7 Alternating Current

Fastrack Revision

- **Alternating Current (AC):** The current whose magnitude varies periodically with respect to time is called alternating current.

$$I = I_0 \sin \omega t \quad \text{or} \quad I = I_0 \cos \omega t$$

The frequency of AC in India is 50 Hz.

- **Time Period:** The time taken to complete one cycle of variations is called time period.

$$T = \frac{2\pi}{\omega}$$

where, ω = angular frequency.
2π = angular displacement in a complete cycle.

- **Frequency:** The number of cycles completed per second by an alternating current is called its frequency.

$$f = \frac{1}{T} = \frac{\omega}{2\pi}$$

- **Peak Value:** The maximum value of alternating current or voltage is called peak value or amplitude.
- **Instantaneous Value:** The instantaneous value is the value of an alternating voltage or current at a particular instant of time in the cycle.
- **Root Mean Square (RMS) Value of AC:** RMS value of AC is defined as the value of steady current, which would generate the same amount of heat in a given resistance in a given time, as done by the AC when passed through the same resistance for same time. It is also called the virtual or effective value of AC.

$$I_{rms} = \frac{I_0}{\sqrt{2}} \quad \text{or} \quad I_{rms} = 0.707 I_0$$

or $$V_{rms} = \frac{V_0}{\sqrt{2}} = 0.707 V_0$$

where, I_0 and V_0 = maximum value of current (I_{max}) and voltage (V_{max}) respectively.

- **Mean Value or Average Value of AC:** The mean or average value of AC over any half cycle is defined as that value of steady current which would send the same amount of charge through a circuit in the time of half cycle as sent by AC in the same circuit and in the same time.

$$I_{avg} = \frac{2I_0}{\pi} = 0.637\, I_0$$

The average value of current for a complete cycle is zero.

- **Peak Factor:** The ratio of peak value to the rms value of an alternating current or voltage is called peak factor. It is also known as crest factor.

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

For current,

$$\text{Peak factor} = \frac{I_0}{I_{rms}} = \frac{I_0}{\frac{I_0}{\sqrt{2}}} = \sqrt{2} = 1.414$$

For voltage,

$$\text{Peak factor} = \frac{V_0}{V_{rms}} = \frac{V_0}{\frac{V_0}{\sqrt{2}}} = \sqrt{2} = 1.414$$

- **Form Factor:** Form factor is defined as the ratio of rms value of AC to its average value during half-cycle.

$$\text{Form factor} = \frac{\text{rms value}}{\text{Average value}}$$

For current,

$$\text{Form factor} = \frac{I_{rms}}{I_{avg}} = \frac{I_0/\sqrt{2}}{\frac{2I_0}{\pi}} = 1.11$$

For voltage,

$$\text{Form factor} = \frac{V_{rms}}{V_{avg}} = 1.11$$

- **AC Circuits:** In an AC circuit, both emf and current change continuously w.r.t. time, so in circuit, we have to calculate average power in complete cycle $(0 \rightarrow T)$. $P_{av} = V_{rms} I_{rms} \cos\phi$ where, $\cos\phi$ = power factor.
- **Pure Resistive Circuit:** The circuit containing resistance only with an AC source ε is called pure resistive circuit. In this circuit, voltage and current are in phase with each other.
  - AC voltage, $V = V_m \sin \omega t$ or $V = V_0 \sin \omega t$
  - Current, $I = I_m \sin \omega t$ or $I = I_0 \sin \omega t$

$$\text{where } I_0 = \frac{V_0}{R}$$

- **Pure Inductive Circuit:** The circuit containing inductor only with an AC source ε is called pure inductive circuit. In this circuit, the current lags the voltage by $\frac{\pi}{2}$ (or 90°) or one quarter. Hence,
  - Voltage, $V = V_0 \sin(\omega t - \pi/2)$
  - Current, $I = I_0 \sin(\omega t - \pi/2)$

$$\text{where, } I_0 = \frac{V_0}{\omega L}$$

The quantity ωL is analogous to the resistance and is called inductive reactance and denoted by X_L. Thus,
  - Inductive reactance, $X_L = \omega L$
  - Power factor, $\cos\phi = \cos\frac{\pi}{2} = 0$

- **Inductive Reactance:** The opposing nature of inductor to the flow of current is called inductive reactance. It is denoted by X_L and its SI unit is Ω (ohm).

$$X_L = \omega L = 2\pi f L = 2\pi \nu L$$

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where ν or f = frequency of alternating current.

The inductive reactance is directly proportional to the inductance and to the frequency of AC current. Thus, if the frequency of AC increases, its inductive reactance also increases.

- **Pure Capacitive Circuit:** The circuit containing capacitor only with an AC source ε is called pure capacitive circuit.

In this circuit, the current is $\pi/2$ (or 90°) ahead of voltage.

- $I = I_0 \sin\left(\omega t + \frac{\pi}{2}\right)$
- where $I_0 = \omega C V_0 = \dfrac{V_0}{\left(\frac{1}{\omega C}\right)}$

$$\because \quad I_0 = \frac{V_0}{R} \qquad \therefore \; R = \frac{1}{\omega C}$$

Here $\frac{1}{\omega C}$ plays the role of resistance and it is called capacitive reactance (X_C).

- Capacitive reactance, $X_C = \dfrac{1}{\omega C}$
- Power factor, $\cos\phi = \cos\frac{\pi}{2} = 0$ (during complete cycle)

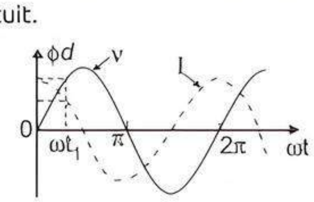
- **Capacitive Reactance:** The opposing nature of capacitor to the flow of an alternating current is called capacitive reactance. It is denoted by X_C and its SI unit is Ω (ohm).

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi\nu C} = \frac{1}{2\pi f C}$$

where ν or f = frequency of alternating current.

It is inversely proportional to the capacitance and frequency of the current. Thus, if frequency of AC increases, then its capacitive reactance decreases.

- **Wattless Current:** The current in a purely inductive or capacitive AC circuit when average power consumption in AC circuit is zero, is referred as wattless current or idle current.
- **Series *LCR* Circuit:** A circuit containing, inductor, capacitor and resistor connected in series with AC source is called series *LCR* circuit.



- Impedance, $Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$
- $\tan\phi = \dfrac{X_C - X_L}{R} \Rightarrow \phi = \tan^{-1}\dfrac{(X_C - X_L)}{R}$
- $I_0 = \dfrac{V_0}{\sqrt{R^2 + (X_L - X_C)^2}} = \dfrac{V_0}{Z}$

If $X_C > X_L$, ϕ is positive and the circuit is predominantly capacitive. Consequently, the current in the circuit leads the source voltage. If $X_C < X_L$, ϕ is negative and the circuit is predominantly inductive. Consequently, the current in the circuit lags the source voltage.

- **Power in AC Circuit:** The power in AC circuit is given by the following formula,

$$P = VI\cos\phi \text{ or } P = I^2 Z \cos\phi$$

The average power dissipated in AC circuits depends not only on the voltage and current but also on the cosine of the phase angle ϕ between them. The quantity $\cos\phi$ is called the power factor. Let us discuss the following cases:

Case (i) Resistive circuit: If the circuit contains only resistance, it is called pure resistive. In that case $\phi = 0$, $\cos\phi = 1$. There is maximum power dissipation.

Case (ii) Purely inductive or capacitive circuit: If the circuit contains only an inductor or capacitor, we know that the phase difference between voltage and current is $\pi/2$. Therefore, $\cos\phi = 0$ and no power is dissipated even though a current is flowing the circuit. This current is sometimes referred to as wattless current.

Case (iii) *LCR* series circuit: In an *LCR* series circuit, power dissipated is given by $P = I^2 Z\cos\phi$, where

$$\phi = \tan^{-1}(X_C - X_L)/R.$$

So, ϕ may be non-zero in an *RL* or *RC* or *RCL* circuit. Even in such cases, power is dissipated only in the resistor.

Case (iv) Power dissipated at resonance in *LCR* circuit: At resonance $X_C - X_L = 0$, and $\phi = 0$. Therefore, $\cos\phi = 1$ and $P = I^2 Z = I^2 R$. That is, maximum power is dissipated in a circuit (through R) at resonance.

- **Resonance:** A circuit in which inductance L, capacitance C and resistance R are connected and the circuit admits maximum current corresponding to a given frequency of AC is called resonance circuit.

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

At resonance, $X_L = X_C$

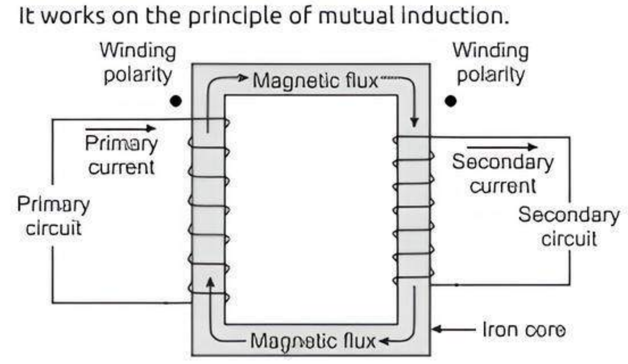
$$\omega L = \frac{1}{\omega C} \text{ or } \omega = \frac{1}{\sqrt{LC}} \text{ or } f = \frac{1}{2\pi\sqrt{LC}}$$

This frequency is known as resonant frequency.

It is important to note that resonance phenomenon is exhibited by a circuit only if both L and C are present in the circuit. Only then do the voltages across L and C cancel each other (both being out of phase) and the current amplitude is v_m/R, the total source voltage appearing across R. This means that we cannot have resonance in an *RL* or *RC* circuit.

- **Transformers:** It is a device used to convert low voltage at high current into high voltage at low current and *vice-versa*. A transformer consists of two sets of coils, are primary and secondary. Primary coil has N_p turns and secondary has N_s turns.

It works on the principle of mutual induction.



- **Types of Transformer:**
  - **Step-up Transformer:** It converts low voltage at high current into high voltage at low current. In this transformer ($N_S > N_P$) and ($E_S > E_P$).

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- **Step-down Transformer:** It converts high voltage at low current into low voltage at high current. In this transformer ($N_P > N_S$) and ($E_S < E_P$).

$$I_P E_P = I_S E_S$$

and
$$\frac{I_P}{I_S} = \frac{E_S}{E_P} = \frac{N_S}{N_P}$$

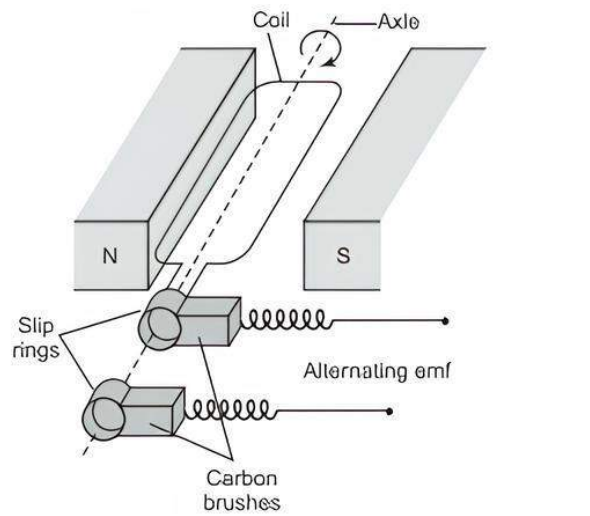
Also,
$$E_S = \left(\frac{N_S}{N_P}\right) E_P \text{ and } I_S = \left(\frac{N_P}{N_S}\right) I_P$$

- **Efficiency of Transformer :** The ratio of output power to input power is called efficiency of transformer.

$$\eta = \frac{\text{Output power}}{\text{Input power}} = \frac{E_S I_S}{E_P I_P}$$

A well designed transformer may have an efficiency of more than 95%.

- **Energy Losses in Transformer:**
  - Resistance of the windings
  - Flux leakage
  - Eddy current
  - Hysteresis
- **AC Generator:** It is an electrical machine which converts mechanical energy into electrical energy by virtue of electromagnetic induction. It is based on the principle of mutual induction.
  - It has mainly three components:
  - **Rotator coil:** It is a rotating part of an AC generator which rotates about an axis on a shaft.
  - **Stator coil:** It is a stationary part of an AC generator which provides magnetic field.
  - **Commutator:** It is a pair of slip rings and carbon brushes which facilitate flow of current.



- Instantaneous value of emf produced by AC generator is given by $e = NBA\,\omega \sin \omega t$.
  where, N = number of turns in the coil, B = strength of magnetic field, A = area of each turn of the coil ω = angular velocity of rotation of coil.

Practice Exercise

Multiple Choice Questions

Q 1. The sum of average current values over one complete cycle is:

a. negative b. positive
c. zero d. Both a. and b.

Q 2. A voltage signal is described by :

$$v = V_0 \text{ for } 0 \le t \le \frac{T}{2}$$
$$= 0 \text{ for } \frac{T}{2} \le t \le T$$

for a cycle. Its rms value is: *(CBSE 2023)*

a. $\frac{V_0}{\sqrt{2}}$ b. V_0 c. $\frac{V_0}{2}$ d. $\sqrt{2}V_0$

Q 3. An alternating voltage given by $V = 140 \sin 314t$ is connected across a pure resistor of 50 Ω. The rms current through the resistor is:

a. 1.98 A b. 5.63 A
c. 8.43 A d. 2.39 A

Q 4. If the rms current in a 50 Hz AC circuit is 5 A, then the value of the current 1/300 seconds after its value becomes zero is: *(NCERT EXEMPLAR)*

a. $5\sqrt{2}$ A b. $5\sqrt{\frac{3}{2}}$ A
c. $\frac{5}{6}$ A d. $\frac{5}{\sqrt{2}}$ A

Q 5. The rms current in a circuit connected to a 50 Hz AC source is 15 A. The value of the current in the circuit $\left(\frac{1}{600}\right)$ s after the instant the current is zero, is: *(CBSE 2021, Term-1)*

a. $\frac{15}{\sqrt{2}}$A b. $15\sqrt{2}$A
c. $\frac{\sqrt{2}}{15}$A d. 8A

Q 6. The equation of AC is given by $I = 100 \sin 314t$. What is the frequency?

a. 314 Hz b. 100 Hz
c. 50 Hz d. 150 Hz

Q 7. When a voltage measuring device is connected to AC mains, the meter shows the steady input voltage of 220 V. This means: *(NCERT EXEMPLAR)*

a. input voltage cannot be AC voltage, but a DC voltage
b. maximum input voltage is 220 V
c. the meter reads not V but $< V^2 >$ and is calibrated to read $\sqrt{< V^2 >}$
d. the pointer of the meter is stuck by some mechanical defect

Q 8. A phasor is a:

a. scalar quantity b. vector quantity
c. tensor quantity d. None of these

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Q 9. In a purely resistive AC circuit, the current:

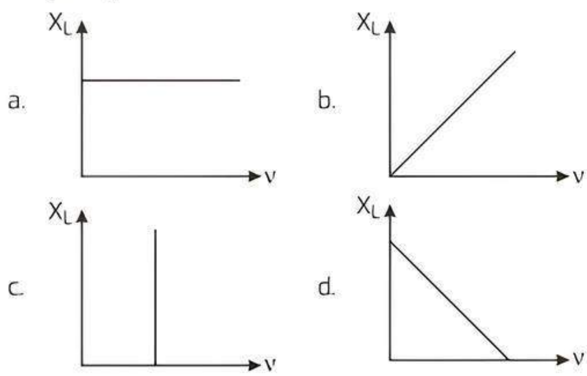
a. is in phase with the emf

b. leads the emf by a difference of π radian phase

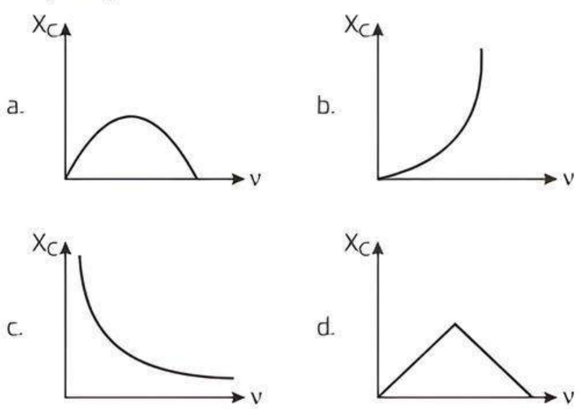
c. leads the emf by a phase difference of $\frac{\pi}{2}$ radians

d. lags behind the emf by phase difference of $\frac{\pi}{4}$ radians

Q 10. Which of the following graphs represents the correct variation of inductive reactance X_L with frequency ν?



Q 11. Which of the following graphs represents the correct variation of capacitive reactance X_C with frequency ν?



Q 12. When AC voltage of 220 V is applied to the capacitor C, then:

a. the maximum voltage between plates is 220 V

b. the current is in phase with the applied voltage

c. the charge on the plate is not in phase with the applied voltage

d. power delivered to the capacitor per cycle is zero

Q 13. A 20 V AC is applied to a circuit consisting of a resistance and a coil with negligible resistance. If the voltage across the resistance is 12V, the voltage across the coil is: *(CBSE SQP 2021 Term-1)*

a. 16 V　　b. 10 V

c. 8 V　　d. 6 V

Q 14. The instantaneous values of emf and the current in a series AC circuit are:

$E = E_0 \sin \omega t$ and $I = I_0 \sin (\omega t + \pi / 3)$ respectively, then it is: *(CBSE SQP 2021 Term-1)*

a. necessarily an *RL* circuit

b. necessarily an *RC* circuit

c. necessarily an *LCR* circuit

d. can be *RC* or *LCR* circuit

Q 15. An alternating voltage source of variable angular frequency ω and fixed amplitude 'V' is connected in series with a capacitance C and electric bulb of resistance R (inductance zero). When ω is increased: *(CBSE SQP 2021 Term-1)*

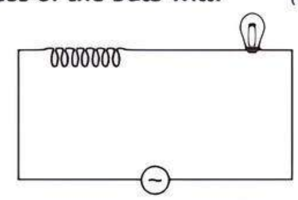
a. the bulb glows dimmer

b. the bulb glows brighter

c. net impedance of the circuit remains unchanged.

d. total impedance of the circuit increases

Q 16. An iron cored coil is connected in series with an electric bulb with an AC source as shown in figure. When iron piece is taken out of the coil, the brightness of the bulb will: *(CBSE SQP 2022-23)*



a. decrease　　b. increase

c. remain unaffected　　d. fluctuate

Q 17. The impedance of series *LCR* circuit is: *(CBSE 2021, Term-1)*

a. $R + X_L + X_C$　　b. $\sqrt{\frac{1}{X_C^2} + \frac{1}{X_L^2} + R^2}$

c. $\sqrt{X_L^2 - X_C^2 + R^2}$　　d. $\sqrt{R^2 + (X_L - X_C)^2}$

Q 18. A 15Ω resistor, an 80 mH inductor and a capacitor of capacitance C are connected in series with a 50 Hz ac source. If the source voltage and current in the circuit are in phase, then the value of capacitance is: *(CBSE 2021 Term-1)*

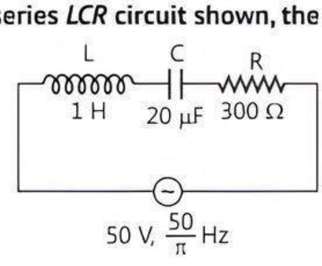
a. 100 μF　　b. 127 μF　　c. 142 μF　　d. 160 μF

Q 19. The voltage across a resistor, an inductor and a capacitor connected in series to an AC source are 20 V, 15 V and 30 V respectively. The resultant voltage in the circuit is: *(CBSE 2021 Term-1)*

a. 5 V　　b. 20 V

c. 25 V　　d. 65 V

Q 20. In the series *LCR* circuit shown, the impedance is:



a. 200 Ω　　b. 100 Ω

c. 300 Ω　　d. 500 Ω

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Q 21. An *LCR* circuit is predominantly capacitive if:
a. $X_L > X_C$
b. $X_L < X_C$
c. $X_L = X_C$
d. None of the above

Q 22. To reduce the resonant frequency in an *LCR* series circuit with a generator: *(NCERT EXEMPLAR)*
a. the generator frequency should be reduced
b. another capacitor should be added in parallel to the first
c. the iron core of the inductor should be removed
d. dielectric in the capacitor should be removed

Q 23. An inductor, a capacitor and a resistor are connected in series across an AC source of voltage. If the frequency of the source is decreased gradually the reactance of: *(CBSE 2023)*
a. both the inductor and the capacitor decreases
b. inductor decreases and the capacitor increases
c. both the inductor and the capacitor increases
d. inductor increases and the capacitor decreases

Q 24. A series *LCR* circuit with $R = 22\Omega$, $L = 1.5$ H and $C = 40\mu$F is connected to a variable frequency 220 V AC supply. When the frequency of the supply equals the natural frequency of the circuit, what is the average power transferred to the circuit in one complete cycle?
a. 2000 W
b. 2200 W
c. 2400 W
d. 2500 W

Q 25. What is the ratio of inductive and capacitive reactance in circuit? *(CBSE 2023)*
a. $\omega^2 LC$
b. LC^2
c. $\frac{LC}{\omega^2}$
d. $\omega^2 L$

Q 26. A sinusoidal voltage of peak value 283 V and frequency 50 Hz is applied to a series *LCR* circuit in which $R = 3\ \Omega$, $L = 25.48$ mH and $C = 796\ \mu$F, then the power dissipated at the resonant condition will be: *(CBSE SQP 2021, Term-1)*
a. 39.70 kW
b. 26.70 kW
c. 13.35 kW
d. zero

Q 27. When an alternating voltage $E = E_0 \sin \omega t$ is applied to a circuit, a current $I = I_0 \sin\left(\omega t + \frac{\pi}{2}\right)$ flows through it. The average power dissipated in the circuit is: *(CBSE 2021 Term-1)*
a. $E_{rms} \cdot I_{rms}$
b. $E_0 I_0$
c. $\frac{E_0 I_0}{\sqrt{2}}$
d. zero

Q 28. A transformer works on the principle of:
a. self induction
b. electrical inertia
c. mutual induction
d. magnetic effect of the electrical current

Q 29. The output of a step down transformer is measured to be 24 V when connected to a 12W light bulb. The value of the peak current is: *(NCERT EXEMPLAR)*
a. $\frac{1}{\sqrt{2}}$ A
b. $\sqrt{2}$ A
c. 2 A
d. $2\sqrt{2}$ A

Q 30. A 60 W load is connected to the secondary of an ideal transformer whose primary draws line voltage. If a current of 0.54 A flows in the load, the current in the primary coil is:
a. 0.27 mA
b. 2.7 A
c. 0.27 A
d. 10 A

Q 31. A step-down transformer converts transmission line voltage from 11000 V to 220 V. The primary of the transformer has 6000 turns and efficiency of the transformer is 60%. If the output power is 9 kW, then the input power will be:
a. 11 kW
b. 12 kW
c. 14 kW
d. 15 kW

Q 32. Which among the following, is not a cause for power loss in a transformer? *(CBSE SQP 2021 Term-1)*
a. Eddy currents are produced in the soft iron core of a transformer.
b. Electric flux sharing is not properly done in primary and secondary coils.
c. Humming sound produced in the transformers due to magnetostriction.
d. Primary coil is made up of a very thick copper wire.

Q 33. The large scale transmission of electrical energy over long distances is done with the use of transformers. The voltage output of the generator is stepped-up because of: *(CBSE SQP 2023-24)*
a. reduction of current
b. reduction of current and voltage both
c. power loss is cut down
d. Both a. and c.

Q 34. The basic principle on which the AC generator works it is:
a. Lenz law
b. energy conservation
c. momentum conservation
d. electromagnetic induction

Assertion & Reason Type Questions

Directions (Q.Nos. 35-43): *In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:*
a. Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
b. Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).
c. Assertion (A) is true but Reason (R) is false.
d. Both Assertion (A) and Reason (R) are false.

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Q 35. Assertion (A): Average value of AC over a complete cycle is always zero.
Reason (R): Average value of AC is always defined over half cycle.

Q 36. Assertion (A): AC is more dangerous than DC.
Reason (R): Frequency of AC is dangerous for human body.

Q 37. Assertion (A): In a purely inductive or capacitive circuit, the current is referred to as wattless current.
Reason (R): No power is dissipated in a purely inductive or capacitive circuit even though a current is flowing in the circuit.

Q 38. Assertion (A): When capacitive reactance is smaller than the inductive reactance in *LCR* series circuit, emf leads the current.
Reason (R): The phase angle is the angle between the alternating emf and alternating current of the circuit.

Q 39. Assertion (A): An electric lamp connected in series with a variable capacitor and AC source, its brightness increases with increase in capacitance.
Reason (R): Capacitive reactance decreases with increase in capacitance of capacitor.

Q 40. Assertion (A): Step-down transformer increases the current.
Reason (R): Transformer obeys the law of conservation of energy.

Q 41. Assertion (A): The core of transformer is made laminated in order to increase the eddy currents.
Reason (R): The sensitivity of transformer increases with increase in the eddy currents.

Q 42. Assertion (A): A step-up transformer cannot be used as a step-down transformer.
Reason (R): A transformer works only in one direction. *(CBSE 2021 Term -1)*

Q 43. Assertion (A): AC generator works on the principle of self induction.
Reason (R): Magnetic flux linked with armature coil during rotation is always zero.

Fill in the Blanks Type Questions

Q 44. The maximum value of .... is called peak value or amplitude.

Q 45. Peak factor = ...

Q 46. The opposing nature of .... to the flow of current is called inductive reactance.

Q 47. In AC circuit, the average power consumed by a pure capacitor during one cycle in pure capacitance is ....

Q 48. Capacitive reactance is inversely proportional to the .... and frequency of the current.

Q 49. $Z = \sqrt{R^2 + \text{..................}}$

Q 50. If the power loss in a circuit is zero, the current is called ....

Q 51. Stator is a .... part of an AC alternator.

Answers

1. (c) zero
The sum of the instantaneous current values over one complete cycle is zero and the average current is also zero.

Knowledge BOOSTER

The average value or mean value of AC is 63% of peak value or maximum value of AC over any half cycle and for a complete cycle of AC, the average value of AC is zero.

2. (a) $\dfrac{V_0}{\sqrt{2}}$

3. (a) 1.98 A
Here, $R = 50\Omega$ and $V_0 = 140$ V

$$\therefore \quad I_{rms} = \frac{V_{rms}}{R} = \frac{0.707V_0}{R}$$

$$= \frac{0.707 \times 140}{50} = 1.98 \text{ A}$$

4. (b) $5\sqrt{\dfrac{3}{2}}$ A

Here, $I_{rms} = 5$ A, $\nu = 50$ Hz, $t = \dfrac{1}{300}$ s

$$I_0 = \sqrt{2}\ I_{rms} = 5\sqrt{2} \text{ A},$$

$$I = I_0 \sin\omega t = I_0 \sin 2\pi\nu t$$

$$= 5\sqrt{2} \sin\left(2\pi \times 50 \times \frac{1}{300}\right)$$

$$= 5\sqrt{2} \sin\frac{\pi}{3} = 5\sqrt{2} \times \frac{\sqrt{3}}{2} = 5\sqrt{\frac{3}{2}} \text{A}$$

5. (a) $\dfrac{15}{\sqrt{2}}$ A

6. (c) 50 Hz
Given, $I = 100 \sin 314t$
From the given equation,

$$\omega = 314 \quad \Rightarrow \quad 2\pi\nu = 314$$

$$\therefore \nu = \frac{314}{2\pi} = 50 \text{ Hz}$$

7. (c) the meter reads not V but $<V^2>$ and is calibrated to read $\sqrt{<V^2>}$

The voltmeter connected to AC mains is calibrated to read root mean square value or virtual value of AC voltage.

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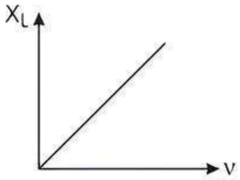
8. (a) scalar quantity

Voltage and current in an AC circuit are represented by phasors-rotating vectors, they are not vectors themselves. They are scalar quantities.

9. (a) is in phase with the emf.

In purely resistive AC circuit, current and voltage are in same phase.

10. (b)

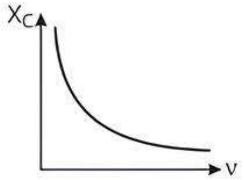


Inductive reactance,

$$X_L = \omega L = 2\pi \nu L \Rightarrow X_L \propto \nu$$

Hence, inductive reactance increases linearly with frequency.

11. (c)



Capacitive reactance,

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi \nu C} \quad \Rightarrow X_C \propto \frac{1}{\nu}$$

With increase in frequency, X_C decreases.

Hence, option (c) represents the correct graph.

12. (d) power delivered to the capacitor per cycle is zero

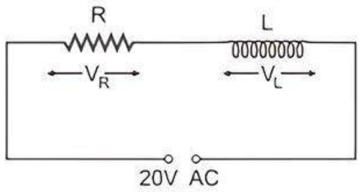
When AC voltage of 220 V is applied to a capacitor C, the charge on the plates is in phase with the applied voltage. As the circuit is pure capacitive, so the current developed leads the applied voltage by a phase angle of 90°. Hence, power delivered to the capacitor per cycle is

$$P = V_{rms} I_{rms} \cos 90° = 0$$

13. (a) 16 V

Let effective voltage across $R = V_R$

and effective voltage across $L = V_L$



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

$$\Rightarrow \quad 20 = \sqrt{(12)^2 + V_L^2}$$

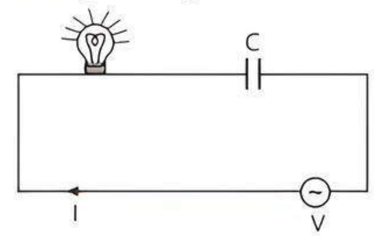
$$\Rightarrow \quad (20)^2 = (12)^2 + V_L^2 \Rightarrow 400 = 144 + V_L^2$$

$$\therefore \quad V_L = \sqrt{400 - 144} = \sqrt{256} = 16 \text{ V}$$

14. (d) can be RC or LCR circuit.

As current I can lead the voltage or emf in RC and LCR circuit, so it can be RC or LCR circuit.

15. (b) the bulb glows brighter



As angular frequency ω increases, capacitive reactance X_C will decrease.

$$X_C = \frac{1}{2\pi f C} = \frac{1}{\omega C}$$

$$X_C \propto \frac{1}{\omega}$$

As X_C decreases, the current I increases. $\left(\because I = \frac{V}{X_C}\right)$

Thus, brightness of bulb will increase.

16. (b) increase

When current passes through the inductor, magnetic field is produced and it opposes the current flow. When iron piece is taken out of the coil, the current flow will be maximum and the brightness of the bulb will increase but when it is inserted, there will be induction effect and the brightness of the bulb will decrease due to opposition in current flow.

17. (d) $\sqrt{R^2 + (X_L - X_C)^2}$

18. (b) 127 μF

As voltage and current are in phase, $\phi = 0$.

This means circuit is in resonance.

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

$$= \frac{1}{(100\pi)^2 \times 80 \times 10^{-3}} = 127 \ \mu\text{F}$$

19. (c) 25 V

20. (d) 500 Ω

Here, $L = 1$ H, $C = 20 \mu\text{F} = 20 \times 10^{-6}$ F

$R = 300 \ \Omega$, $\nu = \frac{50}{\pi}$ Hz

The inductive reactance is

$$X_L = 2\pi \nu L = 2 \times \pi \times \frac{50}{\pi} \times 1 = 100 \ \Omega$$

The capacitive reactance is

$$X_C = \frac{1}{2\pi \nu C} = \frac{1}{2 \times \pi \times \frac{50}{\pi} \times 20 \times 10^{-6}} = 500 \ \Omega$$

The impedance of the series LCR circuit is

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

$$= \sqrt{(300)^2 + (500 - 100)^2}$$

$$= \sqrt{(300)^2 + (400)^2} = 500 \ \Omega$$

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21. (b) $X_L < X_C$

22. (b) another capacitor should be added in parallel to the first

23. (b) inductor decrease and the capacitor increases.

24. (b) 2200 W

When the frequency of the supply equals to the natural frequency of circuit, resonance occurs.

$$\therefore \quad Z = R = 22\,\Omega \text{ and } I_{rms} = \frac{V_{rms}}{Z} = \frac{220}{22} = 10 \text{ A}$$

Average power transferred per cycle,

$$P = V_{rms}\, I_{rms} \cos 0° = 220 \times 10 \times 1 = 2200 \text{ W}$$

25. (a) $\omega^2 LC$

As we know, the inductive reactance is

$$X_L = \omega L \qquad ...(1)$$

and capacitive reactance is

$$X_C = \frac{1}{\omega C} \qquad ...(2)$$

From eqs. (1) and (2),

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

26. (c) 13.35 kW

Given, $V_0 = 283$ V, $f = 50$ Hz

$R = 3\,\Omega$, $L = 25.48$ mH

$C = 746\,\mu$F

Power dissipated, $P = I^2 R$

Current, $I = \frac{I_0}{\sqrt{2}} = \frac{1}{\sqrt{2}}\left(\frac{283}{3}\right) = 66.7$ A

$$\therefore \quad P = I^2 R = (66.7)^2 \times 3 = 13.35 \text{ kW}$$

27. (d) zero

28. (c) mutual induction

29. (a) $\frac{1}{\sqrt{2}}$ A

Here, $V_s = 24$ V, $P_s = 12$ W

$$I_s = \frac{P_s}{V_s} = \frac{12}{24} = 0.5 \text{ A}$$

$$\therefore \quad I_m = \sqrt{2}\, I_s = \sqrt{2} \times 0.5 = \frac{1}{\sqrt{2}} \text{ A}$$

30. (c) 0.27 A

Here, $P_S = 60$ W, $I_S = 0.54$ A, $V_P = 220$ V

$$V_S = \frac{P_S}{I_S} = \frac{60}{0.54} = 111 \text{ V}$$

As, $\frac{V_S}{V_P} = \frac{I_P}{I_S}$, for an ideal transformer

$$\therefore \quad I_P = \frac{V_S}{V_P} \times I_S = \frac{111}{220} \times 0.54 = 0.27 \text{ A}$$

31. (d) 15 kW

Here, $V_P = 11000$ V, $V_s = 220$ V

$N_P = 6000$, $\eta = 60\%$, $P_o = 9$ kW $= 9 \times 10^3$ W

Efficiency, $\eta = \frac{\text{Output power}}{\text{Input power}} = \frac{P_o}{P_i}$

$$\therefore \quad P_i = \frac{P_o}{\eta} = \frac{9 \times 10^3}{60/100} = 15 \times 10^3 = 15 \text{ kW}$$

32. (d) Primary coil is made up of a very thick copper wire.

As primary coil made of thick copper wire, it has very less R. Therefore, there is negligible power loss. Rest all options are reasons for power losses in a transformer.

33. (d) Both a. and c.

34. (d) electromagnetic induction

35. (b) The mean or average value of alternating current or emf during a half cycle is given by

$$I_m = 0.636\, I_0 \text{ or } E_m = 0.636 E_0$$

During the next half cycle, the mean value of AC will be equal in magnitude but opposite in direction. For this reason, the average value of AC over a complete cycle is always zero. So the average value is always defined over a half cycle of AC.

36. (a) The effect of AC on the human body depends largely on the frequency. Low frequency currents of 50 to 60 Hz (cycles/sec), which are commonly used, are usually more dangerous than high frequency currents and are 3 to 5 times more dangerous than DC of same voltage of ampere (current). The usual frequency of 50 cps (or 60 cps) is extremely dangerous as it corresponds to the fibrillation frequency of the myocardium. This results in ventricular fibrillation and instant death.

COMMON ERROR

Often student think DC is more dangerous.

37. (a) In a purely inductive or capacitive circuit, power factor, cos $\phi = 0$ and no power is dissipated even though a current is flowing in the circuit. In such cases, current is referred to as wattless current.

38. (b) The phase angle for the *LCR* series circuit is given by

$$\tan\theta = \frac{X_L - X_C}{R} = \frac{\omega L - 1/\omega C}{R}$$

where X_L and X_C are inductive reactance and capacitive reactance respectively. When $X_L > X_C$, then tan θ is positive *i.e.*, θ is positive (between 0 and π/2). Hence, emf leads the current.

39. (a) Capacitive reactance $X_C = \frac{1}{\omega C}$ when capacitance (C) increases, the capacitive reactance decreases due to decrease in its values, the current in the circuit will increase $\left(I = \frac{E}{\sqrt{R^2 + X_C^2}}\right)$ and hence brightness of source (electric lamp) will also increase.

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40. (b) If there is no loss of energy in transformer, then instantaneous output power is equal to instantaneous input power. From this, we get $\frac{e_S}{e_P} = \frac{I_P}{I_S}$. So in step-up transformer, voltage increases by decreasing the current. Similarly, step-down transformer decreases the voltage by increasing current. Therefore transformer simply transforms the voltage and current, obeying the law of conservation of energy.

41. (d) Eddy current is produced in the iron core due to induced emf. Since, resistance of the iron core is quite small, the magnitude of eddy currents is quite large. As a result, large amount of heat is produced. To avoid it, a laminated core is used in a transformer. In laminated core, iron strips are quite thin and each strip possesses very large resistance, the magnitude of eddy currents very large resistance, the magnitude of eddy currents produced is quite small and hence only a small amount of heat is produced.

42. (d) Both Assertion (A) and Reason (R) are false.

43. (d) AC generator works on the principle of Faraday's law of electromagnetic (mutual) induction. When armature coil is rotated in magnetic field, the magnetic flux linked with it is always a maximum. Thus, both Assertion (A) and Reason (R) are false.

44. alternating current or voltage

45. $\frac{\text{peak value}}{\text{rms value}}$

46. inductor

47. zero

48. capacitance

49. $(X_L - X_C)^2$

50. wattless current

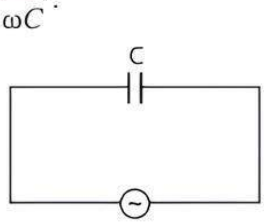
51. stationary

Case Study Based Questions

Case Study 1

Let a source of alternating emf $E = E_0 \sin\omega t$ be connected to a capacitor of capacitance C. If 'I' is the instantaneous value of current in the circuit as instant t, then $I = \frac{E_0}{1/\omega C}\sin\left(\omega t + \frac{\pi}{2}\right)$.

The capacitive reactance limits the amplitude of current in a purely capacitive circuit and it is given by $X_C = \frac{1}{\omega C}$.



Read the given passage carefully and give the answer of the following questions:

Q 1. What is the unit of capacitive reactance?

a. Farad b. Ampere
c. Ohm d. Ohm^{-1}

Q 2. The capacitive reactance of a 5μF capacitor for a frequency of 10^6 Hz is:

a. 0.032 Ω b. 2.52 Ω
c. 1.25 Ω d. 4.51 Ω

Q 3. In a capacitive circuit, resistance to the flow of current is offered by:

a. resistor b. capacitor
c. inductor d. frequency

Q 4. In a capacitive circuit, by what value of phase angle does alternating current leads the emf?

a. 45° b. 90°
c. 75° d. 60°

Q 5. One microfarad capacitor is joined to a 200 V, 50 Hz alternator. The rms current through capacitor is:

a. 6.28×10^{-2} A b. 7.5×10^{-4} A
c. 10.52×10^{-2} A d. 15.25×10^{-2} A

Answers

1. (c) Ohm
Ohm is the unit of capacitive reactance.

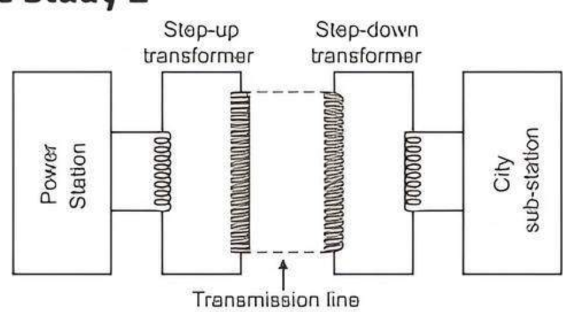
2. (a) 0.032 Ω
Capacitive reactance,
$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi\nu C}$$
$$= \frac{1}{2\pi \times 10^6 \times 5 \times 10^{-6}} = 0.032\,\Omega$$

3. (b) capacitor
In capacitive circuit, resistance to the flow of current is offered by the capacitor.

4. (b) 90°

5. (a) 6.28×10^{-2} A
Current, $I_V = \frac{E_V}{X_C} = \frac{E_V}{1/2\pi\nu C} = (2\pi\nu C)E_V$
$$I_V = 2 \times 3.14 \times 50 \times 1 \times 10^{-6} \times 200 = 6.28 \times 10^{-2}\text{A}$$

Case Study 2



Long distance power transmissions

The large-scale transmission and distribution of electrical energy over long distances is done with the use of transformers. The voltage output of the generator is stepped-up. It is then transmitted over long distances to an area sub-station near the consumers. Then the voltage is stepped-down. It is further stepped-down at distributing sub-stations and utility poles before a power supply of 240 V reaches our homes. *(CBSE SQP 2021 Term-1)*

Read the given passage carefully and give the answer of the following questions:

Q 1. Which of the following statement is true?

a. Energy is created when a transformer steps-up the voltage

b. A transformer is designed to convert an AC voltage to DC voltage

c. Step-up transformer increases the power for transmission

d. Step-down transformer decreases the AC voltage

Q 2. If the secondary coil has a greater number of turns than the primary:

a. the voltage is stepped-up ($V_S > V_P$) and arrangement is called a step-up transformer

b. the voltage is stepped-down ($V_S < V_P$) and arrangement is called a step-down transformer

c. the current is stepped-up ($I_S > I_P$) and arrangement is called a step-up transformer

d. the current is stepped-down ($I_S < I_P$) and arrangement is called a step-down transformer

Q 3. We need to step-up the voltage for power transmission, so that:

a. the current is reduced and consequently, the I^2R loss is cut down

b. the voltage is increased the power losses are also increased

c. the power is increased before transmission is done

d. the voltage is decreased so V^2/R losses are reduced

Q 4. A power transmission line feeds input power at 2300 V to a step-down transformer with its primary windings having 4000 turns. The number of turns in the secondary in order to get output power at 230 V are:

a. 4 b. 40

c. 400 d. 4000

Answers

1. (d) Step-down transformer decreases the AC voltage.

2. (a) the voltage is stepped-up ($V_S > V_P$) and the arrangement is called a step-up transformer.

$$\because \quad \frac{N_S}{N_P} = \frac{E_S}{E_P}$$

If number of turns in secondary coil (N_S) are greater than number of turns in primary (N_P), then voltage is increased or stepped-up in secondary, so the arrangement is called step-up transformer.

3. (a) The current is reduced and consequently, the I^2R loss is cut down.

4. (c) 400

Given, $E_i = 2300$ V

$E_o = 230$ V

$N_P = 4000$

$N_S = ?$

We know, $$\frac{E_i}{E_o} = \frac{N_P}{N_S}$$

$$\frac{2300}{230} = \frac{4000}{N_S}$$

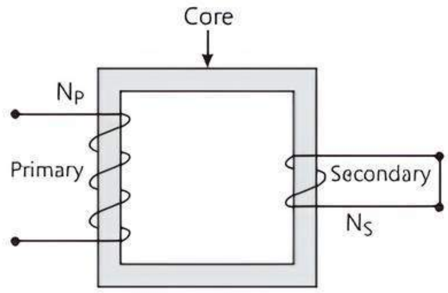
$$\therefore \quad N_S = 400$$

Number of turns in secondary coil, $N_S = 400$

Case Study 3

Step-down transformers are used to decrease or step-down voltages. These are used when voltages need to be lowered for use in homes and factories.

A small town with a demand of 800 kW of electric power at 220 V is situated 15 km away from an electric plant generating power at 440 V. The resistance of the two wire line carrying power is 0.5Ω per km. The town gets power from the line through a 4000-220 V step-down transformer at a sub-station in the town.



Read the given passage carefully and give the answer of the following questions:

Q 1. The value of total resistance of the wire is:

a. 25 Ω b. 30 Ω c. 35 Ω d. 15 Ω

Q 2. The line power loss in the form of heat is:

a. 550 kW b. 650 kW

c. 600 kW d. 700 kW

Q 3. How much power must the plant supply, assuming there is negligible power loss due to leakage?

a. 600 kW b. 1600 kW

c. 500 W d. 1400 kW

Q 4. The voltage drop in the power line is:

a. 1700 V b. 3000 V c. 2000 V d. 2800 V

Q 5. The total value of voltage transmitted from the plant is:

a. 500 V b. 4000 V

c. 3000 V d. 7000 V

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Answers

1. (d) 15 Ω

Resistance of the two wire lines carrying power $= 0.5\ \Omega/\text{km}$

Total resistance = (15 + 15)0.5 = 15 Ω

2. (c) 600 kW

Line power loss $= I^2R$

rms current in the coil,

$$I = \frac{P}{V_l} = \frac{800 \times 10^3}{4000} = 200\text{A}$$

$\therefore$ Power loss = $(200)^2 \times 15 = 600$ kW

3. (d) 1400 kW

Assuming that the power loss is negligible due to the leakage of the current.

The total power supplied by the plant

= 800 kW + 600 kW = 1400 kW

4. (b) 3000 V

Voltage drop in the power line = $IR = 200 \times 15$

= 3000 V

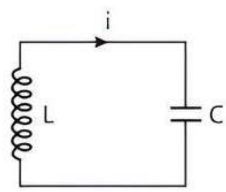
5. (d) 7000 V

Total voltage transmitted from the plant

= 3000 V + 4000 V = 7000 V

Case Study 4

An *LC* circuit also called a resonant circuit or tank circuit or tuned circuit, is an electric circuit consisting of an inductor represented by the letter *L* and a capacitor, represented by the letter *C* connected together. An *LC* circuit is an idealised model since it assumes there is no dissipation of energy due to resistance.



An *LC* circuit contains a 20 mH inductor and a 50 μF capacitor with an initial charge of 10 mC. The resistance of the circuit is negligible. Let the instant of circuit is closed be $t = 0$.

Read the given passage carefully and give the answer of the following questions:

Q 1. What will be the total energy stored initially?

Q 2. What will be the natural frequency of the circuit?

Q 3. At what time is the energy stored completely electrical?

Q 4. At what time is the energy stored completely magnetic?

Q 5. Calculate the value of X_L.

Answers

1. Energy, $E = \frac{1}{2}\frac{Q^2}{C} = \frac{(10 \times 10^{-3})^2}{2 \times 50 \times 10^{-6}} = 1\text{ J}$

2. Frequency, $\nu = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{20 \times 10^{-3} \times 50 \times 10^{-6}}}$

$$= \frac{10^3}{2\pi} = 159.24\text{Hz}$$

3. Total time period,

$$T = \frac{1}{\nu} = \frac{1}{159.24} = 6.28\text{ ms}$$

Total charge on capacitor at time, t

$$Q' = Q\cos\frac{2\pi}{T}t$$

For energy stored in electrical, we can write $Q' = \pm Q$. Hence, energy stored in the capacitor is completely electrical at $t = 0, \frac{T}{2}, T, \frac{3T}{2}, \ldots$

4. Magnetic energy is maximum when electrical energy is equal to zero.

Hence, $t = \frac{T}{4}, \frac{3T}{4}, \frac{5T}{4}, \ldots$

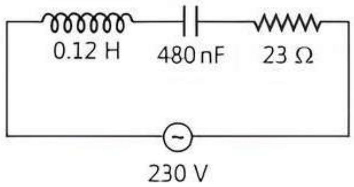
5. $X_L = \omega L = 2\pi\nu L$

$= 2 \times 3.14 \times 159.24 \times 20 \times 10^{-3}$

$\Rightarrow \quad X_L = 20\ \Omega$

Case Study 5

When the frequency of AC supply is such that the inductive reactance and capacitive reactance become equal, the impedance of the series *LCR* circuit is equal to the ohmic resistance in the circuit. Such a series *LCR* circuit is known as resonant series *LCR* circuit and the frequency of the AC supply is known as resonant frequency.



Resonance phenomenon is exhibited by a circuit only if both *L* and *C* are present in the circuit. We cannot have resonance in an *RL* or *RC* circuit.

A series *LCR* circuit with *L* = 0.12 H, *C* = 480 nF, *R* = 23Ω is connected to a 230V variable frequency supply.

Read the given passage carefully and give the answer of the following questions:

Q 1. Find the value of source frequency for which current amplitude is maximum.

Q 2. Calculate the value of maximum current.

Q 3. Calculate the value of maximum power.

Q 4. At resonance, which physical quantity is maximum?

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Answers

1. Here, $L = 0.12$ H, $C = 480$ nF $= 480 \times 10^{-9}$F

$R = 23\Omega$, $V = 230$V

$V_0 = \sqrt{2} \times 230 = 325.22$V

$$I_0 = \frac{V_0}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$$

At resonance, $\omega L - \frac{1}{\omega C} = 0$

$$\omega = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{0.12 \times 480 \times 10^{-9}}}$$

$= 4166.67$ rad s^{-1}

$$\nu_R = \frac{4166.67}{2 \times 3.14} = 663.48 \text{ Hz} \qquad [\because \omega = 2\pi\nu_R]$$

2. Current, $I_0 = \frac{V_0}{R} = \frac{325.22}{23} = 14.14$ A

3. Maximum power, $P_{max} = \frac{1}{2}(I_0)^2 R$

$$= \frac{1}{2} \times (14.14)^2 \times 23 = 2299.3 \text{ W}$$

4. At resonance, current is maximum. A circuit in which inductance L, capacitance C and resistance R are connected and the circuit admits maximum current corresponding to a given frequency of AC is called resonance circuit.

Very Short Answer Type Questions

Q 1. Why is the use of AC voltage preferred over DC voltage? Give two reasons.

Ans. AC voltage is preferred over DC voltage because of the following reasons:

(i) The loss of energy in transmitting the AC voltage over long distances with the help of step-up transformers is negligible as compared to DC voltage.

(ii) AC voltage can be stepped-up and stepped-down as per the requirement by using a transformer.

Q 2. Define capacitor reactance. Write its SI unit. *(CBSE 2015)*

Ans. Capacitor reactance is the resistance offered by a capacitor, when it is connected to an electric circuit.

It is given by $X_C = 1/\omega C = 1/2\pi fC$

where, ω = angular frequency of the source

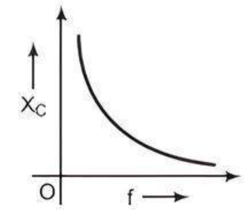
and C = capacitance of the capacitor.

SI unit of capacitor reactance is Ohm (Ω).

Q 3. Plot a graph showing variation of capacitive reactance with the change in the frequency of the AC source. *(CBSE 2015)*

Ans. Variation of capacitive reactance with the change in the frequency of the AC source is given in graph.

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



Q 4. Define the term 'Wattless current'. *(CBSE 2015)*

Ans. The current which flows in a circuit without consuming electrical power is called wattless current.

Q 5. In a series LCR circuit, $V_L = V_C \neq V_R$. What is the value of power factor? *(CBSE 2015)*

Sol. $$V_L = V_C \Rightarrow IX_L = IX_C \Rightarrow X_L = X_C$$

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

$\Rightarrow$ Power factor, $\cos\phi = R/Z = \frac{R}{R} = 1$

Q 6. The power factor of an AC circuit is 0.5. What is the phase difference between the voltage and current in the circuit? *(CBSE 2016)*

Sol. Given that, $\cos\phi = 0.5$

$\therefore$ $\phi = \cos^{-1}(0.5) = 60°$

Q 7. Why is the core of a transformer laminated?

Ans. The core of a transformer is laminated to reduce the energy losses due to eddy currents, thus increasing the efficiency.

Q 8. Which characteristic properties of the material suitable for making core of a transformer? Write any of two.

Ans. (i) Low retentivity or coercivity.

(ii) Low hysteresis loss or high permeability.

Q 9. Name the two main parts of AC generator?

Ans. (i) stator (ii) rotor

Q 10. On which principle, a generator work?

Ans. Generator works on Faraday's law of electromagnetic induction.

Short Answer Type-I Questions

Q 1. In an AC circuit, the instantaneous voltage and current are $V = 200 \sin 300t$ volt and $I = 8 \cos (300t + \pi/2)$ ampere respectively. Is the nature of the circuit capacitive or inductive? Give reason. *(CBSE 2015)*

Ans. Capacitive.

Reason: Given,

$$V = 200\sin 300t \text{ and } I = 8\cos 300t$$

$$\Rightarrow \quad I = 8\sin(300t + \pi/2)$$

As the current leads voltage by phase angle $\pi/2$. Hence the circuit is capacitive.

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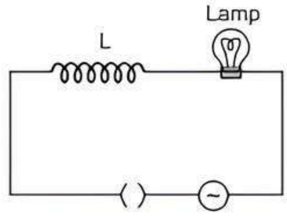
Q 2. A lamp is connected in series with an inductor and an AC source. What happens to the brightness of the lamp when the key is plugged in and an iron rod is inserted inside the inductor? Explain. *(CBSE 2017, 16)*

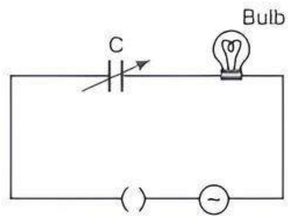


Ans. Brightness decreases

Reason: When iron rod is inserted, inductance L increases.

Therefore, the current flowing across the bulb will decrease, thus decreasing the brightness of the bulb.

Q 3. A bulb is connected in series with a variable capacitor and an AC source as shown. How the brightness of bulb changes on reducing the (i) capacitance and (ii) frequency? Justify your answer. *(CBSE 2016)*



Ans. (i) Brightness will decrease.

Reason: When capacitance is reduced, reactance $\left(X_C = \frac{1}{\omega C}\right)$ increases i.e., $Z = \sqrt{R^2 + X_C^2}$ also increases and current decreases.

Hence, brightness $(I^2 Z)$ decreases.

(ii) Brightness will decrease.

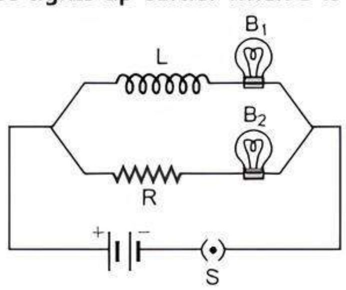
Reason: When frequency is reduced, reactance $\left(X_C = \frac{1}{2\pi f C}\right)$ increases i.e., $Z = \sqrt{R^2 + X_C^2}$ also increases and current decreases.

Hence, brightness $(I^2 Z)$ decreases.

Q 4. Figure shows an inductor L and a resistor R connected in parallel to a battery through a switch S. The resistance R is same as that of coil that makes L. Two identical bulbs are put in each arm of the circuit.

(i) Which of the bulbs lights up earlier when S is closed?

(ii) Will the two bulbs be equally bright after sometime? Give reason for your answer.



Ans. (i) Bulb B_2 lights up earlier.

Reason: Induced emf across L opposes growth of current in B_1.

(ii) Yes, after sometime both bulbs will be equally bright.

Reason: After sometime, current reaches its maximum value in L and self-induction plays no role.

Q 5. In a series LR circuit $X_L = R$ and power factor of the circuit is P_1. When capacitor with capacitance C such that $X_L = X_C$ is put in series, the power factor becomes P_2. Calculate P_1/P_2. *(CBSE 2016, 15)*

Sol. For LR circuit, power factor

$$P_1 = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + X_L^2}} = \frac{R}{\sqrt{R^2 + R^2}} = \frac{R}{R\sqrt{2}} = \frac{1}{\sqrt{2}}$$

When $X_L = X_C$ is put in series, for LCR circuit power factor

$$P_2 = \frac{R}{Z} = \frac{R}{\sqrt{(R)^2 + (X_C - X_L)^2}} = \frac{R}{R} = 1$$

$$\Rightarrow \frac{P_1}{P_2} = \frac{1/\sqrt{2}}{1} = \frac{1}{\sqrt{2}}$$

Q 6. Can the voltage drop across the inductor or the capacitor in a series LCR circuit be greater than the applied voltage of the AC source? Justify your answer.

Ans. Yes, because in series LCR circuit, V_L or V_C are not in same phase, hence cannot be added like ordinary number.

Q 7. Define the term power factor. State the condition under which it is (i) maximum and (ii) minimum.

Ans. **Power factor:** It is the ratio of resistance to the impedance of an AC circuit i.e. $\cos\phi = R/Z$

(i) When $Z = R$, $\cos\phi = R/Z = 1 =$ maximum

i.e., when the circuit is purely resistive, power factor is maximum .

(ii) When $R = 0$, $\cos\phi = R/Z = 0 =$ minimum.

i.e. when the circuit is purely inductive or capacitive, power factor is minimum.

Q 8. 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 winding to get the power output at 220 V. *(CBSE 2017)*

Sol. Given, input power, $V_P = 2200$ V

Number of turns, $N_1 = 3000$

Output power, $V_S = 220$ V

As, $$\frac{V_S}{V_P} = \frac{N_2}{N_1} \Rightarrow \frac{220}{2200} = \frac{N_2}{3000}$$

$$\Rightarrow N_2 = \frac{220}{2200} \times 3000 = 300$$

$\therefore$ Number of turns in the secondary winding,

$N_2 = 300$ turns.

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Q 9. An AC generator produced an output voltage $E = 170 \sin 377t$ volt, where t is in seconds. What is the frequency of AC voltage?

Sol. Given, that

$$E = 170 \sin 377t \text{ volt} \qquad ....(1)$$

We know that,

$$E = E_0 \sin \omega t \qquad ....(2)$$

On comparing eqs. (1) and (2), we get

$$E_0 = 170$$

$$\omega = 377 \Rightarrow 2\pi f = 377$$

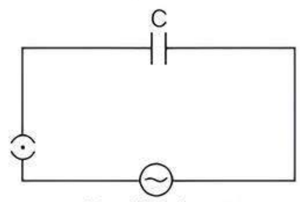
$$f = \frac{377}{2 \times 3.14} = 60.03 \cong 60 \text{ Hz}$$

Short Answer Type-II Questions

Q 1. An AC source $V = V_m \sin \omega t$ is connected across an ideal capacitor. Derive the expression for the (i) current flowing in the circuit and (ii) reactance of the capacitor. Plot a graph of current i versus ωt. *(CBSE 2023)*

Ans. (i) Expression for current flowing through AC source connected across an ideal capacitor:

The circuit diagram for an AC source $V = V_m \sin \omega t$ connected to an ideal capacitor is as follows:



$V = V_m \sin \omega t$

If q is the charge on the capacitor, the corresponding potential difference across the plates of the capacitor is

$$V = \frac{q}{C} \quad \text{or} \quad q = CV$$

Here q and V are the functions of time with

$$V = V_m \sin \omega t$$

The instantaneous current in the circuit,

$$I = \frac{dq}{dt} = \frac{d}{dt}(CV) = \frac{CdV}{dt} = C\frac{d}{dt}V_m \sin \omega t$$

$$= CV_m \cos \omega t.\ \omega$$

$$\therefore \quad I = \frac{V_m}{\left(\frac{1}{\omega C}\right)} \sin\left(\omega t + \frac{\pi}{2}\right)$$

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

where $\frac{V_m}{\left(\frac{1}{\omega C}\right)} = I_m$ is the peak value of current

Thus, the expression for the current I flowing through AC source is $I = I_m \sin\left(\omega t + \frac{\pi}{2}\right)$

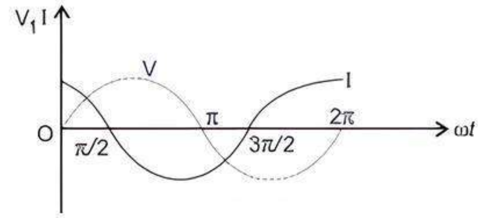
(ii) Comparing above equation with Ohm's law

$$I = \frac{V}{R} \Rightarrow I_m = \frac{V_m}{\left(\frac{1}{\omega C}\right)}$$

We have capacitive reactance,

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

Graph of current I versus ωt:



Q 2. 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 graphs of V and i versus ωt for the circuit. *(CBSE SQP 2022-23)*

Ans. Expression for current i flowing in the AC circuit containing pure inductance: Let us 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.

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 *i.e.*, the inductance acts like a resistance in AC circuit.

The instantaneous value of alternating voltage applied is

$$V = V_0 \sin \omega t \qquad ...(1)$$

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

According to Kirchhoff's loop rule,

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

or $\qquad V = L\frac{di}{dt} \qquad$ or $\qquad \frac{di}{dt} = \frac{V}{L}$

or, $\qquad \frac{di}{dt} = \frac{V_0 \sin \omega t}{L} \Rightarrow di = \frac{V_0 \sin \omega t}{L} dt$

Integrating with respect to time 't', we get

$$i = \frac{V_0}{L}\int \sin \omega t\, dt = \frac{V_0}{L}\left\{\frac{-\cos \omega t}{\omega}\right\}$$

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$$= \frac{-V_0}{\omega L} \cos \omega t = \frac{V_0}{\omega L} \sin\left(\frac{\pi}{2} - \omega t\right)$$

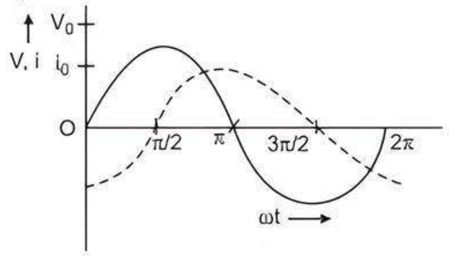
or, $$i = \frac{-V_0}{\omega L} \sin\left(\frac{\pi}{2} - \omega t\right) \quad ...(2)$$

This is the required expression for current.

or, $$i = i_0 \sin\left(\omega t - \frac{\pi}{2}\right) \text{ where } i_0 = \frac{V_0}{\omega L}$$

This shows that the current flowing through the circuit lags behind the applied voltage by a phase angle of $\pi/2$.

Graph of V and i versus ωt for the circuit:



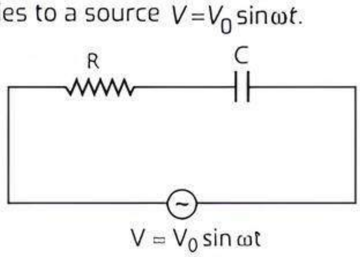
Q 3. A resistance R and a capacitor C are connected in series to a source $V = V_0 \sin \omega t$. Find:

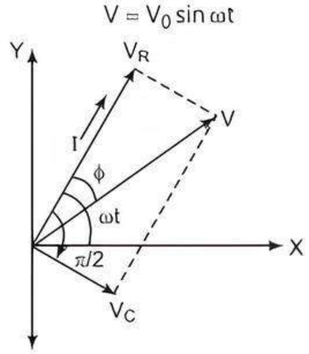
(i) the peak value of the voltage across the (a) resistance and (b) capacitor.

(ii) the phase difference between the applied voltage and current. Which of them is ahead?

(CBSE 2020)

Ans. (i) A resistance R and a capacitor C are connected in series to a source $V = V_0 \sin\omega t$.





From diagram, by parallelogram law of vector addition,

$$V_R + V_C = V$$

Using Pythagorean theorem, we get

$$V^2 = V_R^2 + V_C^2 = (IR)^2 + (IX_C)^2 = I^2(R^2 + X_C^2)$$

$$\Rightarrow \quad I = \frac{V}{\sqrt{R^2 + X_C^2}} = \frac{V}{Z}$$

where, $Z = \sqrt{R^2 + X_C^2}$ is called impedance.

Peak value of current,

$$I_0 = \frac{V_0}{Z} = \frac{V_0}{\sqrt{R^2 + X_C^2}} \qquad \left(\because X_C = \frac{1}{\omega C}\right)$$

(a) Peak value of voltage across resistance,

$$V_R = I_0 R = \frac{V_0 R}{\sqrt{R^2 + X_C^2}}$$

(b) Peak value of voltage across capacitor,

$$V_C = I_0 X_C = \frac{V_0 X_C}{\sqrt{R^2 + X_C^2}}$$

(ii) We know that the voltage across the resistance, then the voltage will be in phase with the current. The voltage across the capacitance lag the current by 90°.
So, the voltage across the resistance will be ahead.

Q 4. A resistance R and a capacitor C are connected in series to an AC source $V = V_0 \sin \omega t$.

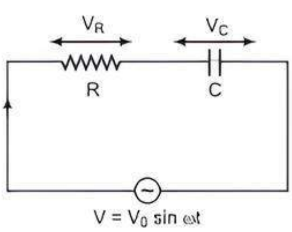
(i) Obtain the expression for the instantaneous current (I) in the circuit.

(ii) Show graphically variations of V and I as a function of ωt.

(CBSE 2020)

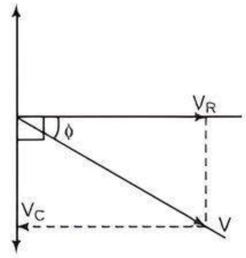
Ans. (i) $Z = \sqrt{R^2 + X_C^2}$ = Impedance

$$\therefore \quad I = \frac{V}{Z} = \frac{V_0 \sin\omega t}{\sqrt{R^2 + X_C^2}}$$



$V_R = IR, \qquad V_C = IX_C$

In phase, I lags V by $\pi/2$.



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

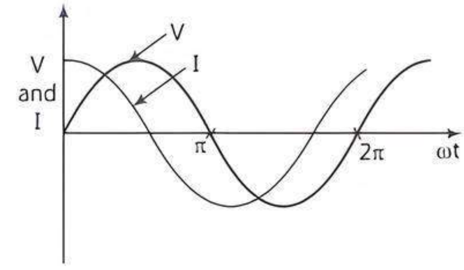
$$= \sqrt{(IR)^2 + (IX_C)^2}$$

$$I = \frac{V}{\sqrt{R^2 + X_C^2}} = \frac{V_0 \sin\omega t}{\sqrt{R^2 + X_C^2}}$$

ϕ = phase difference between V and I

$$\tan\phi = \frac{V_0}{V_R} = \frac{X_C}{R}$$

(ii) Graph showing variation of V and I as a function of ωt.



TiP

Phasor diagrams should be learnt very well.

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Q 5. A circuit containing an 80 mH inductor and a 250 mF capacitor in series connected to a 240 V, 100 rad/s supply.
The resistance of the circuit is negligible.
(i) Obtain rms value of current.
(ii) What is the total average power consumed by the circuit? *(CBSE 2015)*

Ans. (i) Here, $L = 80$ mH, $C = 250$ mF, $\omega = 100$ rad/s and $V_{rms} = 240$ V

$$\text{Reactance} = \left|\omega L - \frac{1}{\omega C}\right|$$

$$= \left|100 \times 80 \times 10^{-3} - \frac{1}{100 \times 250 \times 10^{-3}}\right|$$

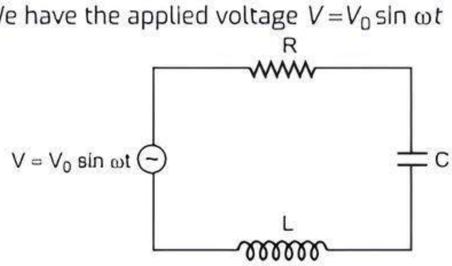
$$= \left|8 - \frac{1}{25}\right| = 7.96$$

$$I_{rms} = \frac{V_{rms}}{\text{Reactance}} = \frac{240}{7.96} = 30.15 \text{ A}$$

(ii) The total average power consumed by circuit is zero.

Q 6. A voltage $V = V_0 \sin \omega t$ is applied to a series LCR circuit. Derive an expression for average power dissipated over a cycle. Under what condition:
(i) no power is dissipated even though the current flows through the circuit?
(ii) maximum power is dissipated in the circuit? *(CBSE 2016, 15)*

Ans. We have the applied voltage $V = V_0 \sin \omega t$



and $\quad I = I_0 \sin(\omega t + \phi)$ where, $\phi = \tan^{-1}\left(\frac{X_C - X_L}{R}\right)$

$$\Rightarrow \quad P = V \times I = V_0 \sin\omega t \times I_0 \sin(\omega t + \phi)$$

$$\Rightarrow \quad P = V_0 I_0 \sin\omega t \times (\sin\omega t \cos\phi + \cos\omega t \sin\phi)$$

$$\Rightarrow \quad P = V_0 I_0 \left[\sin^2 \omega t \cos\phi + \frac{1}{2}\sin 2\omega t \sin\phi\right]$$

Average power per cycle

$$\overline{P} = \frac{1}{T}\int_0^T P\,dt = \frac{1}{T}\int_0^T V_0 I_0 \left[\sin^2 \omega t \cos\phi + \frac{1}{2}\sin 2\omega t \sin\phi\right] dt$$

$$\Rightarrow \overline{P} = \frac{V_0 I_0 \cos\phi}{T}\int_0^T \sin^2 \omega t\,dt + \frac{V_0 I_0 \sin\phi}{2T}\int_0^T \sin 2\omega t\,dt$$

$$\Rightarrow \overline{P} = \frac{V_0 I_0 \cos\phi}{T}\frac{T}{2} + 0$$

$$\left[\because \int_0^T \sin^2 \omega t\,dt = \frac{T}{2} \text{ and } \int_0^T \sin 2\omega t\,dt = 0\right]$$

$$\Rightarrow \quad \overline{P} = \frac{V_0 I_0}{2}\cos\phi = \frac{V_0}{\sqrt{2}} \times \frac{I_0}{\sqrt{2}} \times \cos\phi$$

$$\Rightarrow \quad \overline{P} = V_{rms} \times I_{rms} \times \cos\phi$$

where, $\cos\phi = R/Z$ is called power factor.

(i) For a pure inductive or capacitive circuit, $\phi = \frac{\pi}{2}$

$\Rightarrow \quad \overline{P} = V_{rms} \times I_{rms} \times \cos\frac{\pi}{2} = 0$ which shows that, no power is dissipated even current flows through the circuit.

(ii) At resonance when $X_L = X_C$, $\phi = 0$

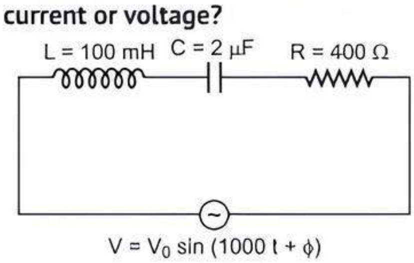
$\Rightarrow \overline{P} = V_{rms} \times I_{rms} \times \cos 0° = V_{rms} \times I_{rms}$ = maximum.

Which shows that at resonance, maximum power is dissipated.

TiP

For pure inductive or capacitive circuit, $\phi = \frac{\pi}{2}$.

Q 7. (i) Find the value of the phase difference between the current and the voltage in the series LCR circuit shown below. Which one leads in phase current or voltage?



(ii) Without making any other change, find the value of the additional capacitor C', to be connected in parallel with the capacitor C, in order to make the power factor of the circuit unity. *(CBSE 2017, 15)*

Sol. Given, $L = 100$ mH $= 100 \times 10^{-3}$ H,
$C = 2\mu$F $= 2 \times 10^{-6}$ F, $\omega = 1000$ rad/s and $R = 400\ \Omega$

(i) For phase difference, $\tan\phi = \frac{\left(\omega L - \frac{1}{\omega C}\right)}{R}$

where, ϕ is phase difference between current and voltage

$\because \quad \omega = 1000 \Rightarrow \omega L = 1000 \times 100 \times 10^{-3} = 100\ \Omega$

$$\frac{1}{\omega C} = \frac{1}{1000 \times 2 \times 10^{-6}} = \frac{1}{2 \times 10^{-3}} = 500\Omega$$

$$\Rightarrow \quad \tan\phi = \frac{100 - 500}{400} = \frac{-400}{400} = -1$$

$$\Rightarrow \quad \phi = \tan^{-1}(-1) \Rightarrow \phi = 135°$$

Since, $\omega L < \frac{1}{\omega C}$ or $X_L < X_C$

Therefore, current is leading in phase by a phase angle 135°.

(ii) For unit power factor, $\cos\phi = 1$

$$\Rightarrow \quad \frac{R}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C_1}\right)^2}} = 1$$

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where, C_1 is the total capacitance.

$$\Rightarrow \quad R^2 + \left(\omega L - \frac{1}{\omega C_1}\right)^2 = R^2$$

$$\Rightarrow \quad \omega L = \frac{1}{\omega C_1} \Rightarrow 100 = \frac{1}{1000\, C_1}$$

$$C_1 = \frac{1}{10^5} = 10^{-5}\ \text{F} = 10\ \mu\text{F}$$

For two capacitances in parallel the resultant capacitance $C_1 = C + C'$

Thus, additional capacitance C' required in parallel $= C_1 - C = 10\ \mu\text{F} - 2\ \mu\text{F} = 8\ \mu\text{F}$

Q 8. A series combination of an inductor L, a capacitor C and a resistor R is connected across an AC source of voltage in a circuit. Obtain an expression for the average power consumed by the circuit. Find power factor for (i) purely inductive circuit and (ii) purely resistive circuit. *(CBSE 2023)*

Ans. In an AC circuit, the dissipation of electric energy depends upon the applied voltage V and current I flowing through it along with the phase between them. Suppose in an LCR series circuit the instantaneous values of voltage and current are as follows:

$V = V_0 \sin \omega t$ and $I = I_0 \sin(\omega t + \phi)$, where ϕ is the phase between V and I.

Thus, we define instantaneous power as the product of instantaneous voltage and instantaneous current. It is denoted by P and is given by

i.e., $P = V \times I$

or $P = V_0 \sin \omega t \times I_0 \sin(\omega t + \phi)$

$= V_0 I_0 \sin \omega t (\sin \omega t \cos \phi + \cos \omega t \sin \phi)$

$= V_0 I_0 (\sin^2 \omega t \cos \phi + \sin \omega t \cos \omega t \sin \phi)$

$$= V_0 I_0 \left[\frac{1}{2}(2\sin^2 \omega t \cos\phi) + \frac{1}{2}(2 \sin \omega t \cos \omega t \sin\phi)\right]$$

$$= V_0 I_0 \left[\frac{1}{2}(1 - \cos 2\omega t) \cos\phi + \frac{1}{2}(\sin 2\omega t \sin \phi)\right]$$

But the average value of $\sin 2\omega t$ and $\cos 2\omega t$ for a complete cycle is zero.

Hence, the average power for one complete cycle of AC is

$$P = \frac{1}{2} V_0 I_0 \cos\phi$$

$$= \frac{V_0}{\sqrt{2}} \times \frac{I_0}{\sqrt{2}} \cos\phi$$

or $$P = V_{rms} \times I_{rms} \times \cos\phi \text{ watt}$$

where $\cos\phi$ is called the power factor of circuit. Its value depends upon the nature of circuit (i.e., elements of circuit such as resistance, capacitance and inductance).

Power Factor for ($\cos\phi$) :

(i) Purely Inductive Circuit : If the circuit contains only an inductor or capacitor, we know that the phase difference between voltage and current is $\pi/2$. Therefore, $\cos\phi = 0$.

(ii) Purely Resistive Circuit : In this circuit, phase difference (ϕ) is zero, i.e., $\phi = 0$ therefore, $\cos\phi = 1$.

Q 9. An AC generator consists of a coil of 10000 turns and of area 100 cm^2. The coil rotates at an angular speed of 140 rpm in a uniform magnetic field of 3.6×10^{-2} T. Find the maximum value of the emf induced.

Sol. Given,

Number of turns = 10000 turns

Area of coil, $A = 100\ \text{cm}^2 = 0.01\ \text{m}^2$

Angular speed, $\omega = 140$ rpm

$$\omega = \frac{140}{60} \times 2 \times \frac{22}{7} \qquad \left[\because 1 \text{ rpm} = \frac{\text{rpm}}{60} \times 2\pi \text{ rad/sec}\right]$$

$= 14.7$ rad/sec

and magnetic field, $B = 3.6 \times 10^{-2}$ T

maximum value of induced emf $= NBA\omega$

$= 10000 \times 3.6 \times 10^{-2} \times 0.01 \times 14.7$

$= 5292 \times 10^{-2} = 52.9$ V.

COMMON ERR(!)R

Often students forget to convert rpm into rad/sec.

Long Answer Type Questions

Q 1. A device X is connected across an AC source of voltage $V = V_0 \sin \omega t$. The current through X is given as $I = I_0 \sin\left(\omega t + \frac{\pi}{2}\right)$.

(i) Identify the device X and write the expression for its reactance.

(ii) Draw graphs showing variation of voltage and current with time over one cycle of AC, for X.

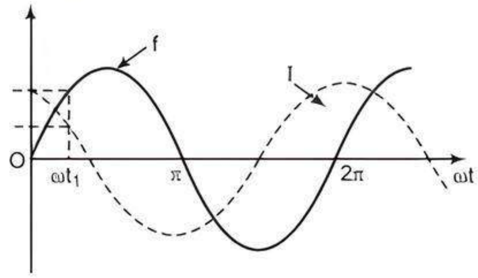
(iii) How does the reactance of the device X vary with frequency of the AC? Show this variation graphically.

(iv) Draw the phasor diagram for the device X. *(CBSE 2018)*

Ans. (i) $X \rightarrow$ Capacitor

Reactance $X_C = \dfrac{1}{\omega C} = \dfrac{1}{2\pi f C}$

(ii) Graph showing variation of voltage and current with time over one cycle of AC for X is given ahead:



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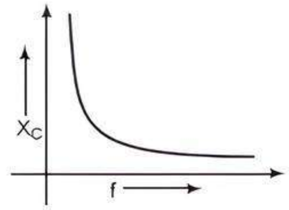
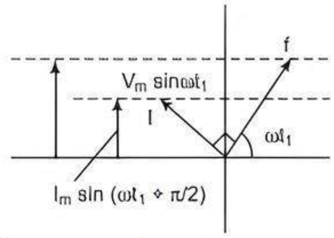
(iii) Reactance of the capacitor varies inversely proportional to the frequency

i.e. $X_C \propto \frac{1}{f}$.



(iv) Phasor diagram for the device X:



Q 2. (i) Draw graphs showing the variations of inductive reactance and capacitive reactance with frequency of applied AC source.

(ii) Draw the phasor diagram for a series LRC circuit connected to an AC source.

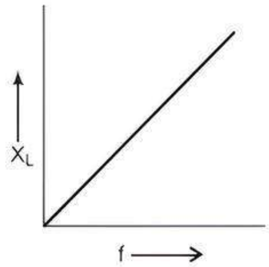
(iii) When an alternating voltage of 220 V is applied across a device *X*, a current of 0.25 A flows which lags behind the applied voltage in phase by $\pi/2$ radian. If the same voltage is applied across another device *Y*, the same current flows but now it is in phase with the applied voltage.

(a) Name the devices *X* and *Y*.

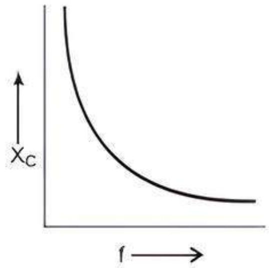
(b) Calculate the current flowing in the circuit when the same voltage is applied across the series combination of *X* and *Y*.

(CBSE SQP 2023-24)

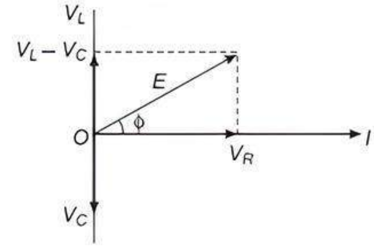
Ans. (i) Inductive reactance $X_L = 2\pi fC$



Capacitive reactance, $X_C = \frac{1}{2\pi fC}$



(ii) Phasor diagram of series *LCR* circuit:



(iii) (a) *X* is inductance and *Y* is resistance.

(b) $\because X_L = \frac{V}{I} = R$

$\therefore X_L = R = \frac{220}{0.25} = 880\,\Omega$

For series combination of *X* and *Y*,

$\therefore \quad I = \frac{V}{Z} = \frac{220}{\sqrt{R^2 + X_L^2}} = \frac{220}{880\sqrt{2}} = 0.177\text{ A}$

Q 3. (i) In a series *LCR* circuit connected across an AC source of variable frequency, obtain the expression for its impedance and draw a plot showing its variation with frequency of the AC source.

(ii) What is the phase difference between the voltages across inductor and the capacitor at resonance in the *LCR* circuit?

(iii) When an inductor is connected to a 200 V DC voltage, a current of 1 A flows through it. When the same inductor is connected to a 200 V, 50 Hz AC source, only 0.5 A current flows. Explain, why? Also, calculate the self inductance of the inductor. *(CBSE 2019)*

Ans. (i) Suppose, a resistance *R*, an inductance *L* and capacitance *C* are connected in series to a source of alternating emf *e* given by

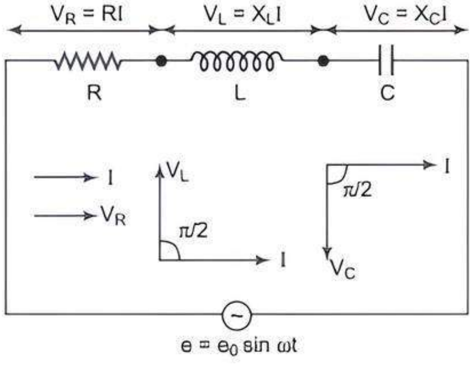
$$e = e_0 \sin \omega t$$

Let *I* be the instantaneous value of current in the series circuit. Then voltage across the three components are:

(a) $V_L = X_L I$. It is ahead of current *I* in phase by 90°

(b) $V_R = RI$. It is in phase with current *I*.

(c) $V_C = X_C I$. It lags behind the current *I* in phase by 90°.



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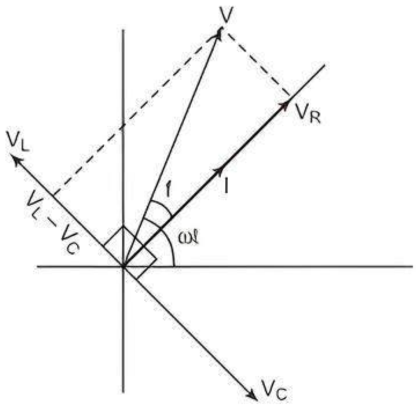


As it is evident from the figure, $\vec{V_L}$ and $\vec{V_C}$ are in opposite direction. Hence, their resultant will be $(\vec{V_L} - \vec{V_C})$. Using the law of parallelogram, $\vec{V_R}$ and $(\vec{V_L} - \vec{V_C})$ resultant is equal to the applied emf $\vec{e}$ as given by the diagonal of the parallelogram.

Assuming $X_L > X_C \Rightarrow V_L > V_C$

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

where, V_L, V_C and V_R are potential differences across L, C and R respectively.

But, $V_R = IR, V_L = IX_L, V_C = IX_C$

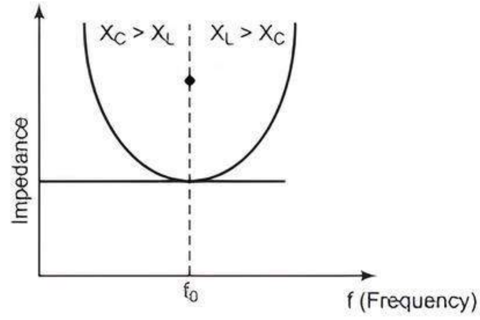
$$V = \sqrt{(IR)^2 + (IX_L - IX_C)^2}$$

$$\frac{V}{I} = \sqrt{R^2 + (X_L - X_C)^2}$$

Impedance of LCR circuit,

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

Graph for variation of an impedance with frequency is as follows:



(ii) At resonance, $X_L = X_C$

At resonance, voltage across inductor is equal to voltage across capacitor in magnitude only but both are on opposite polarities.

Hence, phase difference between V_L and V_C is 180°.

(iii) As in case of DC supply, the current is independent of frequency. So, the value of current is 1 A but in AC supply, the current is 0.5 A as the value of impedance increases and hence value of current decreases.

For DC, $R = \frac{V}{I} = \frac{200}{1} = 200\Omega$

For AC, $Z = \frac{V}{I} = \frac{200}{0.5} = 400\Omega$

$$Z = \sqrt{R^2 + \omega^2 L^2}$$

$\Rightarrow$ $400 = \sqrt{(200)^2 + 4\pi^2 (50)^2 L^2}$ $(\because \omega = 2\pi f)$

$\Rightarrow$ $160000 = 40000 + 4\pi^2 \times 2500 L^2$

$\Rightarrow$ $L^2 = \frac{12}{\pi^2}$

$\Rightarrow$ $L = \frac{\sqrt{12}}{\pi}$ or $\frac{2\sqrt{3}}{\pi}$ H

COMMON ERR(!)R

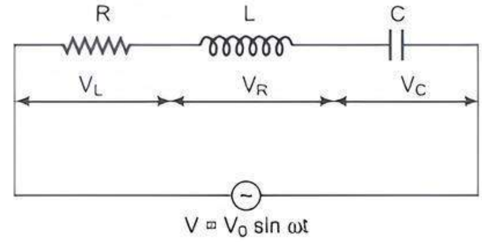
Students generally don't revise graph for variations.

Q 4. (i) A series LCR circuit is connected to an AC source. Using the phasor diagram, derive the expression for the impedance of the circuit.

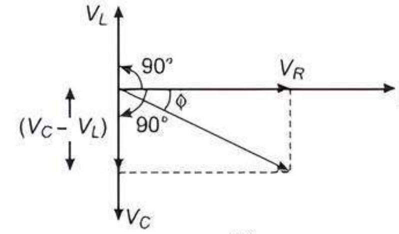
(ii) Plot a graph to show the variation of current with frequency of the AC source, explaining the nature of its variation for two different resistances R_1 and R_2 ($R_1 < R_2$) at resonance.

(CBSE SQP 2023-24)

Ans. (i) **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.



(a)



(b)

Suppose the voltage across resistance R is V_R voltage across inductance L is V_L and voltage across capacitance C is V_C. The voltage V_R and current i

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are in the same phase, the voltage V_L will lead the current by angle 90° while the voltage V_C will lag behind the current by angle 90° (fig. b). Clearly V_C and V_L are in opposite directions, therefore their resultant potential difference = $V_C - V_L$ (if $V_C > V_L$). Thus, V_R 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 V_R and $(V_C - V_L)$ will also be V. From the figure,

$$V^2 = V_R^2 + (V_C - V_L)^2$$

$$\Rightarrow \quad V = \sqrt{V_R^2 + (V_C - V_L)^2} \quad ...(1)$$

But $V_R = R\,i$, $V_C = X_C\,i$ and $V_L = X_L\,i$ ...(2)

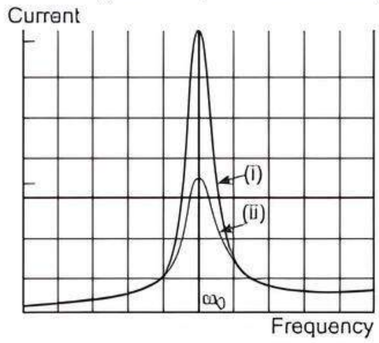
where $X_C = \frac{1}{\omega C}$ = capacitance reactance and $X_L = \omega L$ = inductive reactance

$$\therefore \quad V = \sqrt{(RI)^2 + (X_C I - X_L I)^2}$$

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

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

(ii) The curve (i) is for R_1 and the curve (ii) is for R_2



Q 5. (i) With the help of a labelled diagram, explain the working of a step-up transformer. Give reasons to explain the following:

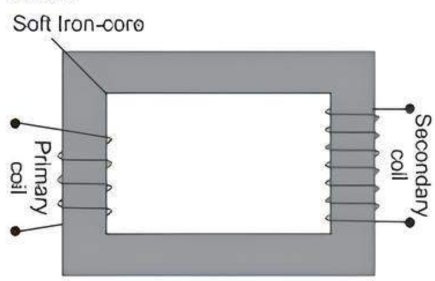
(a) The core of the transformer is laminated.

(b) Thick copper wire is used in windings.

(CBSE 2020)

(ii) State the principle of an AC generator and explain its working with the help of a labelled diagram. Obtain the expression for the emf induced in a coil having *N* turns each of cross-sectional area *A*, rotating with a constant angular speed 'ω' in a magnetic field $\vec{B}$, directed perpendicular to the axis of rotation. *(CBSE 2023, 18)*

Ans. (i) Labelled diagram of a step-up transformer is given below:



Working: When an alternating voltage is applied to the primary, the resulting current produces an alternating magnetic flux which links the secondary coil and induces an emf.

Induced emf across primary coil,

$$e_P = -N_P \frac{d\phi}{dt}$$

Induced emf across secondary coil,

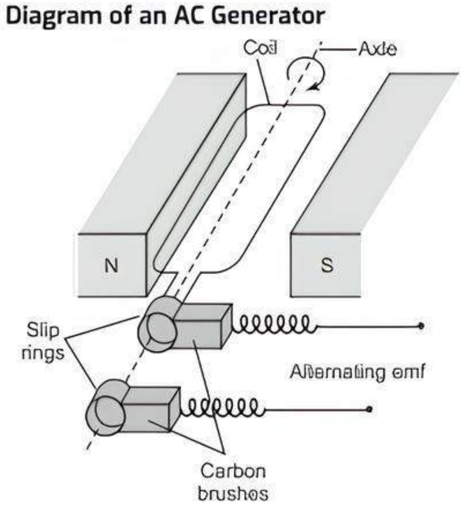
$$e_S = -N_S \frac{d\phi}{dt} \quad \frac{e_S}{e_P} = \frac{N_S}{N_P} = r$$

(a) The core of the transformer is laminated to minimise the eddy currents.

(b) Thick copper wire is used in windings to reduce the heat loss.

(ii) **Principle of AC Generator:** The working of an AC generator is based on the principle of electromagnetic induction. When a closed coil is rotated in a uniform magnetic field with its axis perpendicular to the magnetic field, the magnetic flux linked with the coil changes and an induced emf and hence a current is set-up in it.

Diagram of an AC Generator



Let N be the number of turns in the coil, A be the area of face of each arm, B be the magnitude of the magnetic field, θ be the angle which normal to the coil makes with field $\vec{B}$ at any instant t and ω is the angular velocity with which coil rotates.

The magnetic flux linked with the coil at any instant t will be,

$$\phi = NAB\cos\theta = NAB\cos\omega t$$

By Faraday's rule, the induced emf is given by:

$$E = -\frac{d\phi}{dt} = -\frac{d}{dt}(NAB\cos\omega t)$$

$$\Rightarrow \quad E = NAB\sin\omega t \cdot \omega$$

$$\Rightarrow \quad E = E_0 \sin\omega t \qquad [\text{Here, } E_0 = NAB\omega]$$

When a load of resistance R is connected across the terminals, a current I flows in the external circuit.

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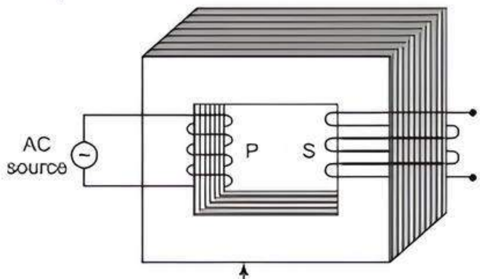
$$I = \frac{E}{R} = \frac{E_0 \sin\omega t}{R} = I_0 \sin\omega t$$

where, $I_0 = \frac{E_0}{R}$

Q 6. (i) Draw the diagram of a device which is used to decrease high AC voltage into a low AC voltage and state its working principle. Write four sources of energy losses in this device.

(ii) A small town with a demand of 1200 kW of electric power at 220 V is situated 20 km away from an electric plant generating power at 440 V. The resistance of the two wires line carrying power is 0.5Ω per km. The town gets the power from the line through a 4000-220 V step-down transformer at a sub-station in the town. Estimate the line power loss in the form of heat. *(CBSE 2019)*

Ans. (i) Transformer is a device which converts high voltage AC into low voltage AC and *vice-versa*. It is based upon the principle of mutual induction. When a variable current is passed through one of the two inductively coupled coils, an induced emf is set up in other coil.



Working: When an alternating current is passed through the primary coil, the magnetic flux through the iron core changes, which does two things, produces emf in the primary coil and an induced emf is set-up in the secondary coil. If we assume that the resistance of primary coil is negligible, then the back emf will be equal to the voltage applied to the primary coil.

Energy Losses in a Transformer

(a) Eddy current in iron core of transformer facilitate the loss of energy in the form of heat.

(b) Total fluxes linked with primary do not completely pass through the secondary which denotes the loss in the flux or flux leakage.

(c) Due to heating, energy loss takes place in copper wires of primary and secondary coils.

(d) The energy loss takes place in magnetising and demagnetising the iron core over every cycle.

(ii) Given, power = 1200 kW = 1200 × 1000 W

$V = 220$ V, $R = 0.5\Omega$

$V_P = 4000$ V, $V_S = 220$ V, distance = 20 km

∴ $\text{Power} = I_P V_P$

$\Rightarrow \quad 1200 \times 1000 = I_P \times 4000 \Rightarrow I_P = 300$ A

∴ $\text{Power loss} = (I_P)^2 \times R(2\text{lines})$

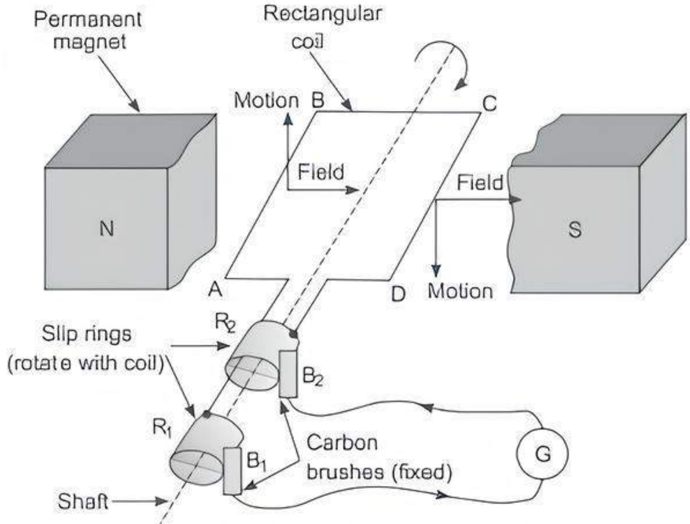
$= (300)^2 \times 0.5 \times 20 \times 2 = 18 \times 10^5$ W

$= 1800$ kW

Q 7. (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 2017)*

Ans. (i) Diagram of AC generator



Let N be the number of turns in the coil, A be the area of face of each arm, B be the magnitude of the magnetic field, θ be the angle which normal to the coil makes with field $\vec{B}$ at any instant t and ω is the angular velocity with which coil rotates.

The magnetic flux linked with the coil at any instant t will be,

$$\phi = NAB\cos\theta = NAB\cos\omega t$$

By Faraday's rule, the induced emf is given by:

$$E = -\frac{d\phi}{dt} = -\frac{d}{dt}(NAB\cos\omega t)$$

$\Rightarrow \quad E = NAB\sin\omega t \cdot \omega$

$\Rightarrow \quad E = E_0 \sin\omega t \qquad$ [Here, $E_0 = NAB\omega$]

(ii) Given, $A = 200\text{cm}^2 = 200 \times 10^{-4}\text{m}^2 = 2 \times 10^{-2}\text{m}^2$

$N = 20$, $\omega = 50$ rad s^{-1}, $B = 3.0 \times 10^{-2}$ T

Maximum emf, $E_0 = NBA\omega$

$= 20 \times 3.0 \times 10^{-2} \times 2 \times 10^{-2} \times 50 = 0.6$ V

Maximum current, $I_0 = \frac{E_0}{R} = \frac{0.6}{R}$ A

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Chapter Test

Multiple Choice Questions

Q 1. In the case of an inductor:

a. voltage lags the current by $\frac{\pi}{2}$

b. voltage leads the current by $\frac{\pi}{2}$

c. voltage leads the current by $\frac{\pi}{3}$

d. voltage leads the current by $\frac{\pi}{4}$

Q 2. When power is drawn from the secondary coil of the transformer, the dynamic resistance:

a. increases
b. decreases
c. remains unchanged
d. changes erratically

Assertion and Reason Type Questions

Directions (Q.Nos. 3-4): *In the following questions, statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:*

a. Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
b. Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).
c. Assertion (A) is true but Reason (R) is false.
d. Both Assertion (A) and Reason (R) are false.

Q 3. Assertion (A): The inductive reactance limits amplitude of the current in a purely inductive circuit.

Reason (R): The inductive reactance is independent of the frequency of the current.

Q 4. Assertion (A): A laminated core is used in transformers to increase eddy currents.

Reason (R): The efficiency of a transformer increase with increase in eddy currents.

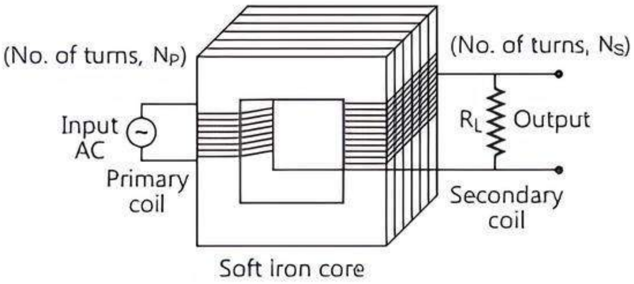
Fill in the blanks

Q 5. Projection of a phasor on any axis, always represents the .... value of a quantity.

Q 6. An alternator is based on the principle of ....

Case Study Based Question

Q 7. A transformer is an electrical device which is used for changing the AC voltages. It is based on the phenomenon of mutual induction *i.e.*, whenever the amount of magnetic flux linked with a coil changes, an emf is induced in the neighbouring coil. For an ideal transformer, the resistances of the primary and secondary windings are negligible.



It can be shown that

$$\frac{E_S}{E_P} = \frac{I_P}{I_S} = \frac{N_S}{N_P} = k$$

where the symbols have their standard meanings.

For a step up transformer,

$$N_S > N_P;\ E_S > E_P,\ k > I\ ;$$

$$\therefore \quad I_S < I_P$$

For a step down transformer,

$$N_S < N_P,\ E_S < E_P\ ,\ k < I$$

The above relations are on the assumptions that efficiency of transformer is 100%.

In fact, efficiency $\eta = \frac{\text{output power}}{\text{input power}} = \frac{E_S I_S}{E_P I_P}$

Read the given passage carefully and give the answer of the following questions:

(i) Which of the following quantity remains constant in an ideal transformer?

a. Current
b. Voltage
c. Power
d. All of the above

(ii) Transformer is used to:

a. convert AC to DC voltage
b. convert DC to AC voltage
c. obtain desired DC power
d. obtain desired AC voltage and current

(iii) The number of turns in primary coil of a transformer is 20 and the number of turns in a secondary is 10. If the voltage across the primary is 220 AC V, what is the voltage across the secondary?

a. 100AC V
b. 120AC V
c. 110AC V
d. 220AC V

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(iv) In a transformer the number of primary turns is four times that of the secondary turns. Its primary is connected to an AC source of voltage V. Then:

a. current through its secondary is about four times that of the current through its primary.

b. voltage across its secondary is about four times that of the voltage across its primary

c. voltage across its secondary is about two times that of the voltage across its primary.

d. voltage across its secondary is about $\frac{1}{2\sqrt{2}}$ times that of the voltage across its primary

(v) A transformer is used to light 100 W-110 V lamp from 220V mains. If the main current is 0.5 A, the efficiency of the transformer is:

a. 95% b. 99%

c. 90% d. 96%

Very Short Answer Type Questions

Q 8. At resonance in *LCR* circuit, what happens to the impedance?

Q 9. A transformer is used to light 140 W, 24V lamp from a 240 V AC mains. If the main current is 0.7 A, what will be the efficiency of the transformer?

Q 10. By which electrical machine, mechanical energy is converted into electrical energy?

Short Answer Type-I Questions

Q 11. Define the term power factor. State the condition under which it is (i) maximum and (ii) minimum.

Q 12. Show the two arrangement for winding of primary and secondary coil in a transformer.

Short Answer Type-II Questions

Q 13. A sinusoidal voltage of peak value 283V and frequency 50Hz is applied to a series *LCR* circuit in which $R = 3\Omega$, $L = 25.48$mH, and $C = 796\mu$F. Find:

(i) the impedance of the circuit,

(ii) the phase difference between the voltage across the source and the current;

(iii) the power dissipated in the circuit.

Q 14. A series *CR* circuit with $R = 200\ \Omega$ and $C = (50/\pi)\ \mu$F is connected across an AC source of peak voltage $e_0 = 100$ V and frequency $\nu = 50$ Hz, calculate:

(i) impedance of the circuit (Z), (ii) phase angle (ϕ) and (iii) voltage across the resistor.

(CBSE 2023)

Long Answer Type Questions

Q 15. (i) For circuits used for transporting electric power, a low power factor implies large power loss in transmission. Explain.

(ii) Power factor can often be improved by the use of a capacitor of appropriate capacitance in the circuit. Explain.

(iii) The power factor of an AC circuit is 0.5. What will be the phase difference between voltage and current?

Q 16. The coil of an AC generator consists of 100 turns of wire, each of area 0.5 m^2. The resistance of the wire is 100 Ω. The coil is rotating in a magnetic field of 0.8 T perpendicular to its axis of rotation, at a constant angular speed of 60 radian per second. Calculate the maximum emf generated and power dissipated in the coil. *(CBSE 2023)*

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