Exponential form: $Z=|Z|ej\theta$

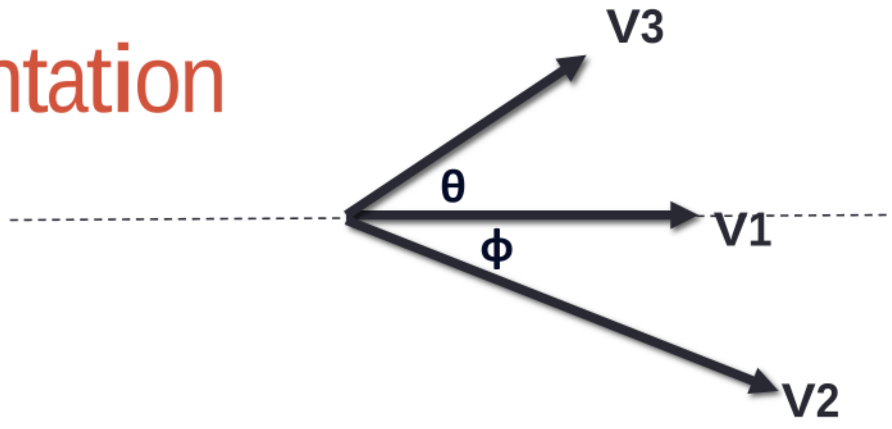
  where $ej\theta=\cos\theta+j\sin\theta$
- Polar form: $Z=|Z|\angle\theta$



$$|Z| = \sqrt{a^2 + b^2}$$

$$\tan\theta = \frac{b}{a}$$

AC and Phasor Representation



If v1= Vm1 sin wt

then $V1_{rms}$=V1 (V1=Vm1/√2)

- It can be assumed as **V1∠ 0**

And if **v2=Vm2 sin(wt -ϕ)**

- Then it can be represented as V2 ∠-ϕ

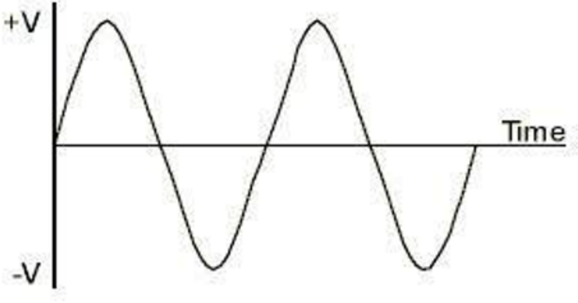
And if **v3=Vm3 sin**(wt+**θ**)

- Then it can be represented as V3 ∠ϕ **θ**

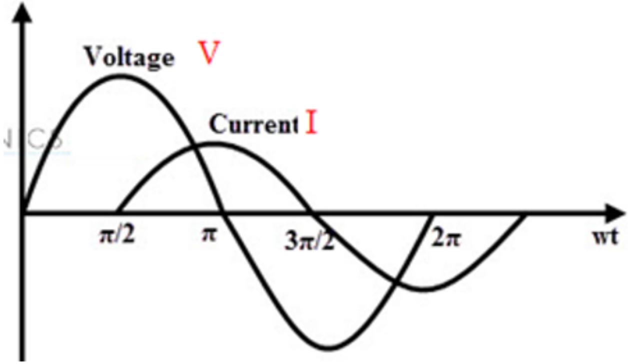
- Imagine a reference plane
- Frequency of all quantity should be same
- Length of line represent magnitude of the AC quantity
- Angle represent phase difference between two same frequency signal
- Here V3 leads VI by angle **θ (Anticlock)**
- And V2 lags V1 by angle **ϕ (Clockwise)**

Waveform and Phasor Representation of AC

Eg.

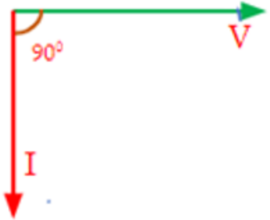


v= Vm sin wt



v= Vm sin wt

i= Im sin(wt-90)



Angle between V and I is known as phase angle. Represented by **ϕ**

For given waveform **ϕ=90 degree.**

Power Factor of AC Circuit

- The numerical value of cosine of the phase angle between the applied voltage and the current drawn from the supply voltage gives the power factor.
- i.e Cos **ϕ**
- It cannot be greater than 1.

- If current lags voltage power factor is said to be lagging.
- If current leads voltage power factor is said to be leading.

MCQ

What does a phasor represent?

a) Current and resistance

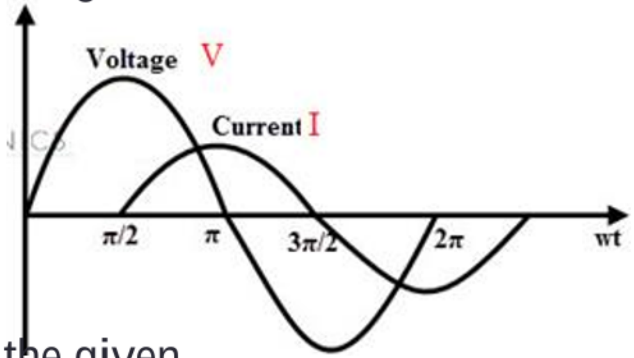
b) Current and voltage

c) Voltage and resistance

d) Voltage and power

Which statement is correct for the given phasor?

a. V leads I by 90 degree.
b. I lags V by 90 degree
c. Both a and b
d. V and I are in phase



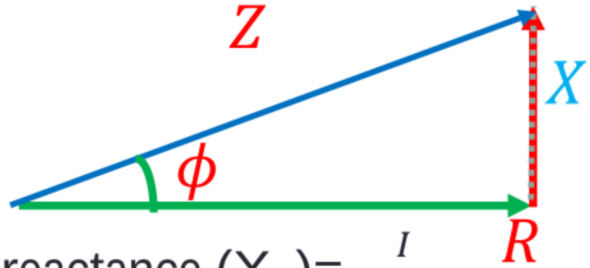
Which statement is correct for the given phasor?

a. V and I have same frequency
b. I lags V by 90 degree
c. Phase difference between V and I is 90 degree
d. Power Factor is 0
e. All of the above

Impedance (Z)

- Opposition to current offered by electrical circuit elements: R, L and C
- Unit: Ohm

$$Z = R + j(X_L - X_C)$$



Where, Inductive reactance(X_L)= $2\pi f L$ and, Capacitive reactance (X_C)= $\frac{I}{2\pi f C}$

Fig: Impedance Triangle

Also, Z is a complex can also be expressed as $|Z|\angle\phi$

where, $|Z| = \sqrt{R^2 + (X_L - X_C)^2}$ and $\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$

so, Power factor $(\cos\phi) = \frac{R}{Z}$

Admittance (Y) is reciprocal of Z, Y=1/Z

AC Power

Apparent Power [S]

- It is defined as the product of **r.m.s.** value of voltage (V) and current (I).
- It is denoted by S.

$$S = V \times I \quad VA$$

- It is measured in unit volt-amp (VA) or kilo volt-amp (kVA).

Real or True or Active Power [P]

- It is defined as the product of the applied voltage and the active component of the current.
- It is real component of the apparent power.

$$P = V \times I\cos\phi \quad \text{Watts}$$

- It is measured in unit watts (W) or kilowatts (kW)

Different Power of AC Series RC Circuit

Reactive Power [Q]

- It is defined as product of the applied voltage and the reactive component of the current.
- It is also defined as imaginary component of the apparent power.
- It is represented by 'Q'.

$$Q = V \times I sin\phi \quad VAR$$

- It is measured in unit volt-amp reactive (VAR) or kilovolt-amp reactive (kVAR).

Hence:

$$S = V \times I \quad VA$$

$$P = V \times I cos\phi \quad \text{Watts}$$

$$Q = V \times I sin\phi \quad VAR$$

$$Power\ Factor\ cos\phi = \frac{True\ Power}{Apparent\ Power} = \frac{P}{S}$$

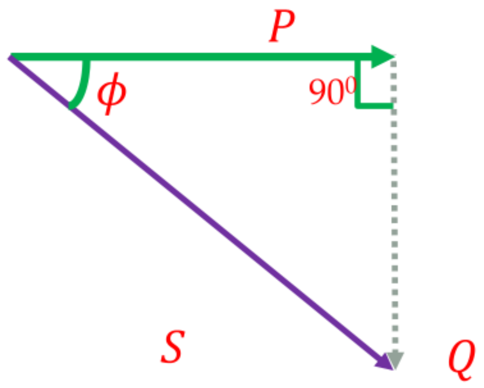


Fig: Power Triangle

Power Factor $\cos\phi$ of AC Circuit

Cosine of angle between voltage and current $\cos\phi$

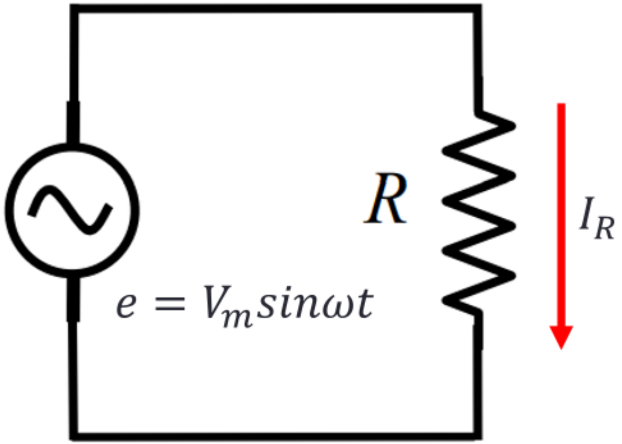
Also in term of Z $\text{Power Factor} = \cos\phi = \frac{R}{Z}$

- It is defined as factor by which the apparent power must be multiplied in order to obtain the true power.

$$Power\ Factor = \frac{True\ Power}{Apparent\ Power} = \frac{P}{S}$$

- If current lags voltage power factor is said to be lagging.
- If current leads voltage power factor is said to be leading.

R in AC



Conclusion:
BOTH V and I are in Phase.
NO PHASE DIFFERENCE

Since, Resistor is connected in parallel with source,

$$V_R = e = V_m sin\omega t$$

Now, Current through Resistor is,[By Ohms Law]

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

$$I_R = \frac{V_m sin\omega t}{R}$$

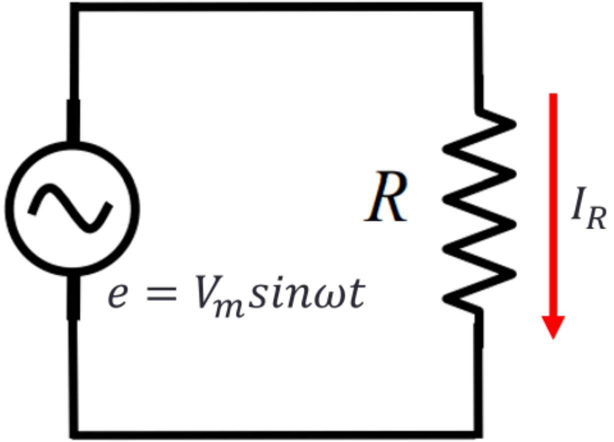
Therefore, Instantaneous Current Through Resistor is,

$$I_R = \frac{V_m}{R} sin\omega t$$

$$I_R = I_m \sin(\omega t)$$

$$\therefore \boldsymbol{I_m = \frac{V_m}{R}}$$

Power in Purely Resistive Circuits



$$V_R = V_m sin\omega t \qquad I_R = I_m sin\omega t$$

Instantaneous Power is given by,

$$p = v \times i$$

$$p = V_m sin\omega t \times I_m sin\omega t$$

$$p = V_m I_m \sin^2 \omega t$$

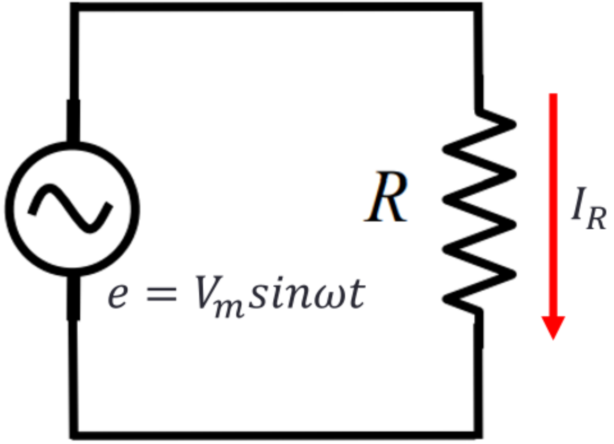
$$p = V_m I_m \frac{[1 - cos2\omega t]}{2}$$

$$p = \frac{V_m I_m}{2} - \frac{V_m I_m}{2} cos2\omega t$$

Constant Power Component

Fluctuating Component

Power in Purely Resistive Circuits



$$p = \frac{V_m I_m}{2} - \frac{V_m I_m}{2} cos2\omega t$$

Average Value of fluctuating part with double frequency over a cycle will be zero. So average power consumption over one cycle will be constant part only.

$$P_{av} = \frac{V_m I_m}{2}$$

$$P_{av} = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}}$$

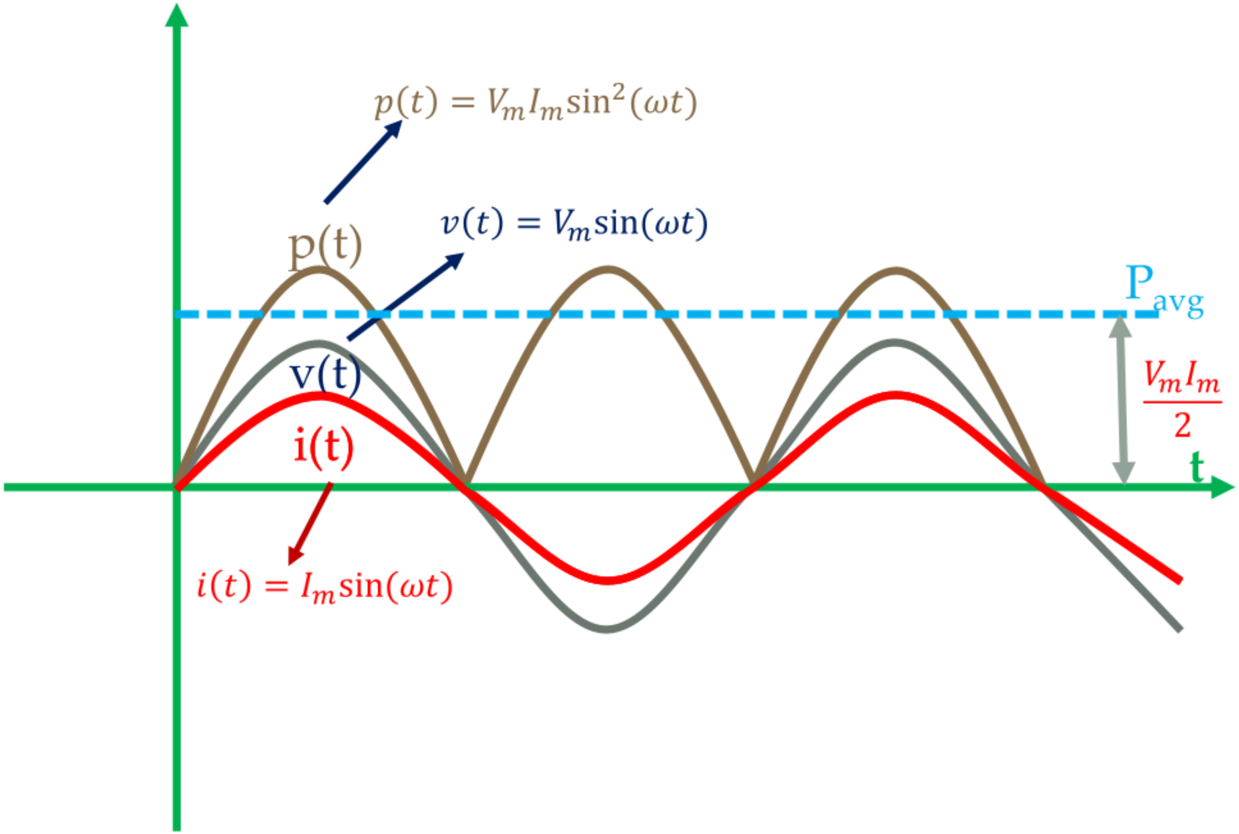
$$P_{av} = V_{rms} I_{rms} \quad Watts$$

$$P_{av} = VI = I^2 R \quad Watts$$

$$P_{av} = \frac{1}{2\pi} \int_0^{2\pi} p \, dwt$$

$$P_{av} = \frac{V_m I_m}{2}$$

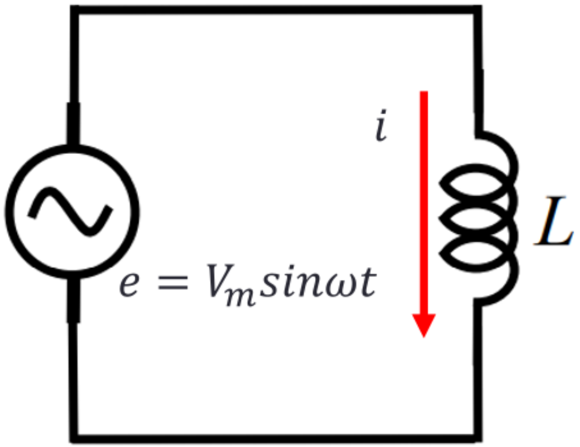
Waveform of AC with Pure Resistance



Conclusion: For R only

- For R only
- V and I are in phase
- Phase angle ϕ=0
- Power Factor Cosϕ=1 (Unity)
- Only Active Power (P) exist no reactive power(Q) ,

AC through Pure Inductor



Due to Current through Inductor , Self EMF is induced and is,

$$v_L = -L\frac{di}{dt}$$

At all instant applied voltage **e** is equal and opposite to the self induced EMF,

$$e = -v_L$$

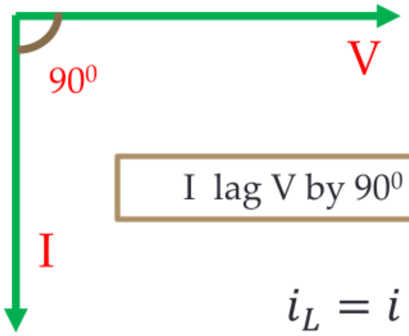
$$-V_m sin\omega t = -L\frac{di}{dt}$$

$$di = \frac{V_m}{L} sin\omega t\, dt$$

$$i = \int di = \frac{V_m}{L}\int sin\omega t\ dt$$

$$i = \frac{V_m}{L}\left[\frac{-cos\omega t}{\omega}\right] = -\frac{V_m}{\omega L}\sin\left(\frac{\pi}{2} - \omega t\right)$$

$$i = \frac{V_m}{\omega L}\sin\left(\omega t - \frac{\pi}{2}\right)$$



I lag V by 90⁰

$$i_L = i = I_m \sin\left(\omega t - \frac{\pi}{2}\right)$$

Inductive Reactance

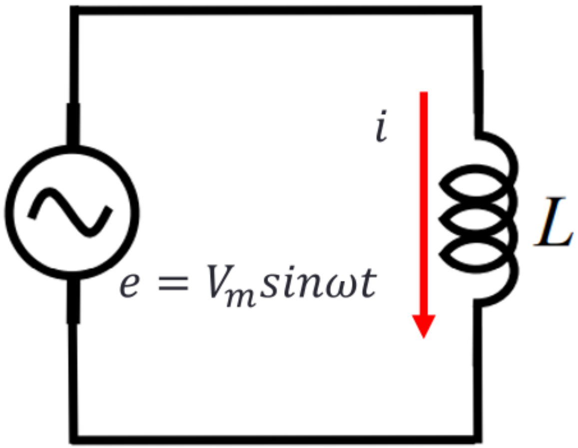
In Purely Inductive Circuit, We have

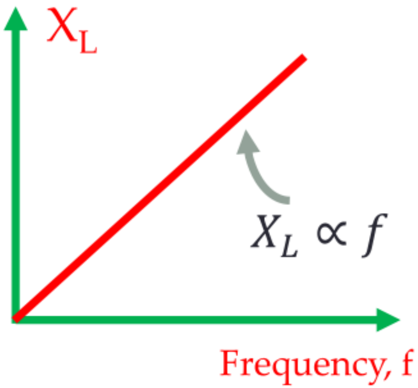
$$I_m = \frac{V_m}{\omega L}$$

$$I_m = \frac{V_m}{X_L}$$

Where, $X_L = \omega L = 2\pi f L \quad Ohms$

This term X_L is known as Inductive Reactance.

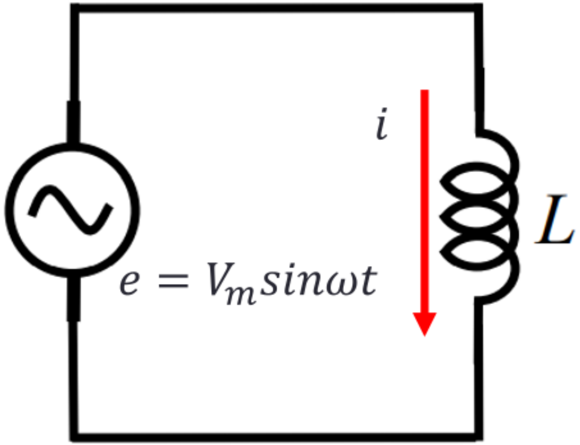




What will happen if supply is DC?

Inductor will behave as short circuit.

Power in Purely Inductive Circuits



$$v_L = V_m sin\omega t$$

$$i_L = I_m \sin\left(\omega t - \frac{\pi}{2}\right) = -I_m cos\omega t$$

Instantaneous Power is given by,

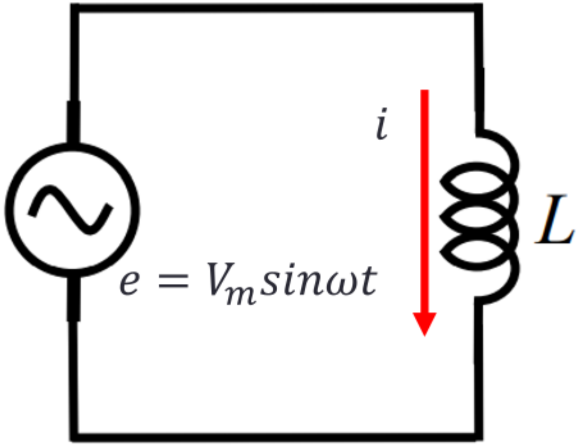
$$p = v_L \times i_L$$

$$p = V_m sin\omega t \times (-I_m cos\omega t)$$

$$p = -V_m I_m \sin\omega t \cos\omega t$$

$$p = -\frac{V_m I_m}{2} sin 2\omega t$$

Power in Purely Inductive Circuits



$$p = -\frac{V_m I_m}{2} \; sin2\omega t$$

Average Value of Instantaneous Power Over a cycle is,

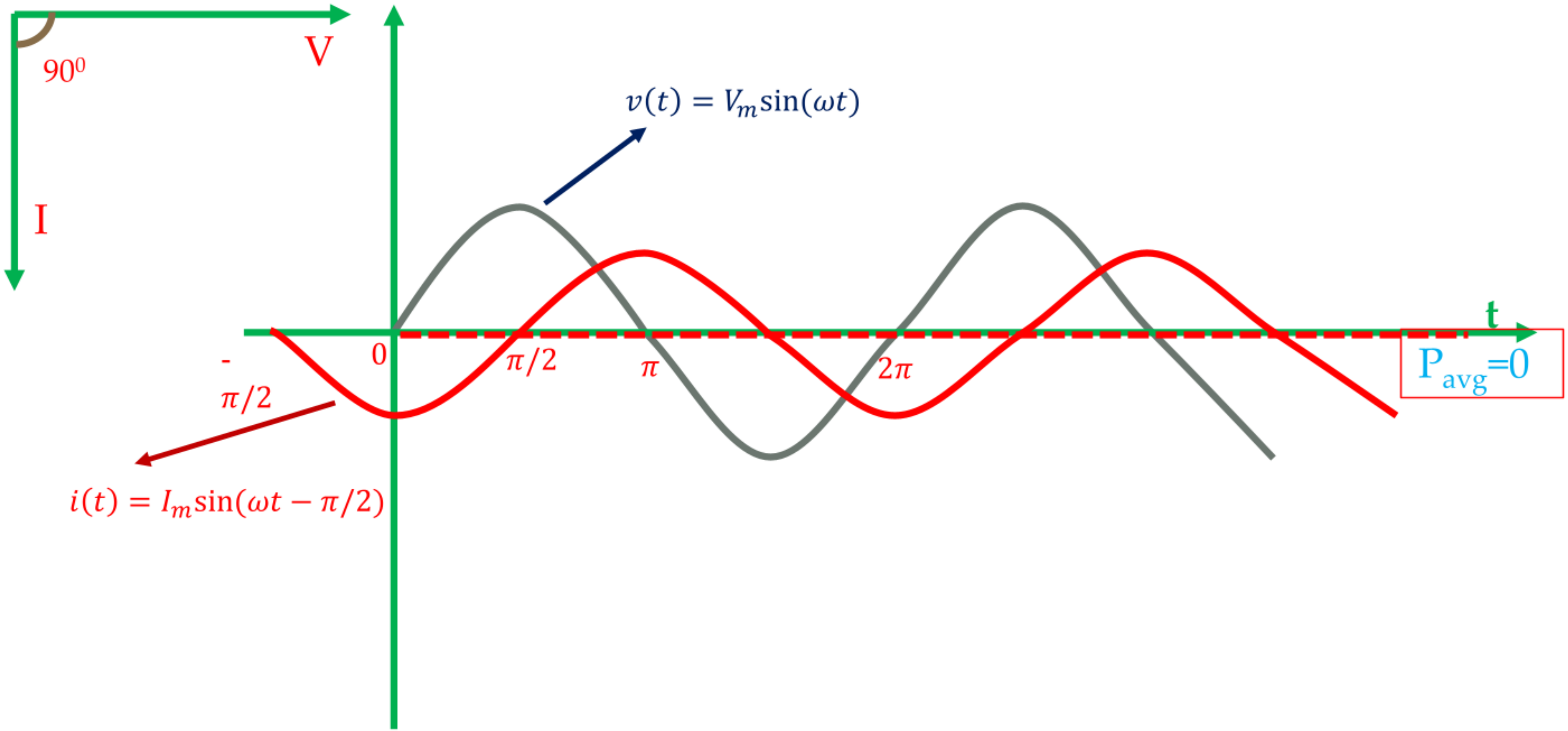
$$P_{av} = \frac{1}{2\pi}\int_0^{2\pi} p \; dwt$$

$$P_{av} = \frac{1}{2\pi}\int_0^{2\pi} -\frac{V_m I_m}{2} \; sin2\omega t \; dwt$$

$$P_{av} = \frac{1}{2\pi}\left[-\frac{V_m I_m}{2}\frac{-cos2\omega t}{2}\right]_0^{2\pi}$$

$$\boxed{P_{av} = 0}$$

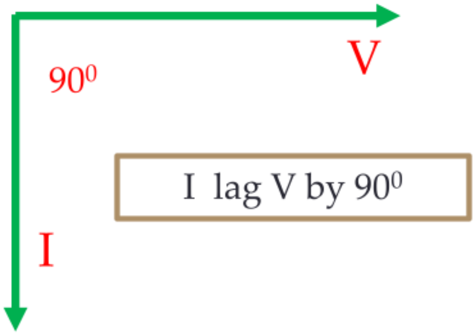
Waveform of AC with Pure Inductor



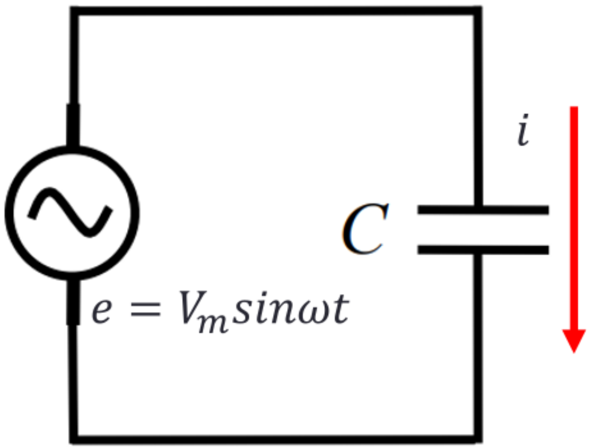
Conclusion: For L only

For L only

- V lead I by 90 degree or I lags V by 90 degree.
- Phase angle ϕ=9
- Power Factor Cosϕ=0
- Only reActive Power (Q) exist no active power(P) ,



AC through Pure Capacitor



We can see,

$$e = v_c = V_m sin\omega t$$

Current charges the capacitor, Instantaneous Charge is,

$$q = C v_c$$

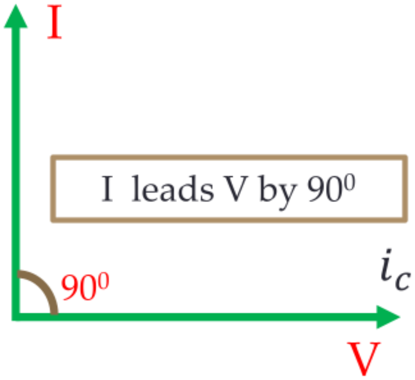
$$q = C V_m sin\omega t$$

$$\frac{dq}{dt} = C V_m \frac{dsin\omega t}{dt}$$

$$i = C V_m cos\omega t . \omega$$

$$i = \omega C V_m \sin\left(\frac{\pi}{2} + \omega t\right)$$

$$i = \omega C V_m \sin\left(\omega t + \frac{\pi}{2}\right)$$



$$i_c = i = I_m \sin\left(\omega t + \frac{\pi}{2}\right)$$

Capacitive Reactance

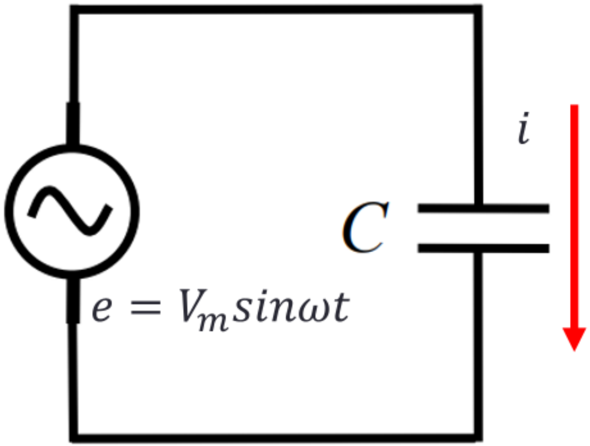
In Purely Inductive Circuit, We have

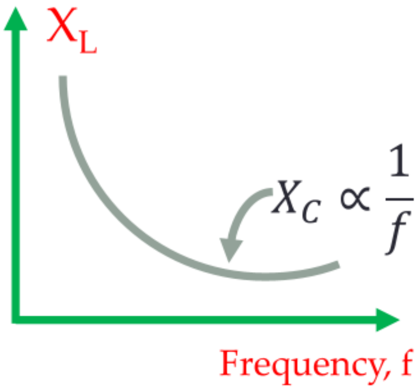
$$I_m = \omega C V_m$$

$$I_m = \frac{V_m}{X_C}$$

Where, $X_C = \frac{1}{\omega C} = \frac{1}{2\pi f L} \quad Ohms$

This term X_C is known as Capacitive Reactance.

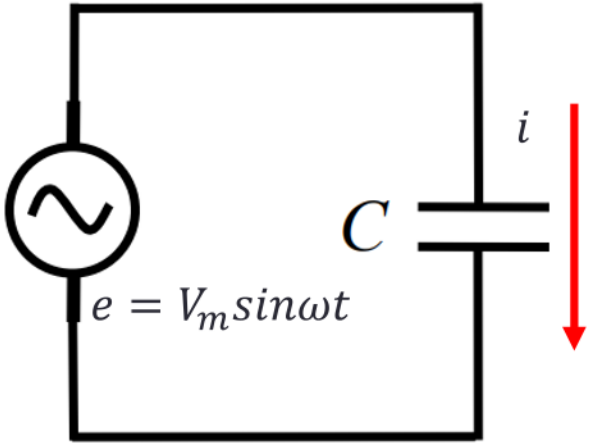




What will happen if supply is DC?

Capacitor will behave as Open circuit.

Power in Purely Capacitor Circuits



$$v_c = V_m sin\omega t \qquad i_c = I_m \sin\left(\omega t + \frac{\pi}{2}\right) = I_m cos\omega t$$

Instantaneous Power is given by,

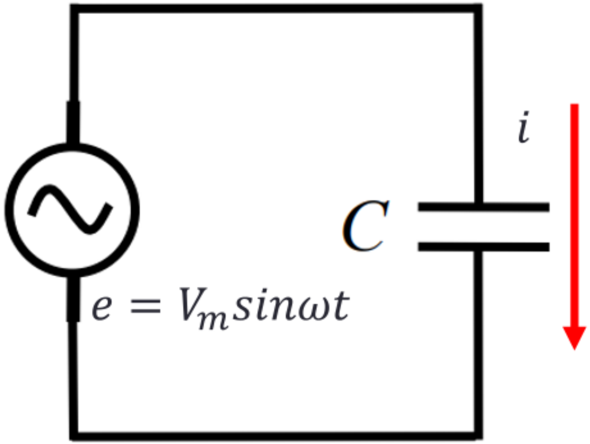
$$p = v_C \times i_C$$

$$p = V_m sin\omega t \times (I_m cos\omega t)$$

$$p = V_m I_m \, sin\,\omega t\, cos\,\omega t$$

$$p = \frac{V_m I_m}{2}\, sin\mathbf{2}\omega t$$

Power in Purely Capacitor Circuits



$$p = \frac{V_m I_m}{2}\, sin2\omega t$$

Average Value of Instantaneous Power Over a cycle is,

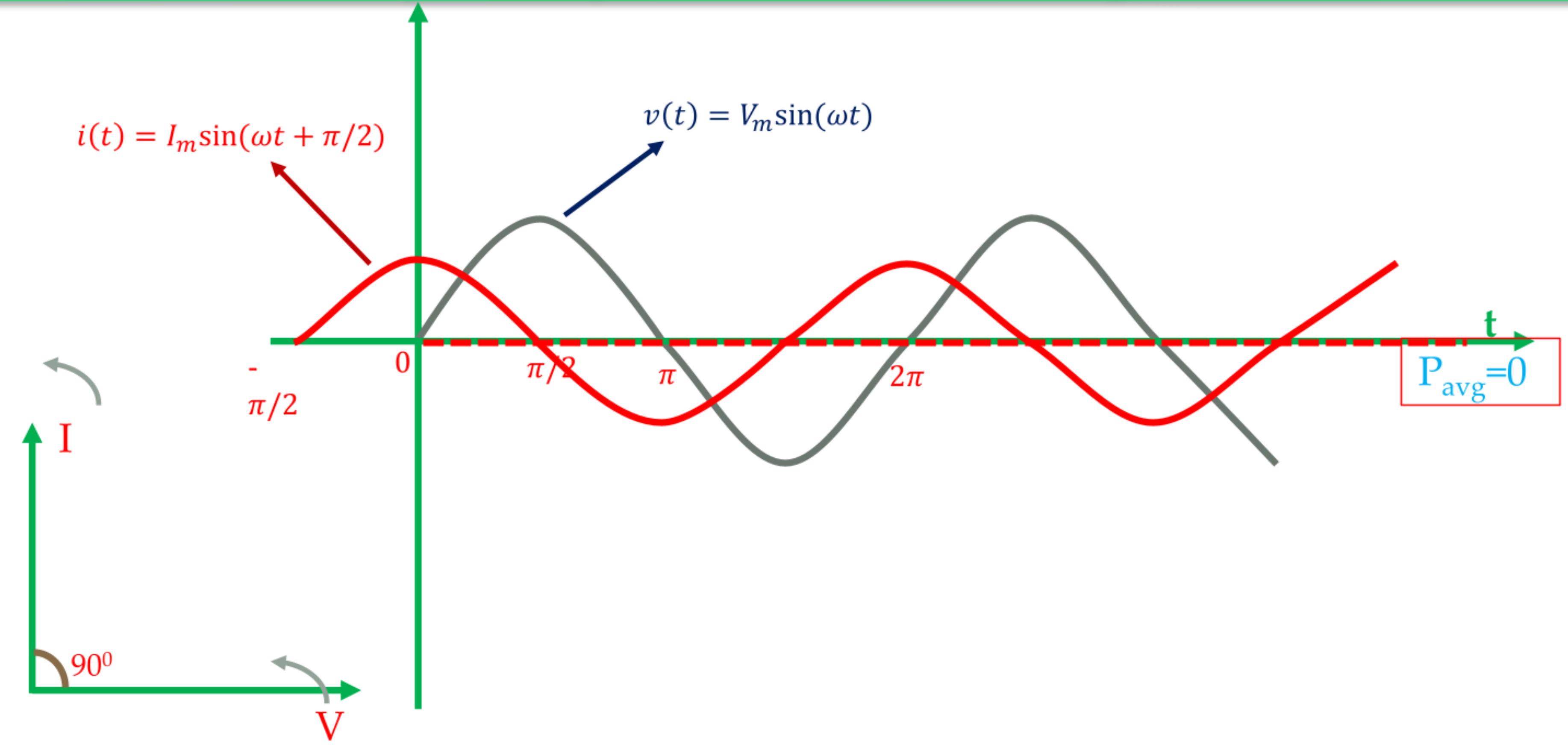
$$P_{av} = \frac{1}{2\pi}\int_0^{2\pi} p\, dwt$$

$$P_{av} = \frac{1}{2\pi}\int_0^{2\pi} \frac{V_m I_m}{2}\, sin2\omega t\, dwt$$

$$P_{av} = \frac{1}{2\pi}\left[\frac{V_m I_m}{2}\,\frac{-cos2\omega t}{2}\right]_0^{2\pi}$$

$$\boxed{P_{av} = 0}$$

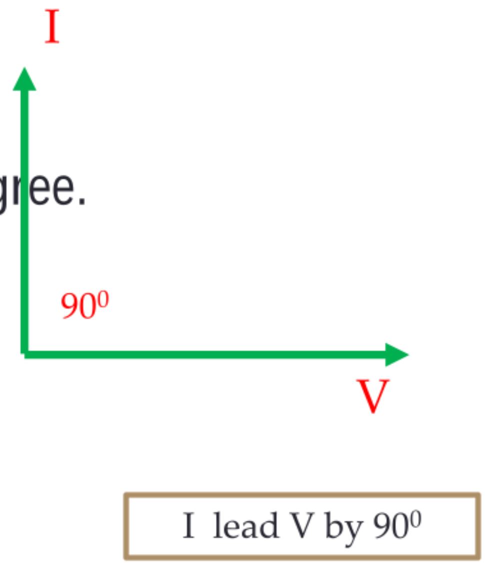
Waveform of AC with Pure Capacitor



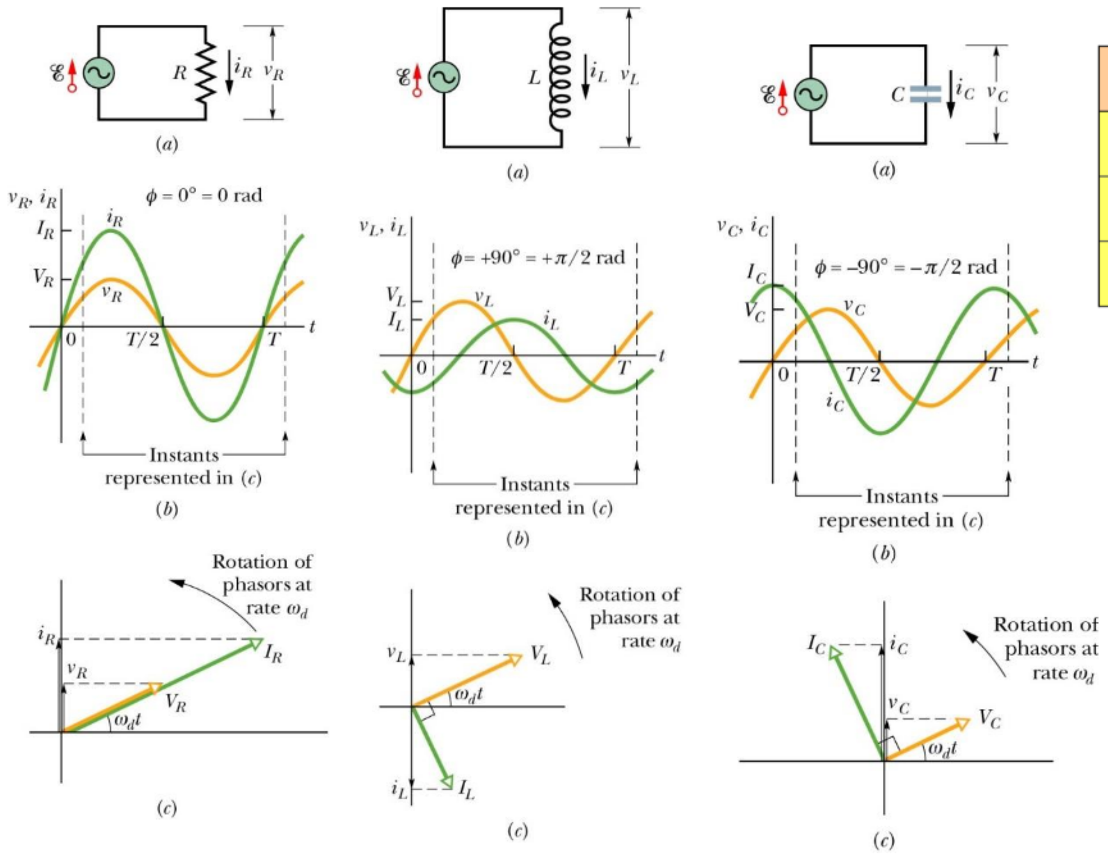
Conclusion: For L only

For C only

- I lead V by 90 degree or in other word V lags I by 90 degree.
- Phase angle ϕ=90
- Power Factor Cosϕ=0
- Only reActive Power (Q) exist no active power(P) ,



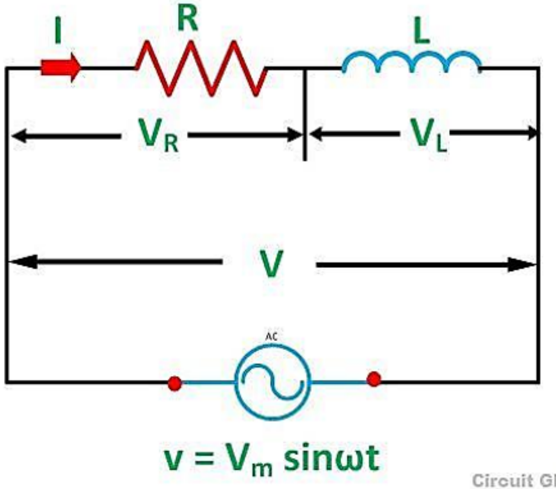
Summary



Circuit Element	Symbol	Resistance or Reactance	Phase of Current	Phase Constant	Amplitude Relation
Resistor	R	R	In phase with v_R	0° (0 rad)	$V_R = I_R R$
Capacitor	C	$X_C = 1/\omega_d C$	Leads v_R by 90°	–90° (–π/2)	$V_C = I_C X_C$
Inductor	L	$X_L = \omega_d L$	Lags v_R by 90°	+90° (π/2)	$V_L = I_L X_L$

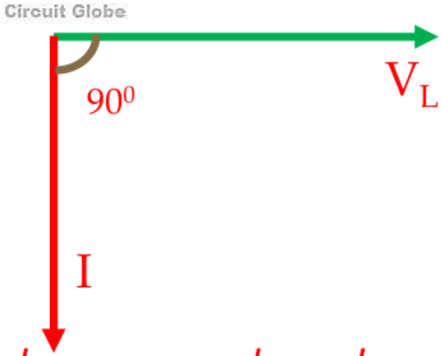
C
I
V
I
L

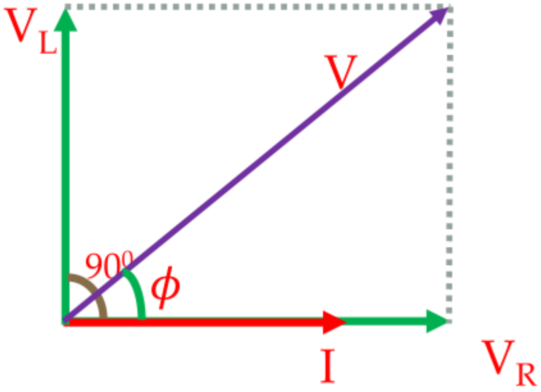
AC Series RL Circuit



BY, KVL

$$\bar{V} = \bar{V}_R + \bar{V}_L$$
$$\bar{V} = \overline{IR} + \overline{IX_L}$$

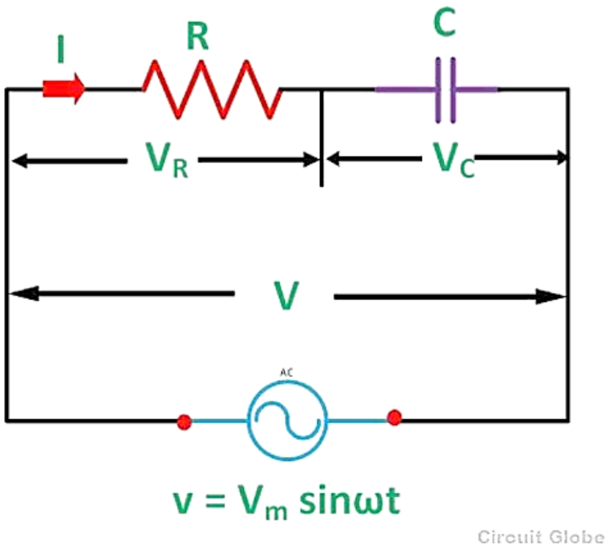




From Phasor I lags V by ϕ, The value of ϕ is $0<\phi<90$

Hence, Power factor is lagging

AC Series RC Circuit



When Current(I) flows through the RC circuit, We have two drops.

i. Drop Across Resistor: $V_R = IR$

ii. Drop Across Inductor: $V_C = IX_C = \frac{I}{2\pi f C}$

What about total voltage?

Can We Apply **KVL** in **AC Circuit**?

Yes

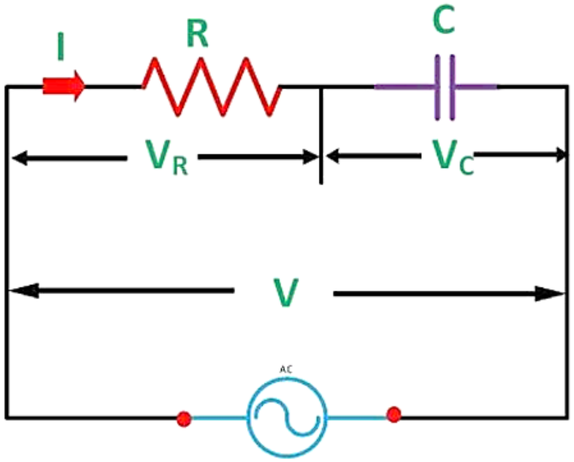
But the addition should be a phasor(vector) not algebraic.

BY, KVL

$$\bar{V} = \bar{V}_R + \bar{V}_C$$
$$\bar{V} = \overline{IR} + \overline{IX_C}$$

Lets Draw Phasor to get final result.

RC Series Circuit

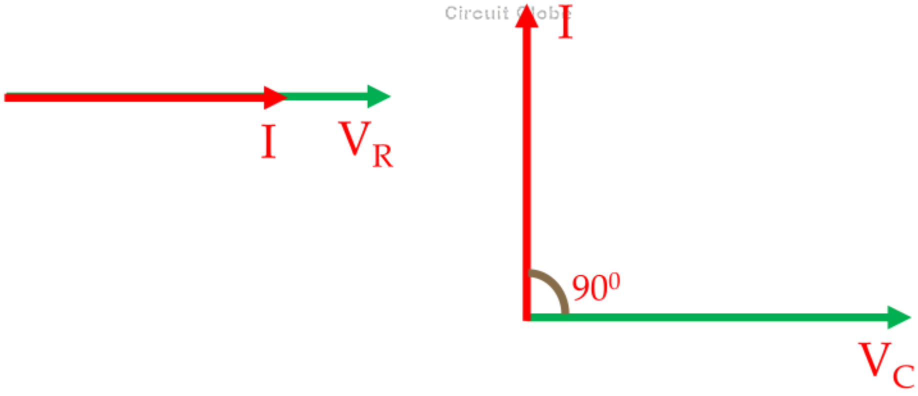


$v = V_m \sin\omega t$

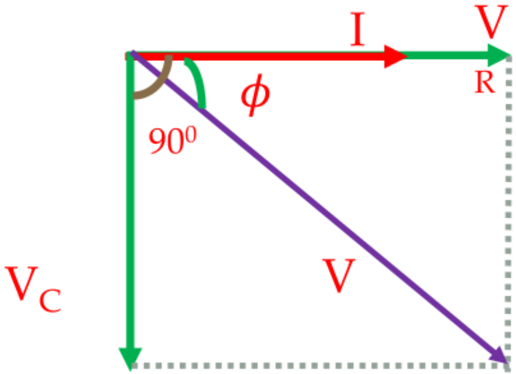
From Phasor I leads V by ϕ

The value of ϕ is $0<\phi<90$

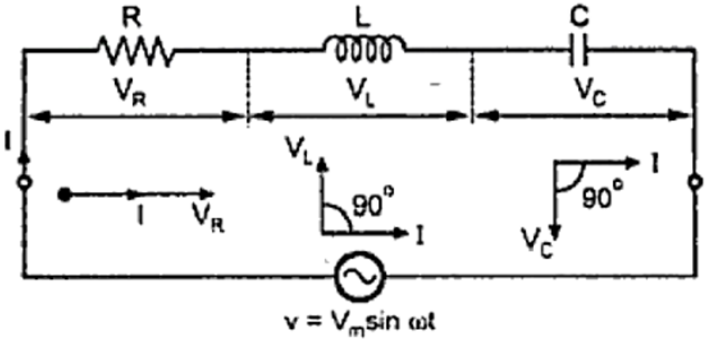
Hence, Power factor is Leading



$$\bar{V} = \bar{V}_R + \bar{V}_C$$



AC Series RLC Circuit



When Current(I) flows through the RC circuit, We have two drops.

i. Drop Across Resistor: $V_R = IR$

ii. Drop Across Inductor: $V_L = IX_L = I\ 2\pi f L$

iii. Drop Across Inductor: $V_C = IX_C = \frac{I}{2\pi f C}$

And Nature of Voltage Drop is,

i. V_R is in phase with I

ii. V_L leads current I by 90^0

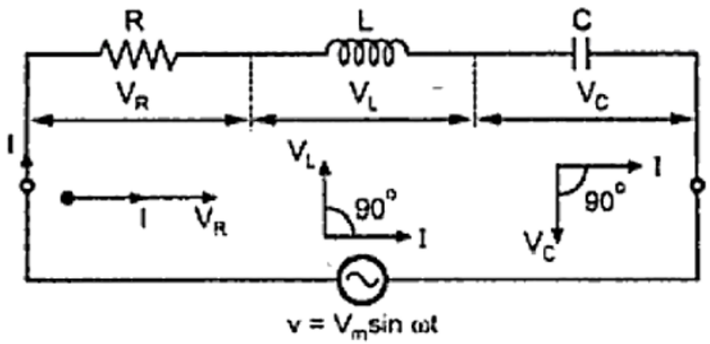
iii. V_C lags current I by 90^0

BY, KVL

$$\bar{V} = \bar{V}_R + \bar{V}_L + \bar{V}_C$$
$$\bar{V} = \overline{IR} + \overline{IX_L} + \overline{IX_C}$$

Lets Draw Phasor to get final result.

RLC Series Circuit



When Current(I) flows through the RLC circuit, We have three drops.

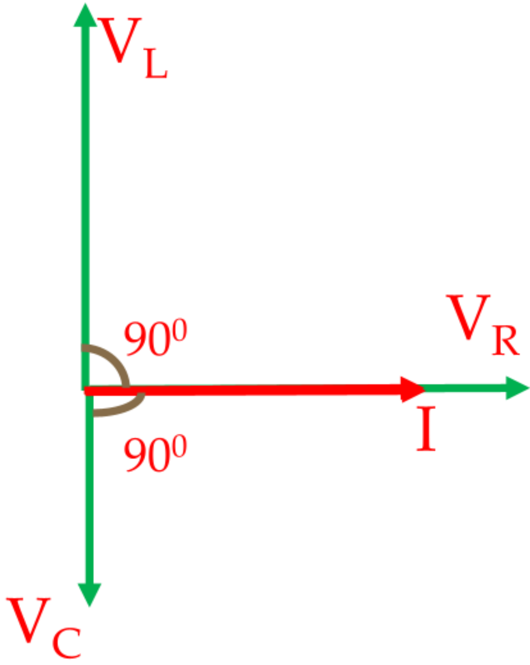
i. Drop Across Resistor: $V_R = IR$

ii. Drop Across Inductor: $V_L = IX_L = I\ 2\pi f L$

iii. Drop Across Inductor: $V_C = IX_C = \frac{I}{2\pi f C}$

$$\overline{Using\ KVL \quad V} = \bar{V}_R + \bar{V}_L + \bar{V}_C$$

$$\bar{V} = \overline{IR} + \overline{IX_L} + \overline{IX_C}$$



Resultant Voltage of AC Series RLC Circuit

Case 1: $X_L > X_C$ and $V_L > V_C$

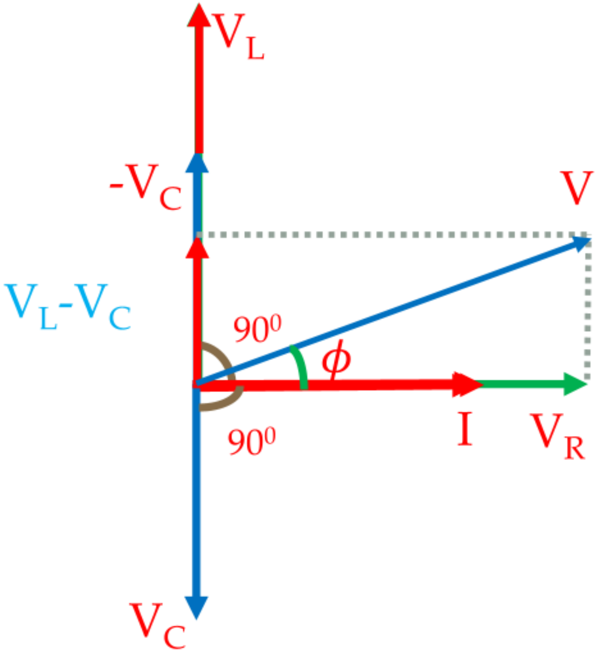


Fig: Phasor Diagram

Circuit is inductive
Power factor is lagging

Resultant Voltage of AC Series RLC Circuit

Case 2: $X_L < X_C$ and $V_L < V_C$

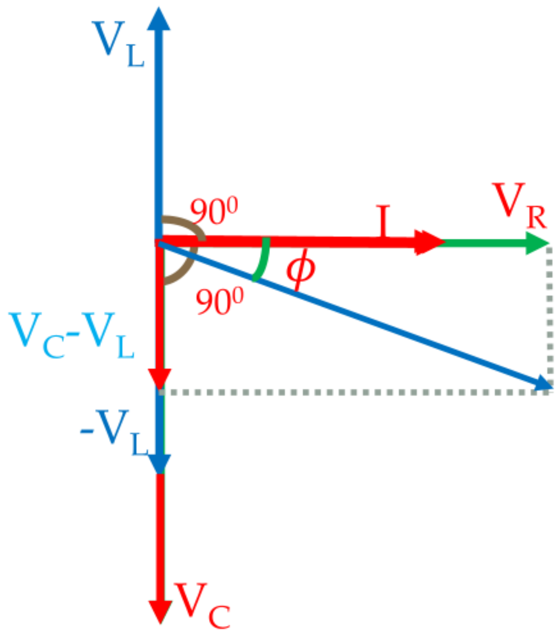


Fig: Phasor Diagram

Circuit is Capacitive
Power factor is leading

Resultant Voltage of AC Series RLC Circuit

Case 3: $X_L = X_C$ and $V_L = V_C$

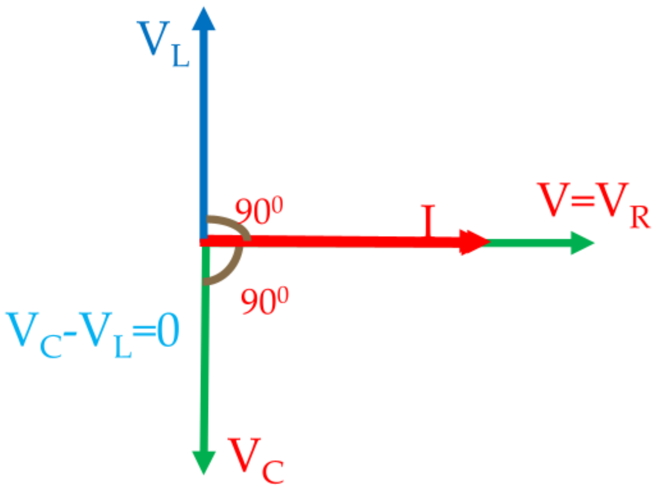


Fig: Phasor Diagram

Circuit is Resistive
Power factor is Unity

This condition is resonance in series RLC circuit

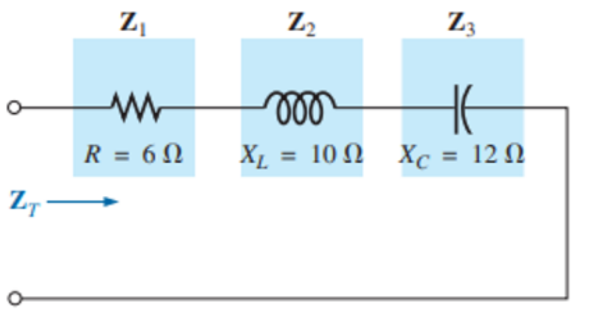
The total impedance Z_T is

a)6.23 ohm

b) 8 ohm

c) 16 ohm

d) 28 ohm



$$= R + jX_L - jX_C$$
$$= R + j(X_L - X_C) = 6\ \Omega + j(10\ \Omega - 12\ \Omega) = 6\ \Omega - j2\ \Omega$$
$$= \mathbf{6.32\ \Omega \angle -18.43^\circ}$$

Answer a

The given circuit is

a)Inductive

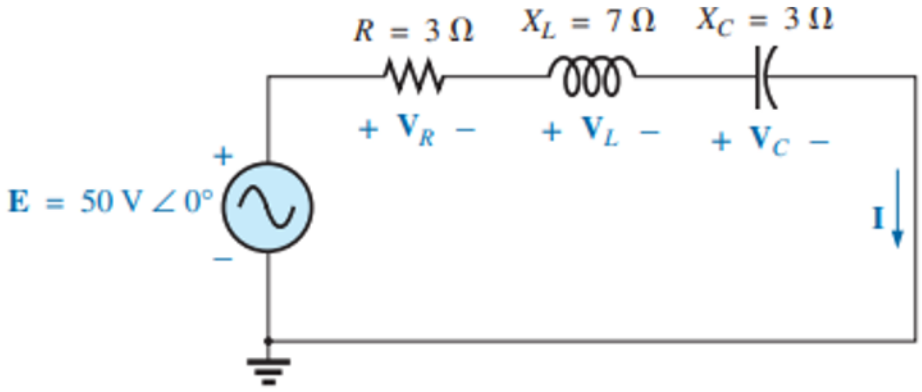
b) Capacitive

c) Resistive

d) All of above

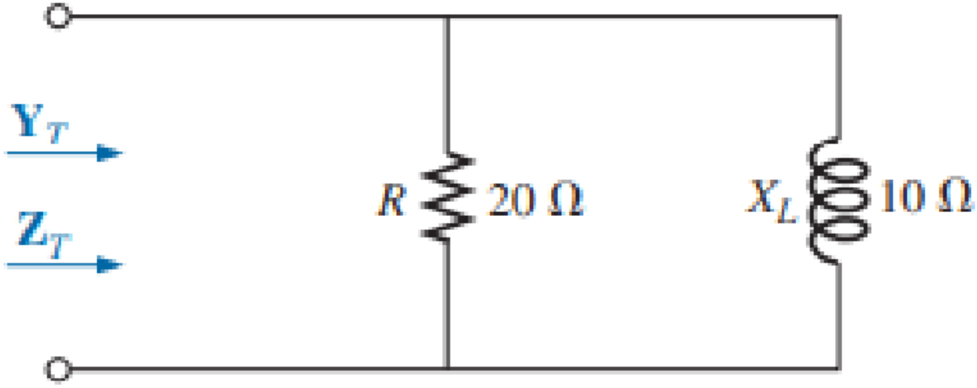
Answer Capacitive

Find **I**, phase angle and Power factor,



Z_T=

a) 8.93 angle 63.43°
b) 2.78 angle 48.36
c) 3.68 angle 60
d) 9.36 angle 48.36



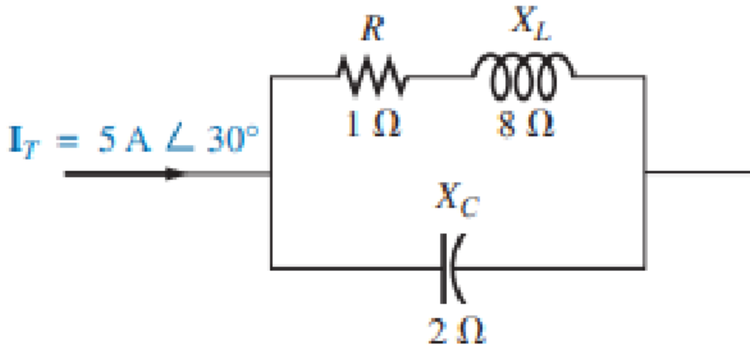
The current across capacitor is:

a) 6.63A

b) 5.26A

c) 2.26A

d) 2.63A



$$\mathbf{I}_C = \frac{\mathbf{Z}_{R-L}\mathbf{I}_T}{\mathbf{Z}_{R-L} + \mathbf{Z}_C} = \frac{(1\,\Omega + j\,8\,\Omega)(5\text{ A} \angle 30^\circ)}{-j\,2\,\Omega + 1\,\Omega + j\,8\,\Omega}$$

$$= \frac{(8.06 \angle 82.87^\circ)(5\text{ A} \angle 30^\circ)}{6.08 \angle 80.54^\circ} = \frac{40.30\text{ A} \angle 112.87^\circ}{6.083 \angle 80.54^\circ}$$

$$= \mathbf{6.63\text{ A} \angle 32.33^\circ}$$

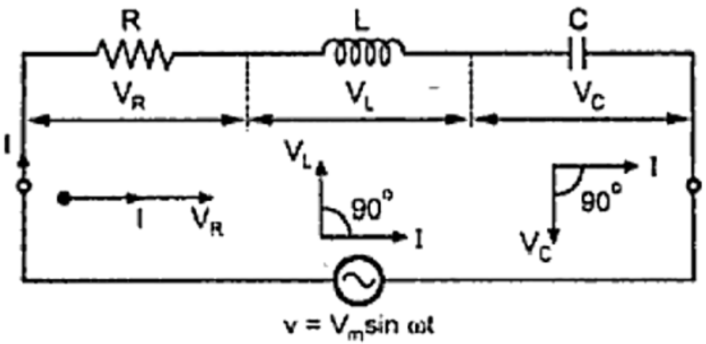
MCQs

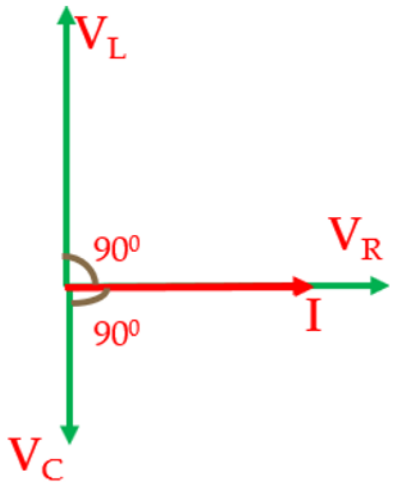
Resonance

- Any passive electric circuit will resonate if it has an inductor and capacitor.
- Resonance is characterized by the input voltage and current being in phase. i.e circuit behaves as resistive circuit i.e net inductive and capacitive reactance effect is zero.

Resonance in a circuit containing at least one inductor and capacitor, is defined as the condition when supply current and voltage are in phase.

Resonance in RLC circuit





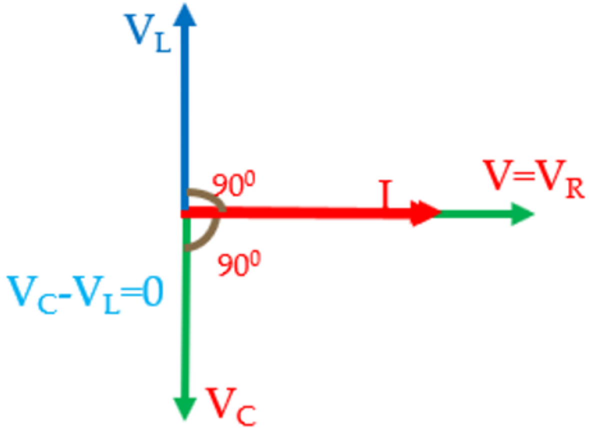
From definition of resonance, In order to have resonance, supply current I and voltage V must be in phase.

This is possible only when, $V_L = V_C$

$$IX_L = IX_C$$

i.e $X_L = X_C$

Therefore above equation is the condition of resonance in series resonance circuit.



Resonant frequency

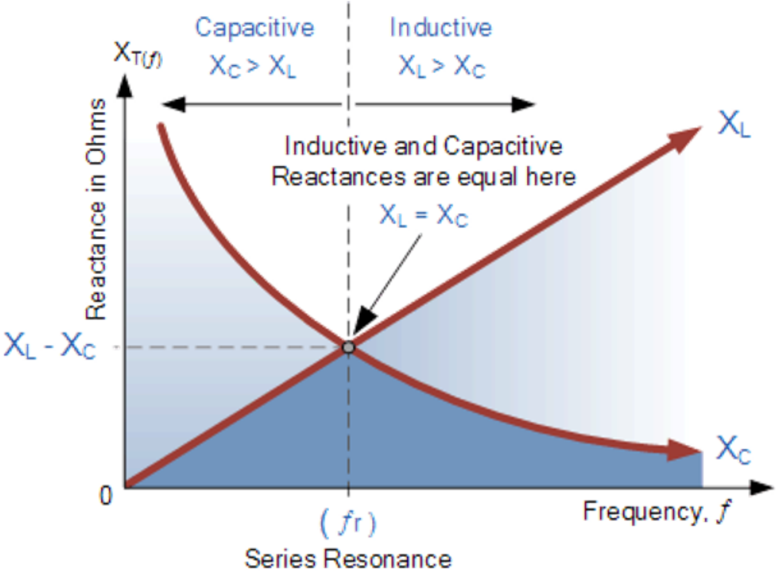
- At resonance $X_L = X_c$

$$\therefore \; 2\pi f L = \frac{1}{2\pi f_r C}$$

(here fr is the resonant frequency)

$$\therefore \; f^2 = \frac{1}{(2\pi)^2 LC}$$

$$\therefore \; f_r = \frac{1}{\sqrt{2\pi \; LC}}$$



Note: if f>fr, circuit is inductive.
if f<fr, circuit is capacitive
if f=fr, circuit is resistive

This is the condition of resonance in series RLC circuit.

Under resonance condition the net reactance is zero i.e X_L-X_c=0 . Hence the impedance of the circuit.

$$|Z| = \sqrt{R^2 + (X_L - X_c)^2} \quad = R \quad [\text{because } XL - XC = 0]$$

This is the minimum possible value of impedance. Hence, circuit current is maximum for the given value of R and its value is given by

$$\boxed{I_m = \frac{V}{Z} = \frac{V}{R}} \qquad [\because Z = R]$$

The circuit behaves like a pure resistive circuit because net reactance is zero . So, the current is in phase with applied voltage .obviously, the power factor of the circuit is unity under resonance condition.

As current is maximum it produces large voltage drop across L and C.

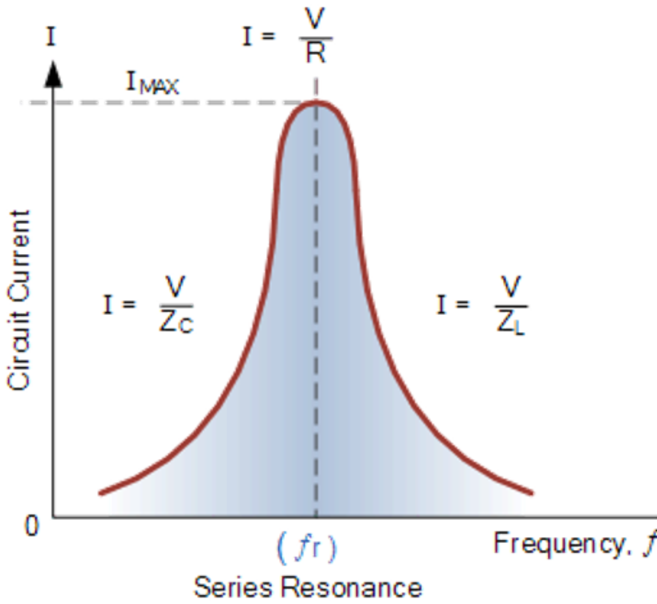


Figure: Resonance Curve
i.e Current Vs frequency

Voltage across Inductor and Capacitor

$$V_L = I_m X_L = I_m \omega_r L$$
$$= I_m (2\pi f_r L)$$
$$= I_m 2\pi \times \frac{1}{2\pi\sqrt{LC}} L = I_m \frac{L}{\sqrt{LC}} = I_m \sqrt{\frac{L^2}{LC}}$$
$$= I_m \sqrt{\frac{L}{C}}$$

$$V_C = I_m X_C$$
$$= I_m \frac{1}{\omega_r C} = I_m \frac{1}{2\pi f_r C}$$
$$= I_m \frac{1}{2\pi \times \frac{1}{2\pi\sqrt{LC}} \times C} = \frac{I_m \sqrt{LC}}{C} = I_m \sqrt{\frac{LC}{C^2}}$$
$$= I_m \sqrt{\frac{L}{C}}$$

Thus voltage drop across L and C are equal and many times the applied voltage. Hence voltage magnification occurs at the resonance condition.so series resonance condition is often refers to as ***voltage resonance*****.**

Resonance Curve and Bandwidth

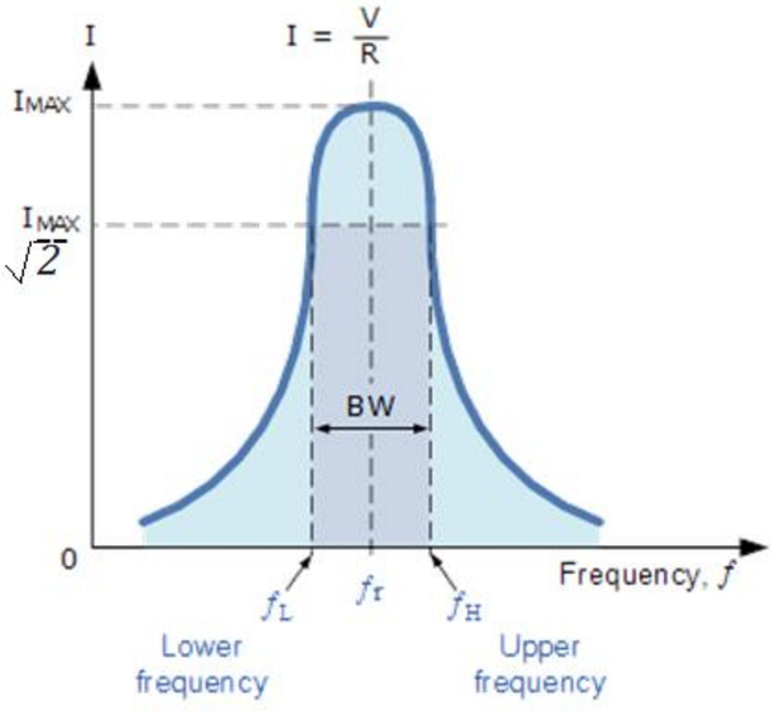


Figure: Resonance Curve showing bandwidth

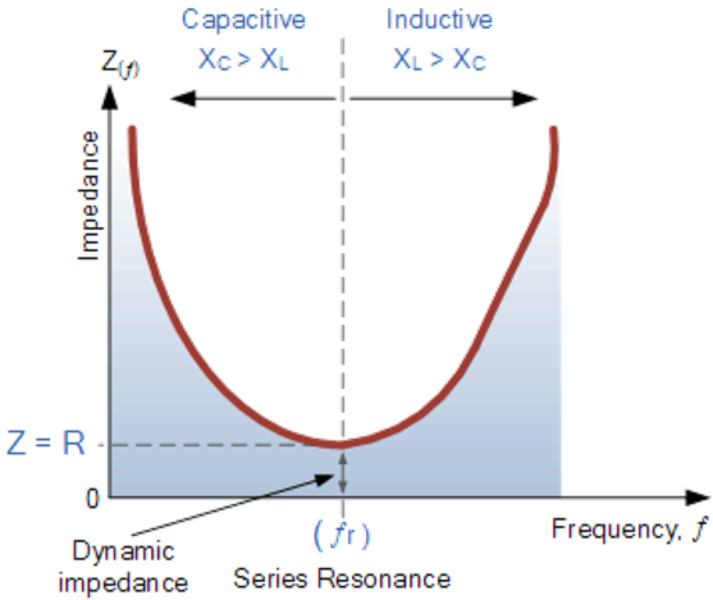


Figure: Impedance vs f

Mathematically, B.W=f_H-f_L= f_2-f_1 $= \frac{R}{2\pi L}$

Quality factor

Q-FACTOR: In case of R-L-C series circuit Q-Factor is defined as the voltage magnification of the circuit at resonance.

Voltage magnification = voltage across L or C /applied voltage

$$= \frac{V_L}{V} \quad \text{OR} \quad = \frac{V_C}{V} \qquad [\because V_L = V_C]$$

$$= \frac{I_m X_L}{I_m R} \quad \text{OR} \quad \frac{I_m X_C}{I_m R}$$

$$\boxed{= \frac{X_L}{R} \, OR = \frac{X_C}{R}}$$

$$= \frac{\omega_r L}{R} OR = \frac{1}{\omega_r CR}$$

$$= \frac{2\pi f_r L}{R} OR = \frac{1}{2\pi f_r CR}$$

$$= \frac{2\pi L}{2\pi\sqrt{LC}R} OR = \frac{1}{2\pi \times \frac{1}{2\pi\sqrt{LC}} CR}$$

$$= \frac{1}{R}\sqrt{\frac{L^2}{LC}} OR = \frac{1}{R}\sqrt{\frac{LC}{C^2}}$$

$$= \frac{1}{R}\sqrt{\frac{L}{C}}$$

$$\boxed{Q - factor = \frac{1}{R}\sqrt{\frac{L}{C}} = \frac{2\pi f_r L}{R} = \frac{1}{2\pi f_r CR}}$$

Quality Factor

$$Q - factor = \frac{1}{R}\sqrt{\frac{L}{C}} = \frac{2\pi f_r L}{R} = \frac{1}{2\pi f_r CR}$$

$$also\ we\ know, BW = \frac{R}{2\pi L}$$

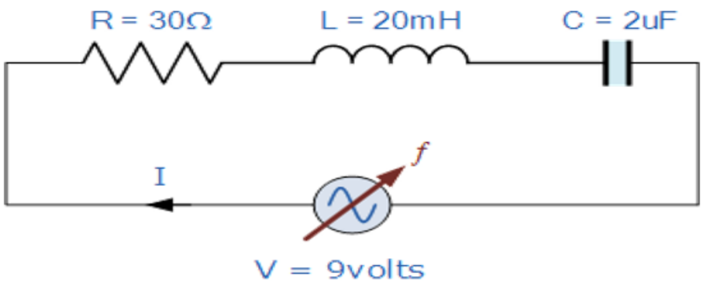
$$Q - factor = \frac{f_r}{R/_{2\pi L}} = \frac{f_r}{B.W}$$

High value of R means, lower value of Q.

Lower Q means, poorer quality, Lower selectivity

Higher Q means, Good quality, Higher selectivity

Problem1: A series resonance network consisting of a resistor of 30Ω, a capacitor of 2uF and an inductor of 20mH is connected across a sinusoidal supply voltage which has a constant output of 9 volts at all frequencies. Calculate, the resonant frequency, the current at resonance, the voltage across the inductor and capacitor at resonance, the quality factor and the bandwidth of the circuit. Also sketch the resonance curve and current voltage waveform at resonance.



fr,
Imax,
VL and Vc,
Q factor
BW,
Resonance curve
waveform

1. Resonant Frequency, f_r

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{0.02\times 2\times 10^{-6}}} = 796\text{Hz}$$

2. Circuit Current at Resonance, I_m

$$I = \frac{V}{R} = \frac{9}{30} = 0.3\text{A or } 300\text{mA}$$

3. Inductive Reactance at Resonance, X_L

$$X_L = 2\pi f L = 2\pi\times 796\times 0.02 = 100\Omega$$

4. Voltages across the inductor and the capacitor, V_L, V_C

$$V_L = V_C$$

$$V_L = I\times X_L = 300\text{mA}\times 100\Omega$$

$$V_L = 30\text{volts}$$

Note: the supply voltage may be only 9 volts, but at resonance, the reactive voltages across the capacitor, V_C and the inductor, V_L are 30 volts peak!

5. Quality factor, Q

$$Q = \frac{X_L}{R} = \frac{100}{30} = 3.33$$

6. Bandwidth, BW

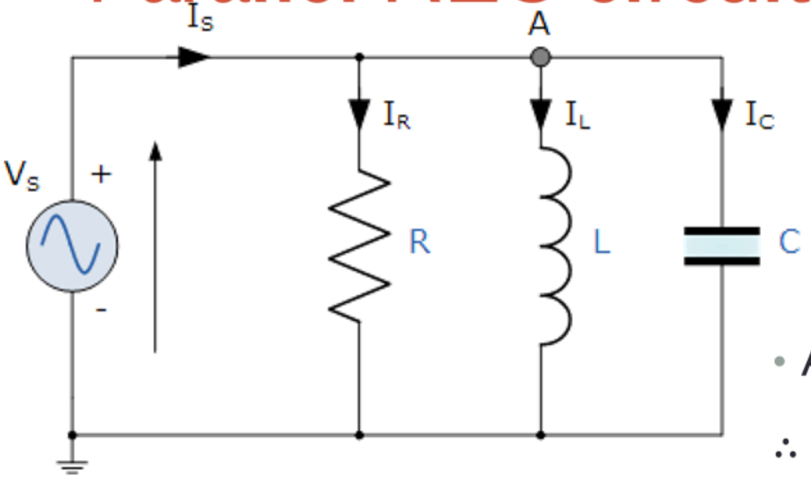
$$BW = \frac{f_r}{Q} = \frac{796}{3.33} = 238\text{Hz}$$

7. The upper and lower -3dB frequency points, f_H and f_L

$$f_L = f_r - \frac{1}{2}BW = 796 - \frac{1}{2}(238) = 677\text{Hz}$$

$$f_H = f_r + \frac{1}{2}BW = 796 + \frac{1}{2}(238) = 915\text{Hz}$$

Parallel RLC circuit



$I_C = I_L$,

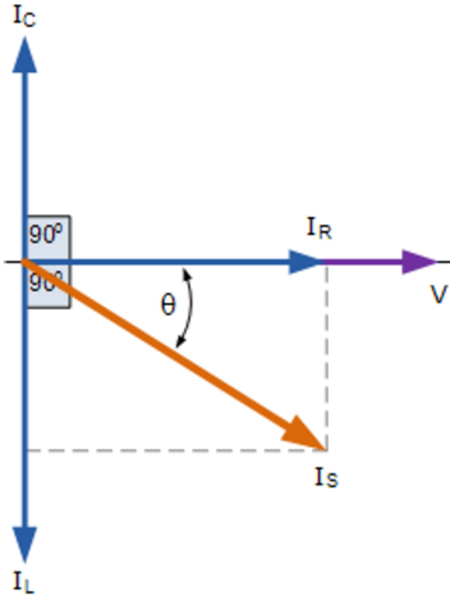
$$\frac{V}{X_L} = \frac{V}{X_C}$$

- At resonance $X_L = X_c$

$$\therefore\ 2\pi f\, L = \frac{1}{2\pi f C}$$

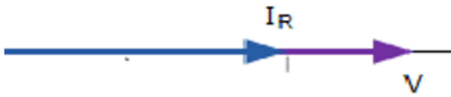
$$\therefore\ f^{\,2} = \frac{1}{(2\pi)^2 LC}$$

$$\therefore\ f_r = \frac{1}{\sqrt{2\pi}\;\; LC}$$



$Is = I_R + I_L + Ic$

For resonance Vs and Is should be in phase. So, it will occur if, $Ic = I_L$, and the phasor will be:



Current at Resonance

At resonance,

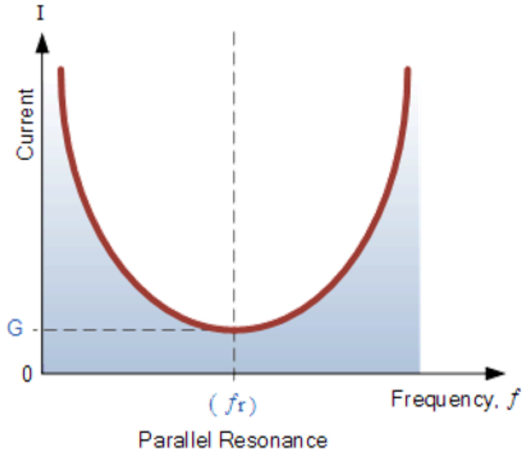
From Phasor, I is minimum possible value,

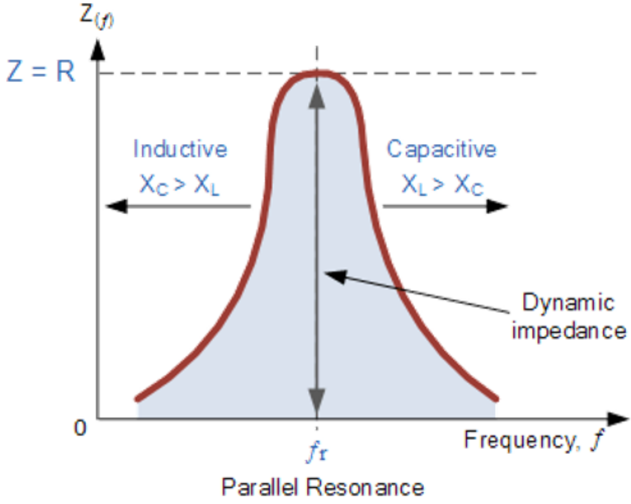
So, I at Resonance is Imin=V/R

Similarly Z iz Zmax at resonace, Zmax=R

Quality factor is the measure of current magnification produced so, Q=$\frac{I_C}{I}$ or $\frac{I_L}{I}$

Quality Factor, $Q = \frac{R}{2\pi f L} = 2\pi f CR = R\sqrt{\frac{C}{L}}$





Q) A parallel resonance network consisting of a resistor of 60Ω, a capacitor of 120uF and an inductor of 200mH is connected across a sinusoidal supply voltage which has a constant output of 100 volts at all frequencies. Calculate, the resonant frequency, the quality factor and the bandwidth of the circuit, the circuit current at resonance and current magnification..

1. Resonant Frequency, f_r

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{0.2.120.10^{-6}}} = 32.5\text{Hz}$$

Quality factor, Q

$$Q = \frac{R}{X_L} = \frac{R}{2\pi f L} = \frac{60}{40.8} = 1.47$$

Bandwidth, BW

$$BW = \frac{f_r}{Q} = \frac{32.5}{1.47} = 22\text{Hz}$$

$$I_R = \frac{V}{R} = \frac{100}{60} = 1.67\text{A}$$

$$I_{MAG} = Q \times I_T = 1.47 \times 1.67 = 2.45\text{A}$$

Parallel Resonance (A coil (LR) and C)

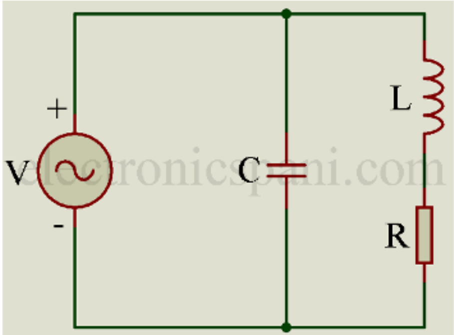


Figure 1: Parallel Resonant Circuit

Resonantig Frequency, $f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}$

Maximum Impeance $= Z_a = \frac{L}{CR}$

MCQs

A circuit with a resistor, inductor and capacitor in series is resonant of f Hz. If all the component values are now doubled then the new resonant frequency is

a. 2f
b. remains unchanged
c. f/2
d. f/4

Answer C

The phenomena of resonance is used in

a. radio
b. capacitor
c. transformer
d. amplifier

- Answer A

In a series RLC circuit, the magnitude of resonance frequency can be changed by changing the value of

a. R only
b. L only
c. C only
d. L or C

Answer d

Q of a resonant transmission line is

a. Q = L/R
b. Q = ωL/R
c. Q = ωR/L
d. Q = ω/LR

AnswerC

In LCR circuit which one of the following statement is correct?

a. L and R oppose each other
b. R values increases with frequency
c. the inductive reactances increases with frequency
d. the capacitive reactances increases with frequency

Answer C

- Current at resonance in a series circuit is _________ and in a parallel circuit is __________

a. Minimum, maximum
b. Maximum, minimum
c. Maximum, maximum
d. Minimum, minimum

Answer b

At a frequency less than the resonant frequency

a. Series circuit is capacitive and parallel circuit is inductive
b. Series circuit is inductive and parallel circuit is capacitive
c. Both circuits are inductive
d. Both circuits are capacitive

Answer a

In an R-C-L series circuit, during resonance, the impedance will be

a. Zero
b. Minimum
c. Maximum
d. None of these

Answer b

The power factor of series and parallel RLC resonant circuit is:

a. Leading, Lagging
b. Lagging, Leading
c. Unity, Unity
d. Cant be determined

Answe C

Magnitude of current at resonance in R-L-C circuit

a. Depends upon magnitude of R
b. Depending upon magnitude of L
c. Depends upon magnitude of C
d. Depends upon magnitude of R, L and C

Answer a

A series RLC circuit is in resonance at 100Hz. If capacitance is made four times, the resonant frequency will be

a. 50 Hz
b. 100 Hz
c. 200 Hz
d. 400 Hz

Answer a

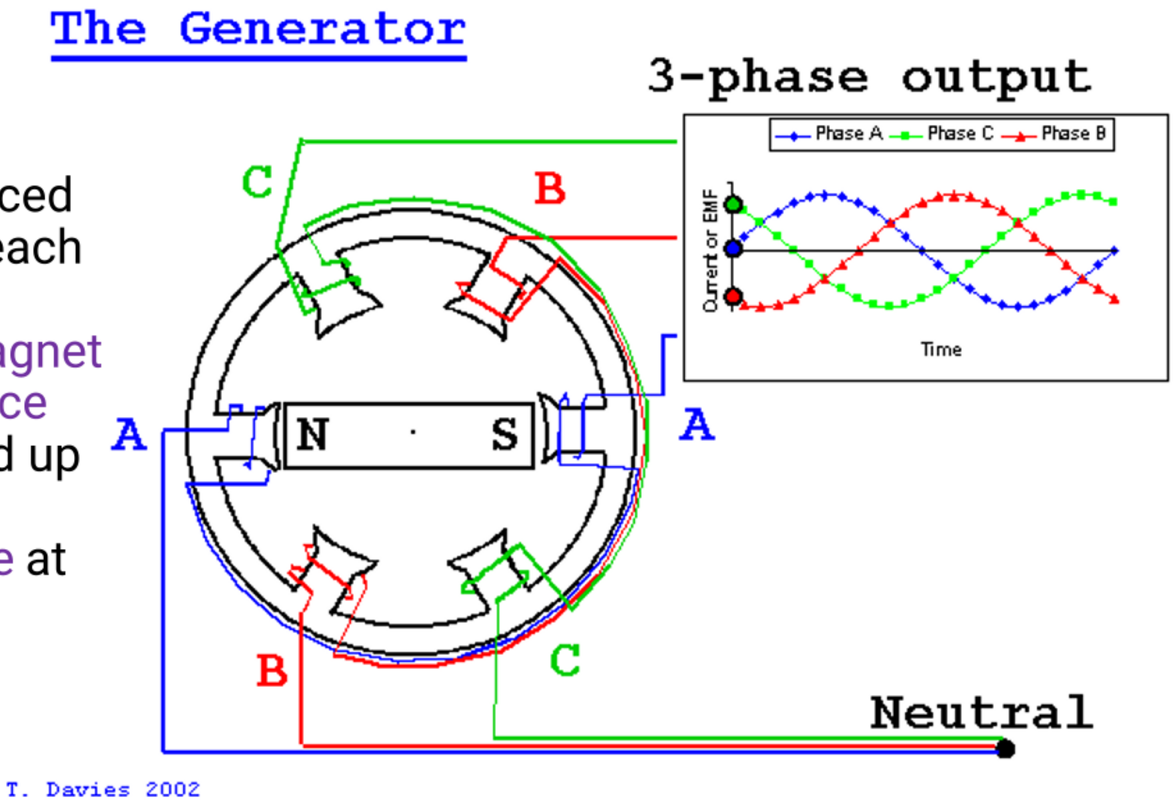
A choke coil having resistance R ohm and of inductance henry is shunted by a capacitor of C farads. The dynamic impedance of the resonant circuit would be

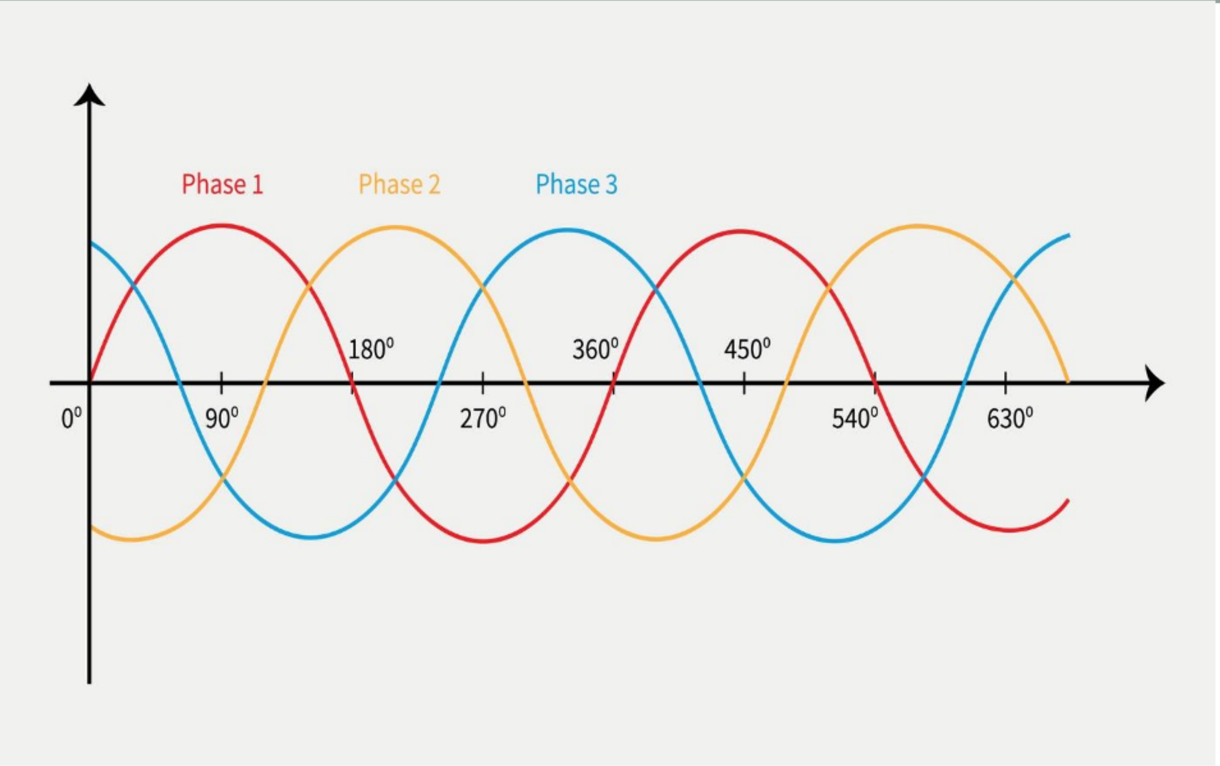
a. R/LC
b. C/RL
c. L/RC
d. 1/RLC

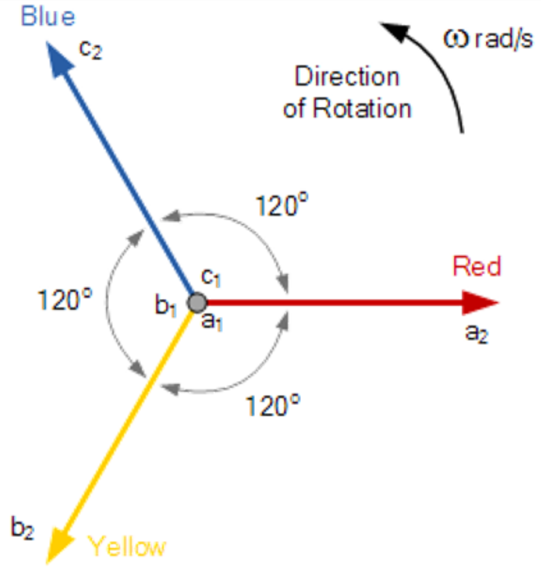
Answer C

Three phase AC

- Three identical coils are placed at 120 degrees apart from each other
- Rotor which is an electromagnet is rotated by an external force
- Stator conductor gets linked up with the rotating flux
- Produces sinusoidal voltage at each phase governed by "Faraday's Law of Electromagnetic Induction"




Phase 1
Phase 2
Phase 3
0°
90°
180°
270°
360°
450°
540°
630°


Blue
c_2
ω rad/s
Direction
of Rotation
120°
120°
120°
Red
c_1
b_1
a_1
a_2
b_2
Yellow

Interconnection of 3 phase

For both star and Delta

Total Active Power

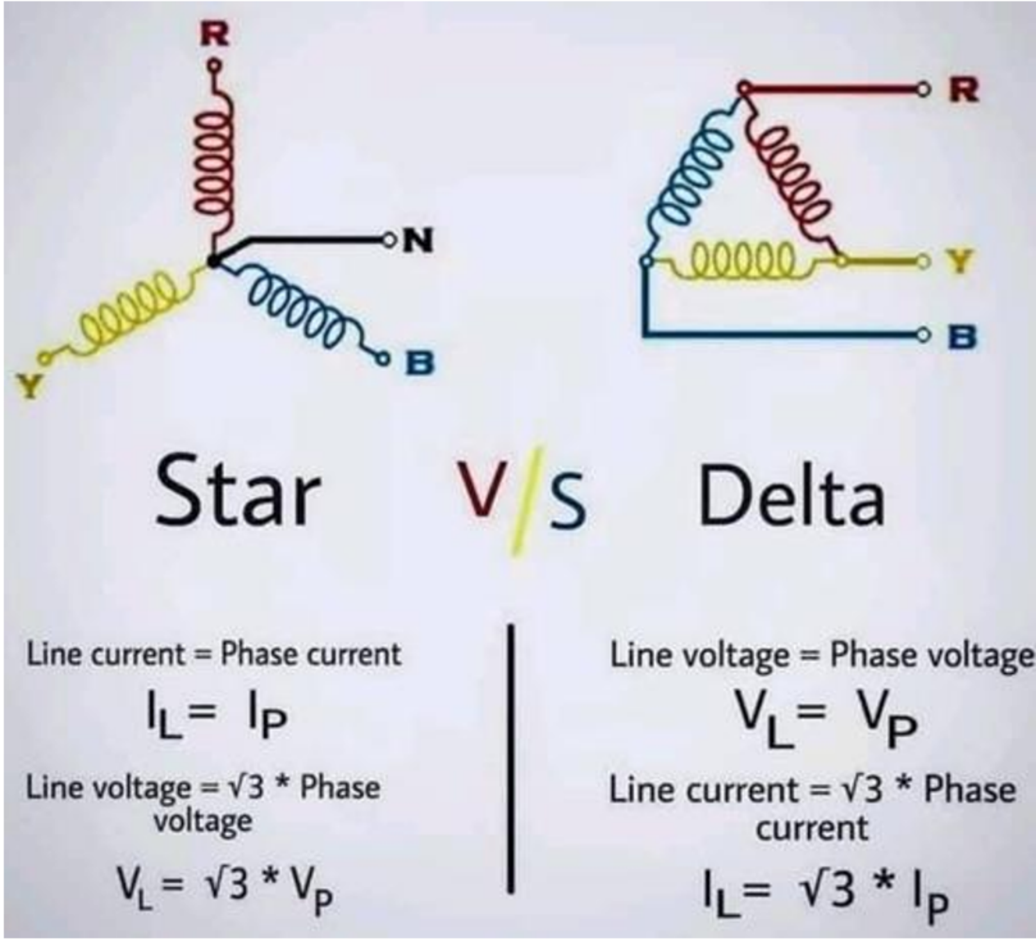
- $P=3V_p*I_p*\cos\emptyset = \sqrt{3}V_LI_L\cos\emptyset$

Total Reactive Power

- $Q=3V_p*I_p*\sin\emptyset = \sqrt{3}V_LI_L\sin\emptyset$

Total Apparent Power

- $S=3V_p*I_p = \sqrt{3}V_LI_L$



MCQ

- Separate file

1. A sine wave has a frequency of 50 Hz. Its angular frequency is ________ radian/second.
(a) 100JT
(b) 50 JT
(c) 25 JT
(d) 5 JT

- A

2. The reactance offered by a capacitor to alternating current of frequency 50 Hz is 20 ohms. If frequency is increased to 100 Hz, reactance becomes_____ohms.
(a) 2.5
(b) 5
(c) 10
(d) 15

- C

3. The period of a wave is
(a) the same as frequency
(6) time required to complete one cycle
(c) expressed in amperes
(d) none of the above

- B

4. The form factor is the ratio of
(a) peak value to r.m.s. value
(6) r.m.s. value to average value
(c) average value to r.m.s. value
(d) none of the above

- C

5. The period of a sine wave is $\frac{1}{50}$ seconds.
Its frequency is
(a) 20 Hz
(b) 30 Hz
(c) 40 Hz
(d) 50 Hz
Ans: d

6. A heater is rated as 230 V, 10 kW, A.C. The value 230 V refers to
(a) average voltage
(b) r.m.s. voltage
(c) peak voltage
(d) none of the above
Ans: b

7. If two sinusoids of the same frequency but of different amplitudes and phase angles are subtracted, the resultant is
(a) a sinusoid of the same frequency
(b) a sinusoid of half the original frequency
(c) a sinusoid of double the frequency
(d) not a sinusoid
Ans: a

8. The peak value of a sine wave is 200 V. Its average value is
(a) 127.4 V
(b) 141.4 V
(c) 282.8 V
(d)200V
Ans: a

9. If two sine waves of the same frequency have a phase difference of JT radians, then
(a) both will reach their minimum values at the same instant
(b) both will reach their maximum values at the same instant
(c) when one wave reaches its maxi¬mum value, the other will reach its minimum value
(d) none of the above
Ans: c

10. The voltage of domestic supply is 220V. This figure represents
(a) mean value
(b) r.m.s. value
(c) peak value
(d) average value
Ans: a

11. Two waves of the same frequency have opposite phase when the phase angle between them is
(a) 360°
(b) 180°
(c) 90°
(d) 0°
Ans: b

B. 12. The power consumed in a circuit element will be least when the phase difference between the current and voltage is
(a) 180"
(b) 90°
(c) 60°
(d) 0°
Ans: b

13. The r.m.s. value and mean value is the same in the case of
(a) triangular wave
(6) sine wave
(c) square wave
(d) half wave rectified sine wave
Ans: c

14. For the same peak value which of the following wave will 'have the highest r.m.s. value ?
(a) square wave
(b) half wave rectified sine wave
(c) triangular wave
(d) sine wave
Ans: a

15. For the same peak value, which of the following wave has the least mean value ?
(a) half wave rectified sine wave
(b) triangular wave
(c) sine wave
(d) square wave
Ans: a

B

21. The phase difference between voltage and current wave through a circuit element is given as 30°. The essential condition is that
(a) both waves must have same frequency
(b) both waves must have identical peak values
(c) both waves must have zero value at the same time
(d) none of the above
Ans: a

22. The r.m.s. value of a sinusoidal A.C. current is equal to its value at an angle of______degrees.
(a) 90
(b) 60
(c) 45
(d) 30
Ans: c

23. Capacitive reactance is more when
(a) capacitance is less and frequency of supply is less
(b) capacitance is less and frequency of supply is more
(c) capacitance is more and frequency of supply is less
(d) capacitance is more and frequency of supply is more
Ans: a

24. In a series resonant circuit, the impedance of the circuit is
(a) minimum
(b) maximum
(c) zero
(d) none of the above
Ans: a

25. Power factor of an electrical circuit is equal to
(a) R/Z
(b) cosine of phase angle difference be-tween current and voltage
(c) kW/kVA
(d) ratio of useful current to total cur¬rent Iw/I
(e) all above
Ans: e

27. Poor power factor
(a) reduces load handling capability of electrical system
(b) results in more power losses in the electrical system
(c) overloads alternators, transformers and distribution lines
(d) results in more voltage drop in the line
(e) results in all above
Ans: e

36. In a highly capacitive circuit the
(a) apparent power is equal to the actual power
(b) reactive power is more than the apparent power
(c) reactive power is more than the actual power
(d) actual power is more than its reactive power
Ans: c

37. Power factor of the following circuit will be zero
(a) resistance
(b) inductance
(c) capacitance
(d) both (b) and (c)
Ans: d

78. The purpose of a parallel circuit resonance is to magnify
(a) current
(b) voltage
(c) power
(d) frequency
Ans: b

79. In an A.C. circuit power is dissipated in
(a) resistance only
(b) inductance only
(c) capacitance only
(d) none of the above
Ans: a

80. In a parallel R-C circuit, the current always______the applied voltage
(a) lags
(b) leads
(c) remains in phase with
(d) none of the above

46. The power factor at resonance in R-L- C parallel circuit is
(a) zero
(b) 0.08 lagging
(c) 0.8 leading
(d) unity
Ans: d

48. In a pure resistive circuit
(a) current lags behind the voltage by 90°
(b) current leads the voltage by 90°
(c) current can lead or lag the voltage by 90°
(d) current is in phase with the voltage
Ans: d

49. In a pure inductive circuit
(a) the current is in phase with the voltage
(b) the current lags behind the voltage by 90°
(c) the current leads the voltage by 90°
(d) the current can lead or lag by 90°
Ans: b

50. In a circuit containing R, L and C, power loss can take place in
(a) C only
(b) L only
(c) R only
(d) all above
Ans: c

51. Inductance of coil
(a) is unaffected by the supply frequency
(b) decreases with the increase in supply frequency
(c) increases with the increase in supply frequency
(d) becomes zero with the increase in supply frequency
Ans: c

52. In any A.C. circuit always
(a) apparent power is more than actual power
(b) reactive power is more than apparent power
(c) actual power is more than reactive power
(d) reactive power is more than actual power
Ans: a

53. Which of the following circuit component opposes the change in the circuit voltage ?
(a) Inductance
(b) Capacitance
(c) Conductance
(d) Resistance
Ans:

54. In a purely inductive circuit
(a) actual power is zero
(b) reactive power is zero
(c) apparent power is zero
(d) none of above is zero
Ans: a

60. Magnitude of current at resonance in R-L-C circuit
(a) depends upon the magnitude of R
(b) depends upon the magnitude of L
(c) depends upon the magnitude of C
(d) depends upon the magnitude of R, Land C
Ans: a

61. In a R-L-C circuit
(a) power is consumed in resistance and is equal to I R
(b) exchange of power takes place between inductor and supply line
(c) exchange of power takes place between capacitor and supply line
(d) exchange of power does not take place between resistance and the supply line
(e) all above are correct
Ans: e

62. In R-L-C series resonant circuit magnitude of resonance frequency can be changed by changing the value of
(a) R only
(b) L only
(c)C only
(d)LorC
(e) R,LorC
Ans: d

87. Which of the following statements pertains to resistors only ?
(a) can dissipate considerable amount of power
(6) can act as energy storage devices
(c) connecting them in parallel in¬creases the total value
(d) oppose sudden changes in voltage
Ans: a

88. Which of the following refers to a parallel circuit ?
(a) The current through each element is same
(b) The voltage across element is in proportion to it's resistance value
(c) The equivalent resistance is greater than any one of the resistors
(d) The current through any one element is less than the source current
Ans: d

89. Aphasoris
(a) a line which represents the magnitude and phase of an alternating quantity
(b) a line representing the magnitude and direction of an alternating quantity
(c) a coloured tag or band for distinction between different phases of a 3-phase supply
(d) an instrument used for measuring phases of an unbalanced 3-phase load
Ans: a

89. A parallel AC. circuit in resonance will
(a) have a high voltage developed across each inductive and capacitive section
(b) have a high impedance
(c) act like a resistor of low value
(d) have current in each section equal to the line current
Ans: b

101. A pure capacitor connected across an A.C. voltage consumed 50 W. This is due to
(a) the capacitive reactance in ohms
(b) the current flowing in capacitor
(c) the size of the capacitor being quite big
(d) the statement is incorrect
Ans: d