Long Answer Questions

Q. 1. Explain the term inductive reactance. Show graphically the variation of inductive reactance with frequency of the applied alternating voltage.

An ac voltage $V = V_0 \sin \omega t$ is applied across a pure inductor of inductance L. Find an expression for the current i, flowing in the circuit and show mathematically that the current flowing through it lags behind the applied voltage by a phase angle of $\frac{\pi}{2}$ Also draw (i) phasor diagram (ii) graphs of V and i versus ωt for the circuit.
[CBSE East 2016]

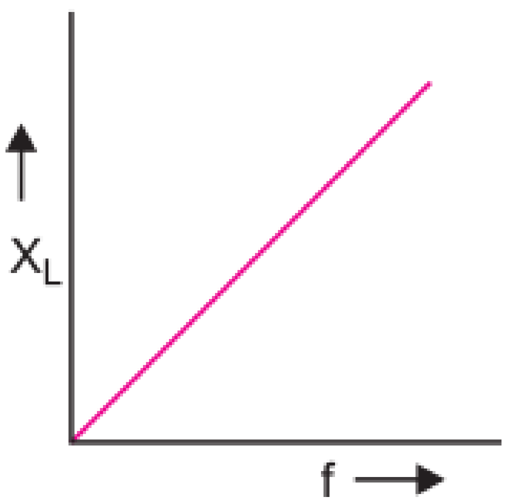
Ans. Inductive Reactance: The opposition offered by an inductor to the flow of alternating current through it is called the inductive reactance. It is denoted by X_L. Its value is X_L. = $\omega L = 2\pi f L$

Where L is inductance and f is the frequency of the applied voltage.

Obviously $X_L \propto f$

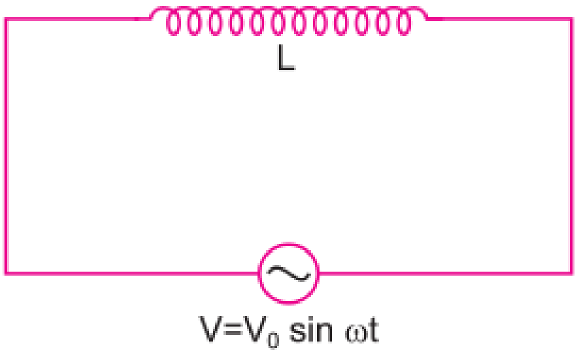
That the graph between X_L and frequency (f) is linear (as shown in fig.).

Phase Difference between Current and Applied Voltage in Purely Inductive circuit:



AC circuit containing pure inductance: Consider a coil of self-inductance L and negligible ohmic resistance. An alternating potential difference is applied across its ends. The magnitude and direction of AC changes periodically, due to which there is a continual change in magnetic flux linked with the coil. Therefore according to Faraday's law, an induced emf is produced in the coil, which opposes the applied voltage. As a result the current in the circuit is reduced. That is **inductance acts like a resistance in ac circuit.** The instantaneous value of alternating voltage applied

$V = V_0 \sin \omega t$ ...(i)



(a)

If i is the instantaneous current in the circuit and $\frac{di}{dt}$ the rate of change of current in the circuit at that instant, then instantaneous induced emf

$$\varepsilon = -L\frac{\mathrm{di}}{\mathrm{dt}}$$

According to Kirchhoff's loop rule

$$V + e = 0 \Rightarrow V - L\frac{\mathrm{di}}{\mathrm{dt}} = 0$$

or $$V = L\frac{\mathrm{di}}{\mathrm{dt}} \text{ or } \frac{\mathrm{di}}{\mathrm{dt}} = \frac{V}{L}$$

or $$\frac{\mathrm{di}}{\mathrm{dt}} = \frac{V_0 \sin \omega t}{L} \text{ or } \mathrm{di} = \frac{V_0 \sin \omega t}{L}\mathrm{dt}$$

Integrating with respect to time 't',

$$i = \frac{V_0}{L} \int \sin \omega t \, \mathrm{dt} = \frac{V_0}{L}\left\{-\frac{\cos \omega t}{\omega}\right\} = -\frac{V_0}{\omega L}\cos \omega t = -\frac{V_0}{\omega L}\sin\left(\frac{\pi}{2} - \omega t\right)$$

or $\qquad i = \frac{V_0}{\omega L} \sin\left(\omega t - \frac{\pi}{2}\right) \qquad ...(ii)$

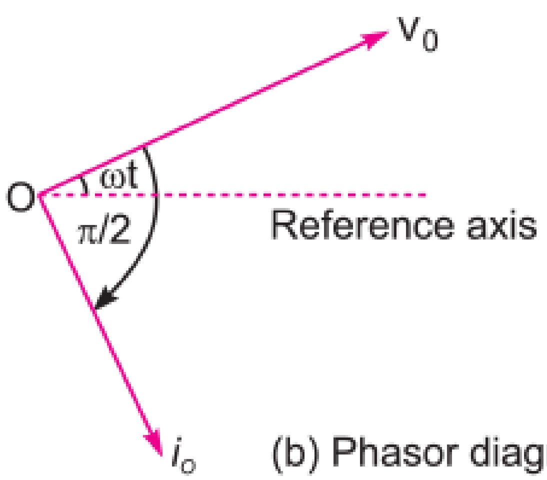
This is required expression for current

or $\qquad i = i_0 \sin\left(\omega t - \frac{\pi}{2}\right) \qquad ...(iii)$

where $\qquad i_0 = \frac{V_0}{\omega L} \qquad ...(iv)$

is the peak value of alternating current

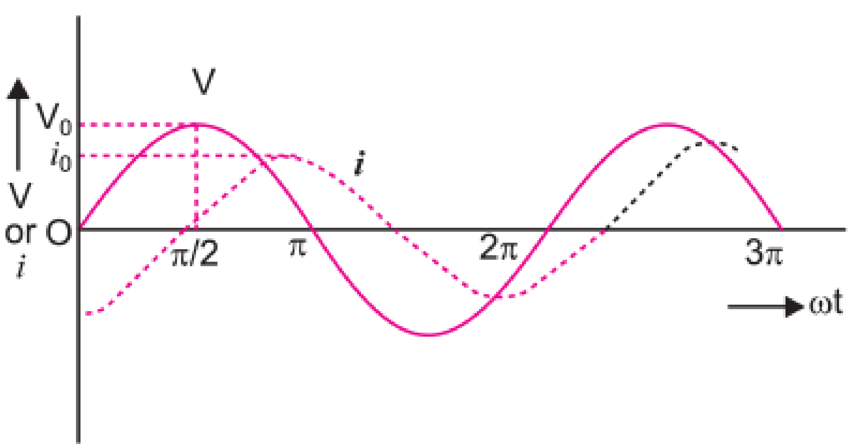
Also comparing (i) and (iii), we note that current lags behind the applied voltage by an angle $\frac{\pi}{2}$ (Fig. b).



(b) Phasor diagram

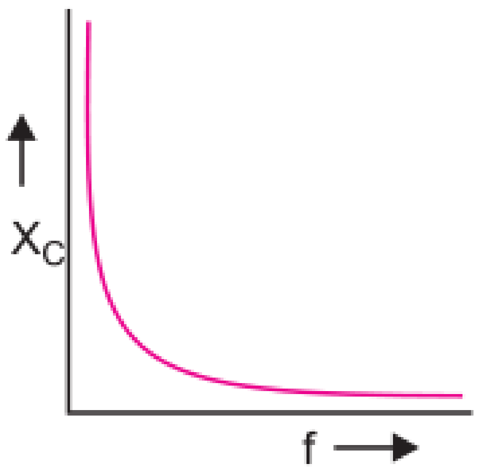
Phasor diagram: The phasor diagram of circuit containing pure inductance is shown in Fig. (b).

Graphs of V and I versus ωt for this circuit is shown in Fig. (c).



Q. 2. Define the term capacitive reactance. Show graphically the variation of capacitive reactance with frequency of applied alternating voltage.

An ac voltage $V = V_0 \sin \omega t$ is applied across a pure capacitor of capacitance C. Find an expression for current flowing through it. Show mathematically the current flowing through it leads the applied voltage by angle π /2.

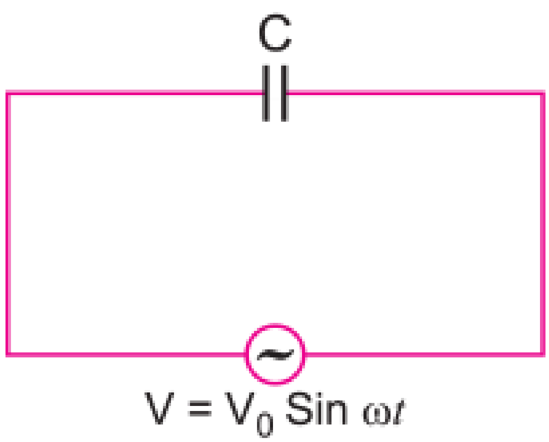


Ans. Capacitive Reactance: The opposition offered by a capacitor alone to the flow of alternating current through it is called the capacitive reactance.

It is denoted by X_C. Its value is $X_C = \frac{1}{\omega C} = \frac{1}{2\pi fC}$

The graph of variation of capacitive reactance with frequency is shown in figure.

Phase Difference between Current and Applied voltage in Purely Capacitive Circuit:



(a)

Circuit Containing Pure Capacitance: Consider a capacitor of capacitance C; connected to an alternating voltage source as shown.

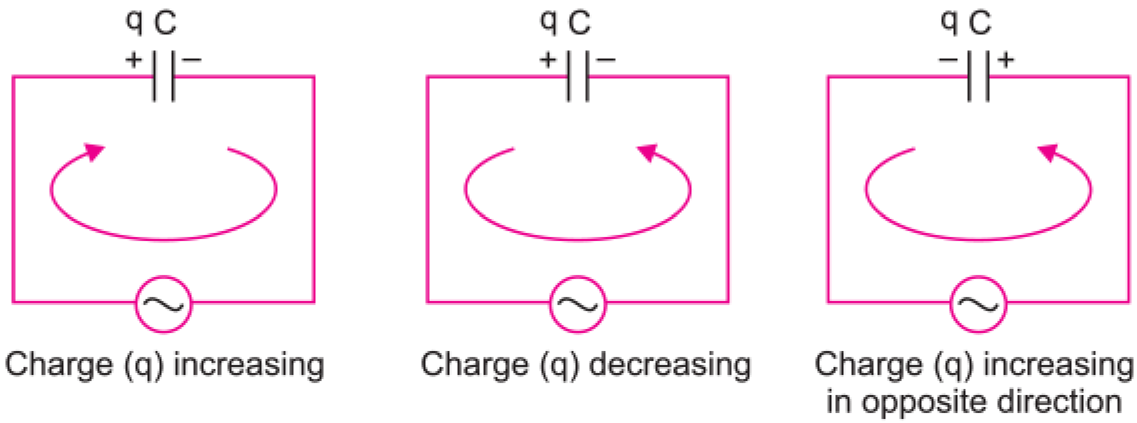
As ac voltage changes in magnitude and direction periodically with a definite frequency; therefore the plates of capacitor get charged, discharged and charged in opposite direction, discharged continuously (Fig. b). Therefore the flow of alternating current in the circuit is maintained. The instantaneous voltage,

$V = V_0 \sin \omega t$ ...(i)

Let q be the charge on capacitor and i , the current in the circuit at any instant, then instantaneous potential difference,

$V = \frac{q}{C}$ ...(ii)

Or $q = CV0 \sin \omega t$



The instantaneous current,

$$i = \frac{\mathrm{dq}}{\mathrm{dt}} = \frac{d}{\mathrm{dt}}(C\ V_0 \sin \omega t) = C\ V_0 \frac{d}{\mathrm{dt}}(\sin \omega t) = C\ V_0\ \omega\ \cos\ \omega t$$

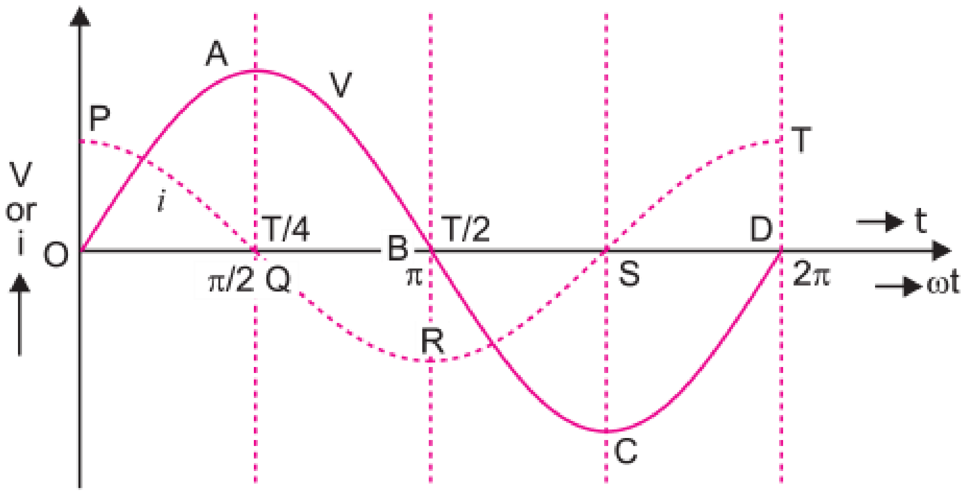
or $$i = \frac{V_0}{(1/\omega C)} \cos\ \omega t = \frac{V_0}{1/\omega C} \sin\left(\omega t + \frac{\pi}{2}\right)$$

or $$i = I_0 \sin\left(\omega t + \frac{\pi}{2}\right) \quad ...(iii)$$

where $i_0 = \frac{V_0}{(1/\omega C)}$ = peak value of A.C. ...(iv)

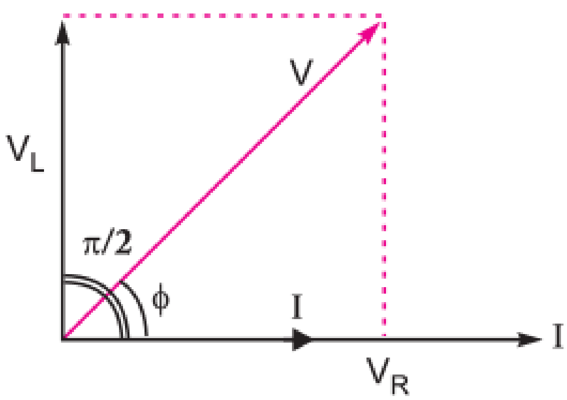
Also comparing (i) and (iii), we note that the current leads the applied emf by an angle $\frac{\pi}{2}$

This is shown graphically in fig. (*c*).



Q. 3. Derive an expression for impedance of an a.c. circuit consisting of an inductor and a resistor. [CBSE Delhi 2008]

Ans. Let a circuit contain a resistor of resistance R and an inductor of inductance L connected in series. The applied voltage is $V = V_0 \sin \omega t$. Suppose the voltage across resistor VR and that across inductor is VL. The voltage V_R and current I are in the same phase, while the voltage V_L leads the current by an angle $\frac{\pi}{2}$. Thus, V_R and V_L are mutually perpendicular. The resultant of VR and VL is the applied voltage i.e.,



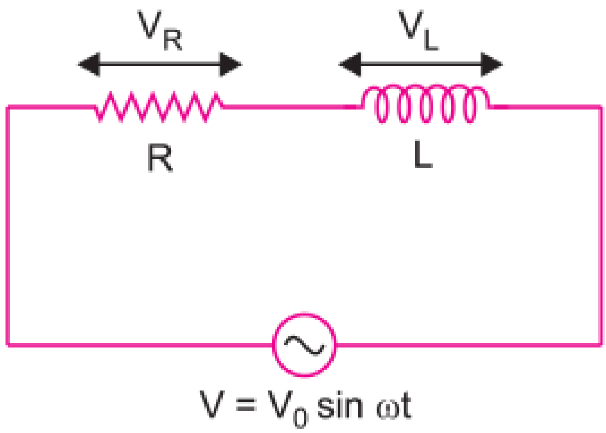
$$V = \sqrt{V_R^2 + V_L^2}$$

But $V_R = Ri,$ $V_L = X_L \ i = \omega L i$

∴ where $X_L = \omega L$ is inductive reactance

∴ $V = \sqrt{(\text{Ri})^2 + (X_L i)^2}$

∴ Impedance, $Z = \frac{V}{i} = \sqrt{R^2 + X_L^2} \Rightarrow Z = \sqrt{R^2 + (\omega L)^2}$



Q. 4. (a) What is impedance?

(b) A series LCR circuit is connected to an ac source having voltage $V = V_0 \sin \omega t$. Derive expression for the impedance, instantaneous current and its phase relationship to the applied voltage. Find the expression for resonant frequency. [CBSE Delhi 2010]

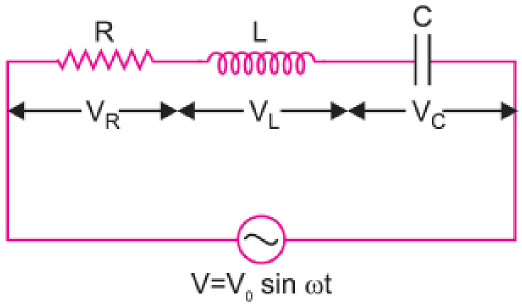
OR

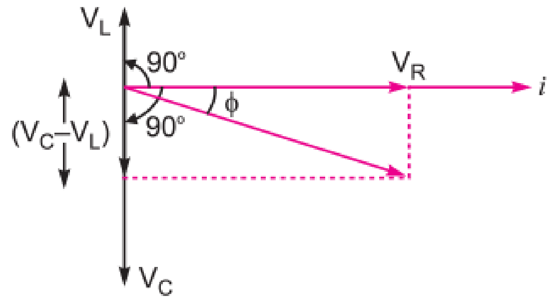
An ac source of voltage $V = V_0 \sin \omega t$ is connected to a series combination of L, C and R. Use the phasor diagram to obtain expressions for impedance of the circuit and phase angle between voltage and current. Find the condition when current will be in phase with the voltage. What is the circuit in this condition called?

In a series L_R circuit $X_L = R$ and power factor of the circuit is P_1. When capacitor with capacitance C such that XL = XC is put in series, the power factor becomes P_2. Calculate $\frac{P1}{P2}$. [CBSE Delhi 2016]

Ans. Impedance: The opposition offered by the combination of a resistor and reactive component to the flow of ac is called impedance. Mathematically it is the ratio of rms voltage applied and rms current produced in circuit i.e., $Z = \frac{V}{1}$.

Expression for Impedance in LCR series circuit: Suppose resistance R, inductance L and capacitance C are connected in series and an alternating source of voltage $V = V_0 \sin \omega t$ is applied across it. (fig. a) On account of being in series, the current (i) flowing through all of them is the same.





Suppose the voltage across resistance R is V_R voltage across inductance L is V_L and voltage across capacitance C is VC. The voltage VR and current i are in the same phase, the voltage V_L will lead the current by angle 90° while the voltage VC will lag behind the current by angle 90° (fig. b). Clearly VC and VL are in opposite directions, therefore their resultant potential difference = $V_C – V_L$ (if $V_C > V_L$)

Thus VR and ($V_C – V_L$) are mutually perpendicular and the phase difference between them is 90°. As applied voltage across the circuit is V, the resultant of VR and ($V_C – V_L$) will also be V. From fig.

$$V^2 = V_R^2 + (V_C - V_L)^2 \quad \Rightarrow \quad V = \sqrt{V_R^2 + (V_C - V_L)^2} \qquad \ldots(i)$$

But $V_R = R\,i$, $V_C = X_C\,i$ and $V_L = X_L\,i$ ...(*ii*)

where $X_C = \frac{1}{\omega C}$ = capacitance reactance and $X_L = \omega L$= inductive reactance

$$V = \sqrt{(\mathrm{Ri})^2 + (X_C i - X_L i)^2}$$

Impedance of circuit, $Z = \frac{V}{i} = \sqrt{R^2 + (X_C - X_L)^2}$

i.e., $Z = \sqrt{R^2 + (X_C - X_L)^2} = \sqrt{R^2 + \left(\frac{1}{\omega C} - \omega L\right)^2}$

Instantaneous current $I = \frac{V_0 \sin(\omega t + \varphi)}{\sqrt{R^2 + \left(\frac{1}{\omega C} - \mathrm{wL}\right)^2}}$

The phase difference (φ) between current and voltage φ is given by tan $\varphi = \frac{X_C - X_L}{R}$

Resonant Frequency: For resonance φ= 0, so $X_C - X_L = 0$

$$\frac{1}{\omega C} = \omega L \Rightarrow \omega^2 = \frac{1}{LC}$$

∴ Resonant frequency $\omega_r = \frac{1}{\sqrt{LC}}$

a. Phase difference (φ) in series LCR circuit is given by

$$\tan\varphi = \frac{V_C - V_L}{V_R} = \frac{i_m(X_C - X_L)}{i_m R} = \frac{(X_C - X_L)}{R}$$

When current and voltage are in phase

$\varphi = 0$ ⇒ $X_C - X_L = 0$ ⇒ $X_C = X_L$

This condition is called resonance and the circuit is called resonant circuit.

b. **Case I:** $X_L = R$

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

Power factor, $P_1 = \cos\varphi = \frac{R}{Z} = \frac{R}{\sqrt{2}R} = \frac{1}{\sqrt{2}}$

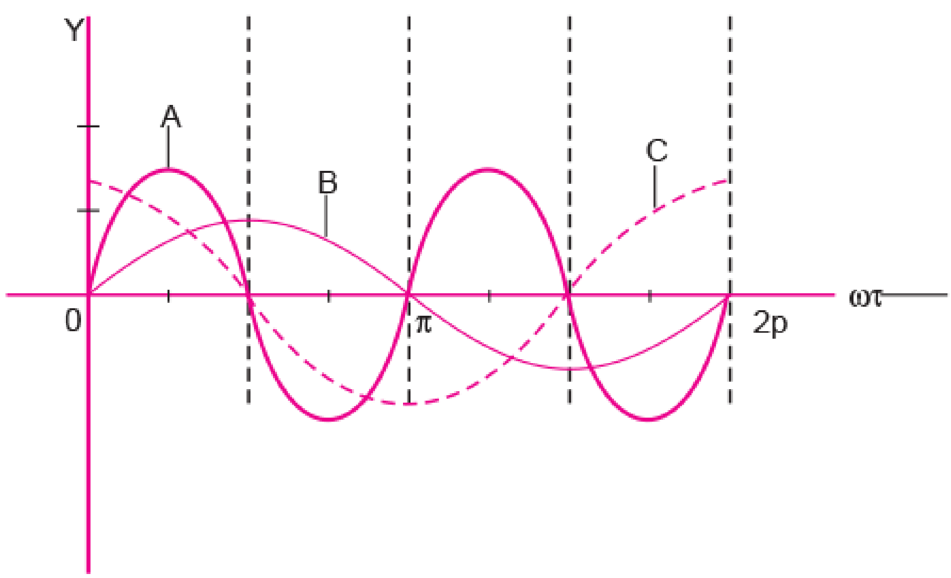
Case II: $X_L = X_C$

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

Power factor, $P_2 = \frac{R}{Z} = \frac{R}{R} = 1$

∴ $\frac{P_1}{P_2} = \frac{1}{\sqrt{2}}$

Q. 5. A device 'X' is connected to an ac source $V = V_0 \sin \omega t$. The variation of voltage, current and power in one cycle is show in the following graph:



(i) Identify the device 'X'.

(ii) Which of the curves, A, B and C represent the voltage, current and the power consumed in the circuit? Justify your answer.

(iii) How does its impedance vary with frequency of the ac source? Show graphically.

(iv) Obtain an expression for the current in the circuit and its phase relation with ac voltage.

Ans. (i) The device 'X' is a capacitor.

(ii) Curve B: Voltage

Curve C: Current

Curve A: Power consumed in the circuit

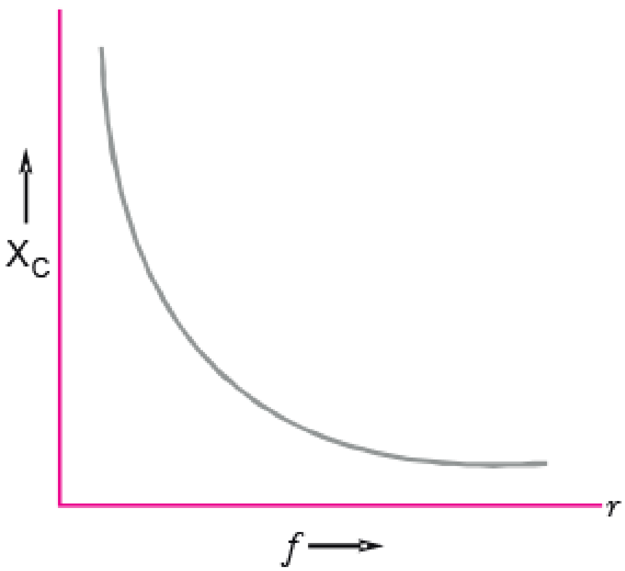
Reason: This is because current leads the voltage in phase by $\frac{\pi}{2}$ for a capacitor.

(iii) Impedance:

XC = $\frac{1}{\omega C} = \frac{1}{2\pi} = C$

$$\Rightarrow \qquad X_C \propto \frac{1}{f}$$

(iv)



Voltage applied to the circuit is

$V = V_0 \sin \omega t$

Due to this voltage, a charge will be produced which will charge the plates of the capacitor with positive and negative charges.

$$V = \frac{Q}{C} \qquad \Rightarrow \qquad Q = \mathrm{CV}$$

Therefore, the instantaneous value of the current in the circuit is

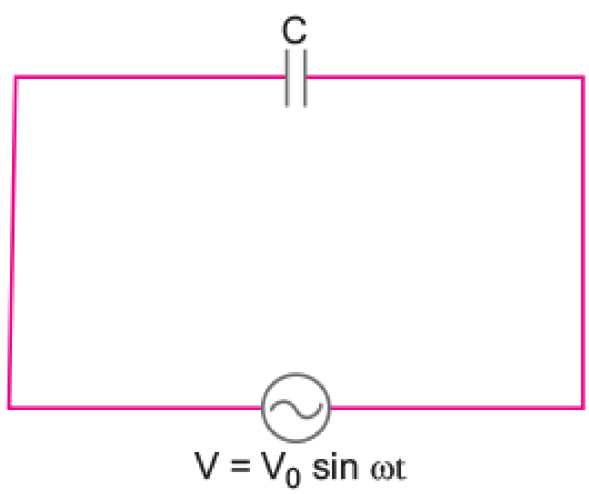
$$I = \frac{\mathrm{dQ}}{\mathrm{dt}} = \frac{d(\mathrm{CV})}{\mathrm{dt}} = \frac{d}{\mathrm{dt}}(\mathrm{CV}_0 \ \sin \ \omega t)$$

$$I = \omega \mathrm{CV}_0 \ \cos \ \omega t = \frac{V_0}{\frac{1}{\omega C}} \sin\left(\omega t + \frac{\pi}{2}\right)$$

$$I = I_0 \ \sin \ \left(\omega t + \frac{\pi}{2}\right)$$

where, $I_0 = \frac{V_0}{\frac{1}{\omega C}}$ = Peak value of current

Hence, current leads the voltage in phase by $\frac{\pi}{2}$.



Q. 6. (a) State the condition for resonance to occur in series LCR a.c. circuit and derive an expression for resonant frequency. [CBSE Delhi 2010]

(b) Draw a plot showing the variation of the peak current (i_m) with frequency of the a.c. source used. Define the quality factor Q of the circuit.

Ans. (a) Condition for resonance to occur in series LCR ac circuit:

For resonance the current produced in the circuit and emf applied must always be in the same phase.

Phase difference (φ) in series LCR circuit is given by

$$\tan \varphi = \frac{X_C - X_L}{R}$$

For resonance $\varphi = 0 \Rightarrow X_C - X_L = 0$

or $X_C = X_L$

If ω_r is resonant frequency, then $X_C = \frac{1}{\omega_r C}$

and $X_C = \omega_r L$

$$\frac{1}{\omega_r C} = \omega_r L \quad \Rightarrow \quad \omega_r = \frac{1}{\sqrt{LC}}$$

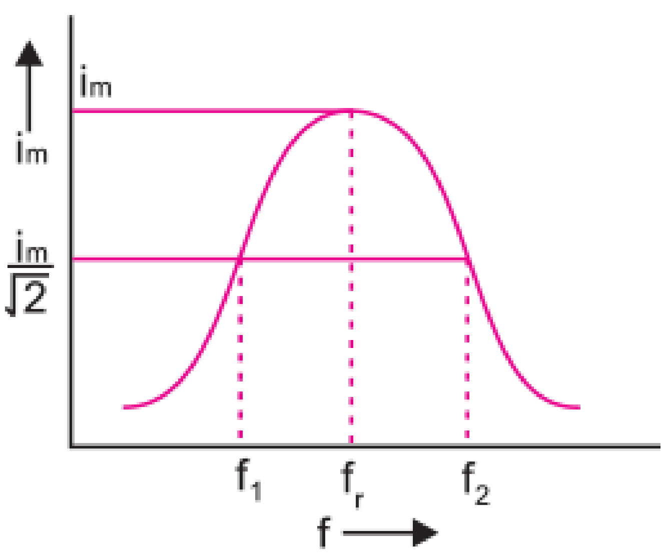
Linear resonant frequency, $f_r = \frac{\omega_r}{2\pi} = \frac{1}{2\pi\sqrt{LC}}$

(b) The graph of variation of peak current i_m with frequency is shown in fig.

Half power frequencies are the frequencies on either side of resonant frequency for which current reduces to half of its maximum value. In fig. f_1 and f_2 are half power frequencies.

Quality Factor (Q): The quality factor is defined as the ratio of resonant frequency to the width of half power frequencies.

$$i.e., \quad Q = \frac{\omega_r}{\omega_2 - \omega_1} = \frac{f_r}{f_2 - f_1} = \frac{\omega_r L}{R}$$

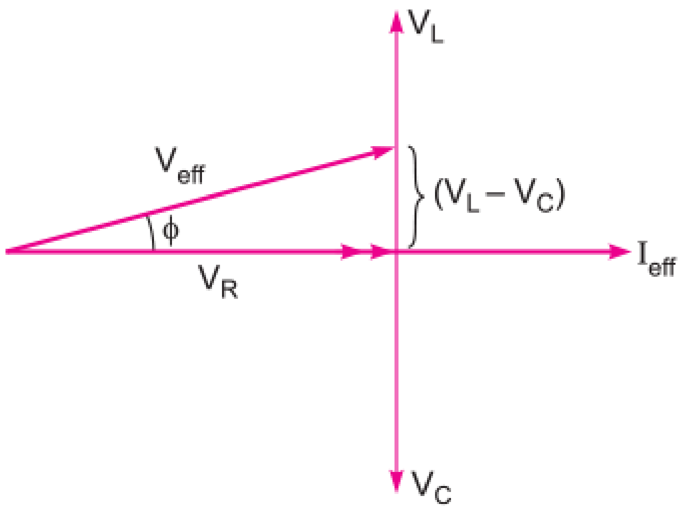


Q. 7. Using phasor diagram for a series LCR circuit connected to an ac source of voltage v = v_0 sin ωt, derive the relation for the current flowing in the circuit and the phase angle between the voltage across the resistor and the net voltage in the circuit.

Draw a plot showing the variation of the current I as a function of angular frequency 'ω' of the applied ac source for the two cases of a series combination of (i) inductance L_1, capacitance C_1 and resistance R1 and (ii) inductance L_2, capacitance C_2 and resistance R_2 where $R_2 > R_1$.

Write the relation between L_1, C_1 and L_2,C_2 at resonance. Which one, of the two, would be better suited for fine tuning in a receiver set? Give reason. [CBSE (F) 2013]

Ans. For I_{eff} flow of current through each element R, L and C, effective voltage across the combination can be given as.



⇒ $$\overrightarrow{V_{\text{eff}}} = \hat{i}V_R + \hat{j}(V_L - V_C)$$

⇒ $$|V_{\text{eff}}| = \sqrt{|V_R|^2 + (V_L - V_C)^2}$$

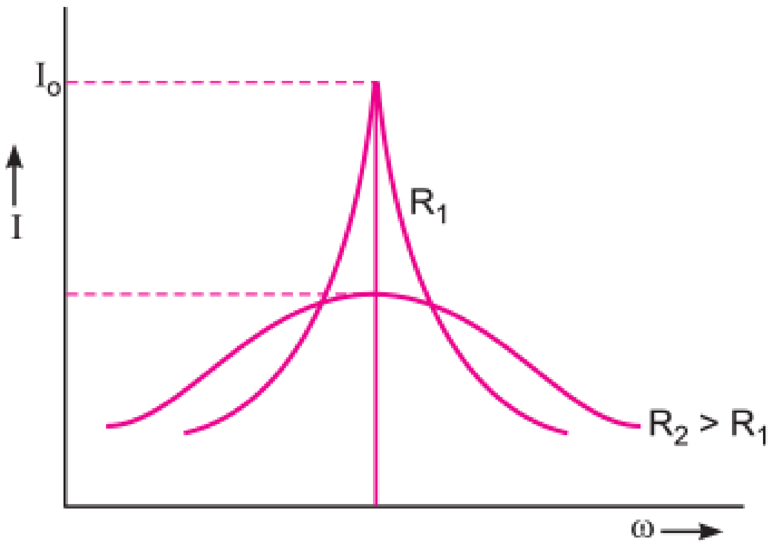
⇒ $$I_{\text{eff}}\, Z = \sqrt{(I_{\text{eff}}R)^2 + (I_{\text{eff}}X_L - I_{\text{eff}}X_C)^2}$$

⇒ $$|Z| = \sqrt{R^2 + (X_L - X_C)^2}$$

Effective current flow $I_{\text{eff}} = \frac{E_{\text{eff}}}{Z} = \frac{E_{\text{eff}}}{\sqrt{R^2 + (X_L - X_C)^2}}$

Phase angle between V_R and V_{eff} is

$$\cos\varphi = \frac{V_R}{V_{\text{eff}}} = \frac{V_R}{\sqrt{{V_R}^2 + (V_L - V_C)^2}}$$

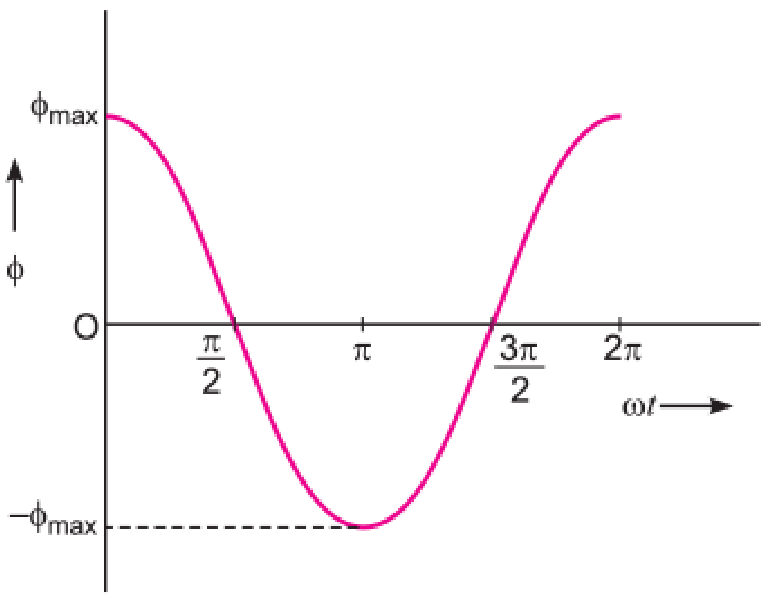


(i) $I = I_0 \sin(\omega t - \varphi)$ For $V_L > V_C$ or $X_L > X_C$

(ii) $I = I_0 \sin(\omega t + \varphi)$ For $V_L < V_C$ or $X_L < X_C$

Variation of the current I as a function of angular frequency ω.

At resonance, when maximum current flows through the circuit.

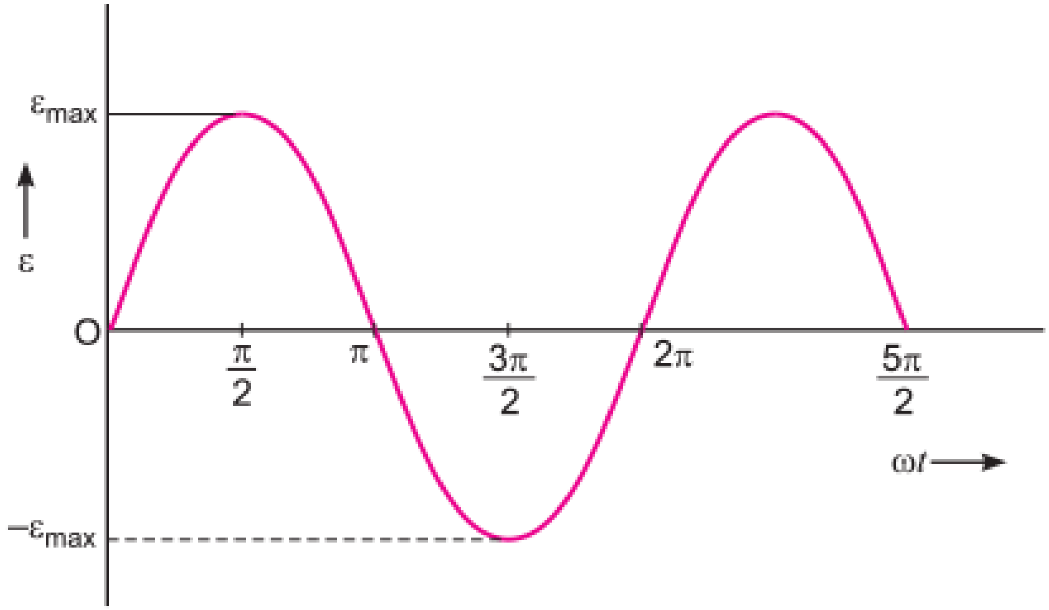


$$\omega_r = \frac{1}{\sqrt{L_1C_1}} = \frac{1}{\sqrt{L_2C_2}}$$

$$L_1C_1 = L_2C_2 \Rightarrow \frac{L_1}{L_2} = \frac{C_2}{C_1}$$

For fine tuning in the receiver set, combination L_1C_1 and R_1 is better because maximum current flows through the circuit.

From Lenz's law, induced emf



$$\varepsilon = -\frac{d\Phi}{dt}$$

$$= -|B|\,|A|\,\frac{d}{dt}\cos\omega t$$

$$= |B|\,A\,\omega\,\sin\omega t$$

Q. 8. Answer the following question :

(i) An alternating voltage V = V_m Sin ωt (applied to a series LCR circuit drives a current given by i = i_m sin (ωt +φ) . Deduce an expression for the average power dissipated over a cycle.

(ii) For circuits used for transporting electric power, a low power factor implies large power loss in transmission. Explain. [CBSE (F) 2011]

Ans. (i) $V = V_m \sin \omega t$ and $i = i_m (\omega t + \varphi)$

And instantaneous power, $P = V_i$

$= V_m \sin \omega t.\ i_0 \sin (\omega t + \varphi)$

$= V_m\, i_m \sin \omega t \sin (\omega t + \varphi)$

$$= \frac{1}{2} V_m i_m 2 \sin \omega t . \sin (\omega t + \varphi)$$

From trigonometric formula

$$2 \sin A \sin B = \cos (A - B) - \cos (A + B)$$

$\therefore$ Instantaneous power, $P = \frac{1}{2} V_m i_m [\cos (\omega t + \varphi - \omega t) - \cos (\omega t + \varphi + \omega t)]$

$$= \frac{1}{2} V_m i_m [\cos \varphi - \cos (2\omega t + \varphi)] \quad \ldots (i)$$

Average power for complete cycle $\vec{P} = \frac{1}{2} V_m i_m [\cos \varphi - \cos (2\overline{\omega t} + \varphi)]$

where $\cos (\overline{\omega t} + \varphi)$ is the mean value of $\cos (2\omega t + \varphi)$ over complete cycle. But for a complete cycle, $\cos \overline{(2\omega t + \varphi)} = 0$

$\therefore$ Average power, $\vec{P} = \frac{1}{2} V_m i_m \cos \varphi = \frac{V_0}{\sqrt{2}} \frac{i_0}{\sqrt{2}} \cos \varphi$

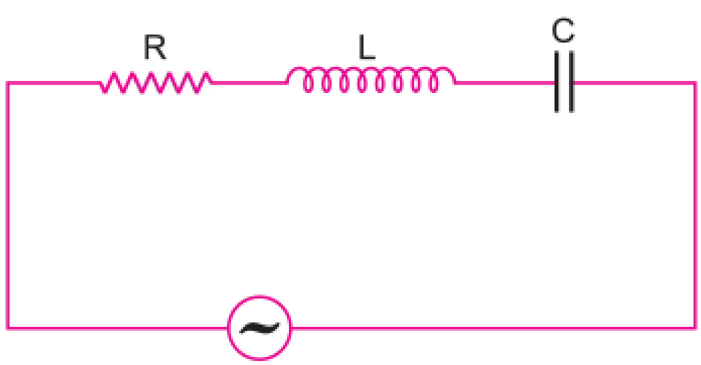
$$\vec{P} = V_{\text{rms}} i_{\text{rms}} \cos \varphi$$

(ii) The power is $P = V_{rms} I_{rms} \cos \varphi$. If $\cos \varphi$ is small, then current considerably increases when voltage is constant. Power loss, we know is I_2R. Hence, power loss increases.

Q. 9. A voltage $V = V_0 \sin \omega t$ is applied to a series LCR circuit. Derive the expression for the average power dissipated over a cycle.

Under what condition is (i) no power dissipated even though the current flows through the circuit, (ii) maximum power dissipated in the circuit? [CBSE (AI) 2014]

Ans.



The voltage V = V0 sin ωt is applied across the series LCR circuit. However due to impedance of the circuit, either current lags or leads the voltage by phase opposite so the current in the circuit is given by

$I = I_0 \sin(\omega t - \varphi)$

Instantaneous power dissipation in the circuit

P = VI

$$V_0 \sin\omega t \times I_0 \sin(\omega t - \varphi) = \frac{V_0 I_0}{2} \times 2\sin\omega t . \sin(\omega t - \varphi)$$

$$= \frac{V_0 I_0}{2}(\cos\varphi - \cos(2\omega t - \varphi)) \qquad [\cos(A-B) - \cos(A+B) = 2\sin A \sin B]$$

Average power loss over one complete cycle

$$\bar{P} = \frac{1}{T}\int_0^T \mathrm{Pdt} = \frac{V_0 I_0}{2T}\left[\int_0^T \cos\varphi\, \mathrm{dt} - \int_0^T \cos(2\omega t - \varphi)\, \mathrm{dt}\right]$$

However, $$\int_0^T \cos(2\omega t - \varphi)\mathrm{dt} = 0 = \frac{V_0 I_0}{2T} . \cos\varphi \int_0^T \mathrm{dt} = \frac{V_0 I_0}{2}\cos\varphi$$

$$P_{av} = \frac{V_0}{\sqrt{2}}\frac{I_0}{\sqrt{2}}\cos\varphi$$

$$P_{av} = V_{eff} . I_{eff} \cos\varphi$$

(i) If phase angle φ =90° (resistance R is used in the circuit) then no power dissipated.

(ii) If phase angle φ =0° or circuit is pure resistive (or XL= XC) at resonance then

$$\text{Max power } P = V_{eff} \times I_{eff} = \frac{V_0 I_0}{2}$$

Q. 10. Explain with the help of a labelled diagram, the principle and working of an ac generator? Write the expression for the emf generated in the coil in terms of speed of rotation. Can the current produced by an ac generator be measured with a moving coil galvanometer?

OR

Describe briefly, with the help of a labelled diagram, the basic elements of an ac generator. State its underlying principle. Show diagrammatically how an alternating emf is generated by a loop of wire rotating in a magnetic field. Write

the expression for the instantaneous value of the emf induced in the rotating loop.
[CBSE Delhi 2010]

OR

State the working of ac generator with the help of a labelled diagram.

The coil of an ac generator having N turns, each of area A, is rotated with a constant angular velocity ω. Deduce the expression for the alternating emf generated in the coil.

What is the source of energy generation in this device? [CBSE (AI) 2011]

Ans. AC generator: A dynamo or generator is a device which converts mechanical energy into electrical energy.

Principle: It works on the principle of electromagnetic induction. When a coil rotates continuously in a magnetic field, the effective area of the coil linked normally with the magnetic field lines, changes continuously with time. This variation of magnetic flux with time results in the production of an alternating emf in the coil.

Construction: It consists of the four main parts:

(i) Field Magnet: It produces the magnetic field. In the case of a low power dynamo, the magnetic field is generated by a permanent magnet, while in the case of large power dynamo, the magnetic field is produced by an electromagnet.

(ii) Armature: It consists of a large number of turns of insulated wire in the soft iron drum or ring. It can revolve round an axle between the two poles of the field magnet. The drum or ring serves the two purposes: (i) It serves as a support to coils and (ii) It increases the magnetic field due to air core being replaced by an iron core.

(iii) Slip Rings: The slip rings R1 and R2 are the two metal rings to which the ends of armature coil are connected. These rings are fixed to the shaft which rotates the armature coil so that the rings also rotate along with the armature.

(iv) Brushes: These are two flexible metal plates or carbon rods (B1 and B2) which are fixed and constantly touch the revolving rings. The output current in external load RL is taken through these brushes.

Working: When the armature coil is rotated in the strong magnetic field, the magnetic flux linked with the coil changes and the current is induced in the coil, its direction being given by Fleming's right hand rule. Considering the armature to be in vertical position and as it rotates in anticlockwise direction, the wire ab moves upward and cd downward, so that the direction of induced current is shown in fig. In the external circuit, the current flows along B_1 R_LB_2. The direction of current remains unchanged during the first half turn of armature. During the second half revolution, the wire ab moves downward and cd upward, so the direction of current is reversed and in external circuit it flows along $B_2 R_L B_1$. Thus the direction of induced emf and current changes in the external circuit after each half revolution.

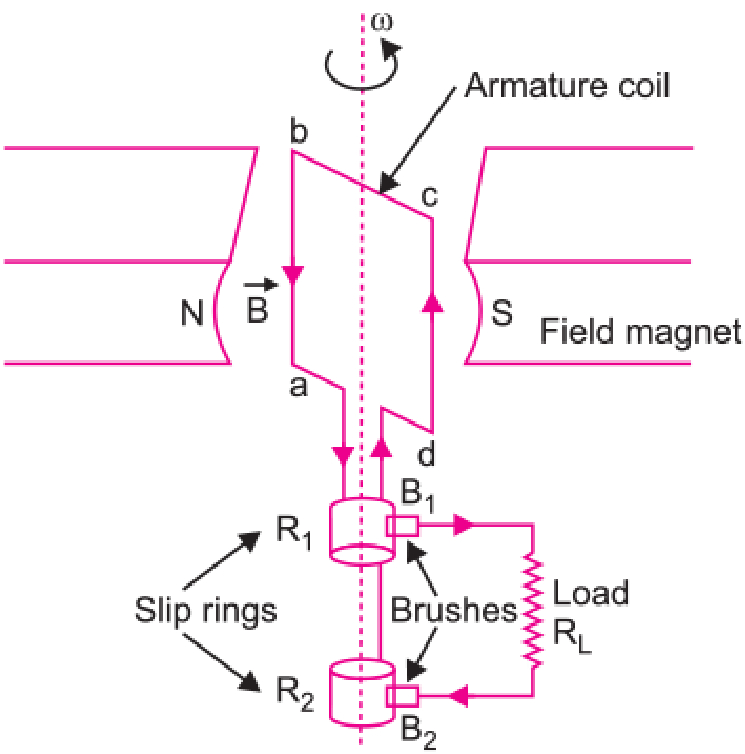
Expression for Induced emf: When the coil is rotated with a constant angular speed ω , the angle θ between the magnetic field vector B and the area vector A of the coil at any instant t is θ = ωt

(Assuming θ = 0° at t = 0). As a result, the effective area of the coil exposed to the magnetic field lines changes with time, the flux at any time t is

$\Phi_B = BA \cos\theta = BA \cos \omega t$

From Faraday's law, the induced emf for the rotating coil of N turns is then,

$$\varepsilon = -N \frac{d\Phi_B}{dt} = -NBA \frac{d}{dt}(\cos \omega t)$$



Thus, the instantaneous value of the emf is

$\varepsilon = NBA\omega \sin \omega t$

Where $NBA\omega = 2\pi \nu NBA$ is the maximum value of the emf, which occurs when $\sin \omega t = \pm 1$. If we denote $NBA\omega$ as ε_0, then

$\varepsilon = \varepsilon_0 \sin \omega t \quad \Rightarrow \varepsilon = \varepsilon_0 \sin 2\pi \nu t$

Where v is the frequency of revolution of the generator's coil.

Obviously, the emf produced is alternating and hence the current is also alternating.

Current produced by an ac generator cannot be measured by moving coil ammeter; because the average value of ac over full cycle is zero.

The source of energy generation is the mechanical energy of rotation of armature coil.

Q. 11. (a) Describe briefly, with the help of a labelled diagram, the working of a step up transformer.

(b) Write any two sources of energy loss in a transformer. [CBSE (F) 2012]

(c) A step up transformer converts a low voltage into high voltage. Does it not violate the principle of conservation of energy? Explain. [CBSE Delhi 2011, 2009]

OR

Draw a schematic diagram of a step-up transformer. Explain its working principle. Deduce the expression for the secondary to primary voltage in terms of the number of turns in the two coils. In an ideal transformer, how is this ratio related to the currents in the two coils?

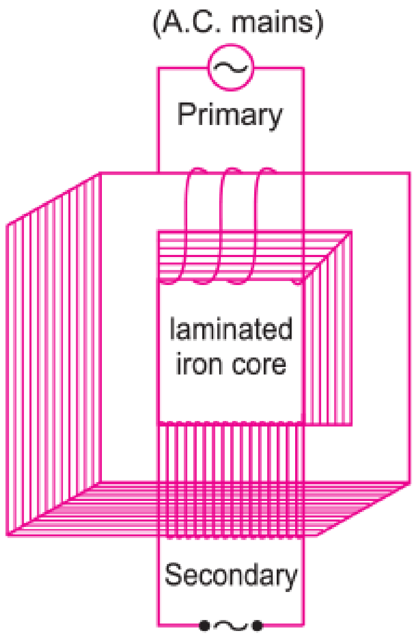
How is the transformer used in large scale transmission and distribution of electrical energy over long distances? [CBSE (AI) 2010, (East) 2016]

Ans. (a) Transformer: A transformer converts low voltage into high voltage ac and vice-versa.

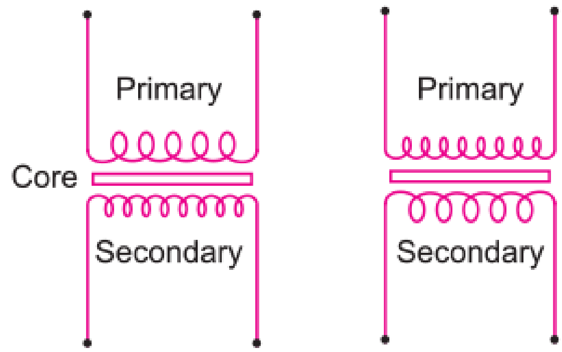
Construction: It consists of laminated core of soft iron, on which two coils of insulated copper wire are separately wound. These coils are kept insulated from each other and from the iron-core, but are coupled through mutual induction. The number of turns in these coils are different. Out of these coils one coil is called primary coil and other is called the secondary coil. The terminals of primary coils are connected to AC mains and the terminals of the secondary coil are connected to external circuit in which alternating current of desired voltage is required. Transformers are of two types:

1. Step up Transformer: It transforms the alternating low voltage to alternating high voltage and in this the number of turns in secondary coil is more than that in primary coil. (i.e., $N_S > N_p$)

2. Step down Transformer: It transforms the alternating high voltage to alternating low voltage and in this the number of turns in secondary coil is less than that in primary coil (i.e., $N_S < N_p$).



Transformer



(a) Step up (b) Step down

Working: When alternating current source is connected to the ends of primary coil, the current changes continuously in the primary coil; due to which the magnetic flux linked with the secondary coil changes continuously, therefore the alternating emf of same frequency is developed across the secondary.

Let N_P be the number of turns in primary coil, NS the number of turns in secondary coil and φ the magnetic flux linked with each turn. **We assume that there is no leakage of flux so that the flux linked with each turn of primary coil and secondary coil is the same.** According to Faraday's laws the emf induced in the primary coil

$$\varepsilon_p = -N_p \frac{\Delta\varphi}{\Delta t} \qquad \ldots(i)$$

and emf induced in the secondary coil

$$\varepsilon_S = -N_S \frac{\Delta\varphi}{\Delta t} \qquad \ldots(ii)$$

From (i) and (ii)

$$\frac{\varepsilon_S}{\varepsilon_p} = \frac{N_S}{N_p} \qquad \ldots(iii)$$

If the resistance of primary coil is negligible, the emf (ε_p) induced in the primary coil, will be equal to the applied potential difference (V_P) across its ends. Similarly if the secondary circuit is open, then the potential difference VS across its ends will be equal to the emf (ε_S) induced in it; therefore

$$\frac{V_S}{V_p} = \frac{\varepsilon_S}{\varepsilon_p} = \frac{N_S}{N_p} = r \text{ (say)} \qquad ...(iv)$$

where $r = \frac{N_S}{V_P}$ is called the transformation ratio. If i_P and i_S are the instantaneous currents in primary and secondary coils and there is no loss of energy; then

For about 100% efficiency, Power in primary = Power in secondary

$V_P\, i_P = V_S\, i_S$

$$\frac{i_s}{i_p} = \frac{V_p}{V_S} = \frac{N_p}{N_S} = \frac{1}{r} \qquad ...(v)$$

In step up transformer, $N_S > N_P \rightarrow r > 1$;

So $V_S > V_P$ and $i_S < i_p$

i.e. step up transformer increases the voltage.

In step down transformer, $N_S < N_P \rightarrow r < 1$

So $V_S < V_P$ and $i_S > i_p$

i.e. step down transformer decreases the voltage, but increases the current.

Laminated core: The core of a transformer is laminated to reduce the energy losses due to eddy currents, so that its efficiency may remain nearly 100%.

In a transformer with 100% efficiency (say),

Input power = output power $V_P I_P = V_S I_S$

(b) The sources of energy loss in a transformer are (i) eddy current losses due to iron core (ii) flux leakage losses. (iii) Copper losses due to heating up of copper wires (iv) Hysteresis losses due to magnetisation and demagnetisation of core.

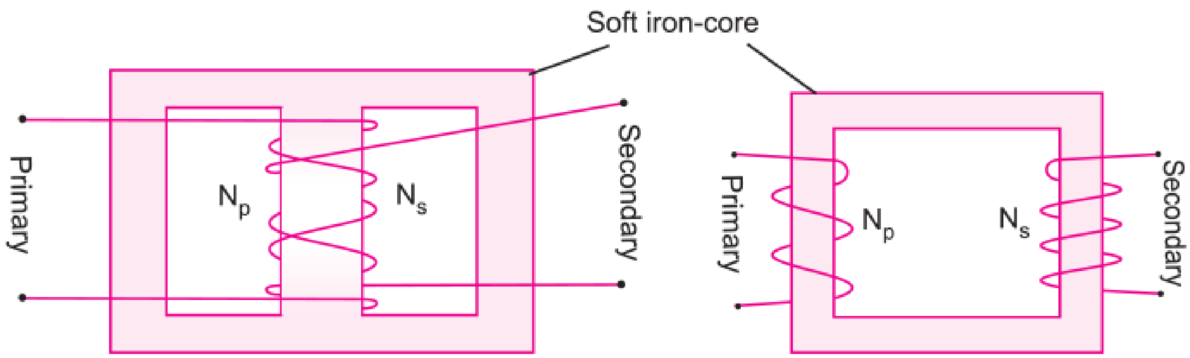
(c) When output voltage increases, the output current automatically decreases to keep the power same. Thus, there is no violation of conservation of energy in a step up transformer.

Q. 12. Show diagrammatically two different arrangements used for winding the primary and secondary coils in a transformer. Assuming the transformer to be an ideal one, write the expression for the ratio of its

(i) Output voltage to input voltage
(ii) Output current to input current.

Mention two reasons for energy losses in an actual transformer. [CBSE (F) 2012]

Ans. Arrangements of winding of primary and secondary coil in a transformer are shown in fig. (a) and (b).



(a) Two coils on top of each other (b)Two coils on separate limbs of the core

(i) Ratio of output voltage to input voltage

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

(ii) Ratio of output current to input current

$$\frac{I_s}{I_p} = \frac{N_p}{N_s}$$

Reasons for energy losses in a transformer

(i) Joule Heating: Energy is lost due to heating of primary and secondary windings as heat (I_2Rt).

(ii) Flux Leakage: Energy is lost due to coupling of primary and secondary coils not being perfect, i.e., whole of magnetic flux generated in primary coil is not linked with the secondary coil.

Q. 13. A 2 μF capacitor, 100 W resistor and 8 H inductor are connected in series with an AC source.

(i) What should be the frequency of the source such that current drawn in the circuit is maximum? What is this frequency called?

(ii) If the peak value of emf of the source is 200 V, find the maximum current.

(iii) Draw a graph showing variation of amplitude of circuit current with changing frequency of applied voltage in a series LRC circuit for two different values of resistance R_1 and R_2 ($R_1 > R_2$).

(iv) Define the term 'Sharpness of Resonance'. Under what condition, does a circuit become more selective? [CBSE (F) 2016]

Ans. (i)

For maximum frequency

$$\omega L = \frac{1}{\omega C}$$

$$\Rightarrow \quad 2\pi\nu 8 = \frac{1}{2\pi\nu \times 10^{-6} \times 2} \quad \Rightarrow \quad (2\pi\nu)^2 = \frac{1}{16 \times 10^{-6}}$$

$$\Rightarrow \quad 2\pi\nu = \frac{1}{4 \times 10^{-3}} \quad \Rightarrow 2\pi\nu = \frac{10^3}{4}$$

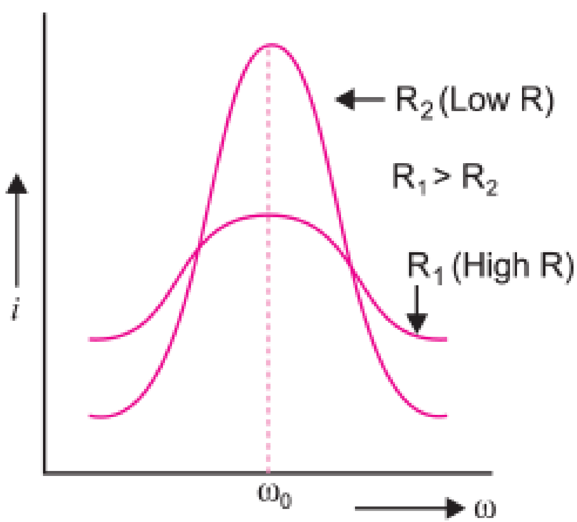
$$\Rightarrow \quad \nu = \frac{250}{2\pi} = 39.77\ s^{-1}$$

This frequency is called resonance frequency.

(ii)

Maximum current, $I_0 = \frac{E_0}{R} = \frac{200}{100} = 2A\ [E_0 \text{ maximum emf}]$

(iii)



(iv) $\frac{\omega_0}{2\Delta\omega}$ is measure of sharpness of resonance, where ω_0 is the resonant frequency and $2\Delta\omega$ is the bandwidth.

Circuit is more selective if it has greater value of sharpness. The circuit should have smaller bandwidth $\Delta\omega$.

Q. 14. (i) Draw a labelled diagram of AC generator. Derive the expression for the instantaneous value of the emf induced in the coil.

(ii) A circular coil of cross-sectional area 200 cm^2 and 20 turns is rotated about the vertical diameter with angular speed of 50 rad s^{-1} in a uniform magnetic field of magnitude 3.0 × 10^{-2} T. Calculate the maximum value of the current in the coil. [CBSE Delhi 2017]

Ans. Given, N = 20

$A = 200\ cm^2$

$= 200 \times 10^{-4} m^2$

$B = 3.0 \times 10^{-2}\ T$

$\omega = 50\ rad\ s^{-1}$

EMF induced in the coil

$\varepsilon = NBA\omega \sin \omega t$

Maximum emf induced

$\varepsilon_{max} = NBA$

$= 20 \times 3.0 \times 10^{-2} \times 200 \times 10^{-4} \times 50$

$= 600\ mV$

Maximum value of current induced

$$I_{max} = \frac{\varepsilon_{max}}{R} = \frac{600}{R} mA$$

Q. 15. (i) Draw a labelled diagram of a step-up transformer. Obtain the ratio of secondary to primary voltage in terms of number of turns and currents in the two coils.

(ii) A power transmission line feeds input power at 2200 V to a step-down transformer with its primary windings having 3000 turns. Find the number of turns in the secondary to get the power output at 220 V. [CBSE Delhi 2017]

Ans.

ii. Given, V_p = 2200 V

N_p = 3000 turns

V_s = 220 V

We have, $\frac{V_s}{V_p} = \frac{N_s}{N_p}$

$$N_s = \frac{V_s}{V_p} \times N_p$$

$$= \frac{220}{2200} \times 300$$

N_s = 300 turns