07

Alternating Current

TREND ANALYSIS 3 YEARS

	Average No. of Questions Across all Sets			
	Types of Questions	2023	2020	2019
TOPIC 01 Introduction of Alternating Current	1 Mark	2	2	–
	2 Marks	–	1	–
	3 Marks	7	–	–
	5 Marks	–	1	1
TOPIC 02 AC Devices	1 Mark	–	–	–
	2 Marks	1	1	–
	3 Marks	–	–	–
	5 Marks	–	–	1

TOPIC 1

Introduction to Alternating Current

Alternating Current (AC)

An alternating current is the current whose magnitude changes continuously with time between zero and a maximum value and whose direction reverses periodically.

$$\boxed{I = I_0 \sin \omega t}$$

$$\Rightarrow \quad I = I_0 \sin 2\pi v t = I_0 \sin \frac{2\pi}{T} t$$

where, ω = angular frequency in rad/s

and I_0 = peak value or maximum value of AC.

Average or Mean Value of AC

It is defined as the value of AC which would send same amount of charge through a circuit in half-cycle that is sent by steady current in the same time. (i.e. $T/2$)

$$I_{av} = \frac{2I_0}{\pi} = 0.637 I_0$$

The 63.7% of peak value of AC gives average or mean value of AC.

Mean value of AC (I_m) is 63% of peak value of AC(I_0) over any half-cycle. In a complete cycle of AC, the mean value of AC will be zero.

Effective Value or rms Value of AC

It is defined as the value of AC over a complete cycle which would generate same amount of heat in a given resistors that is generated by steady current in the same resistor and in the same time during a complete cycle.

$$I_{rms} = \frac{I_0}{\sqrt{2}} = 0.707 I_0 = 70.7\% \text{ of } I_0$$

The 70.7% of peak value of current gives effective or rms value of AC.

Alternating emf or Voltage

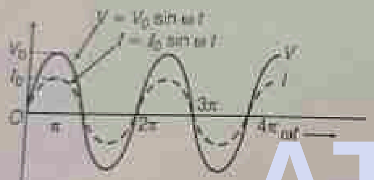
It is the emf or voltage which varies in both magnitude as well as direction alternatively and periodically. The instantaneous alternating emf is given by

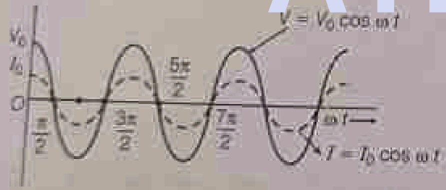
$$V = V_0 \sin \omega t \quad \text{or} \quad V = V_0 \cos \omega t$$

$$V_{rms} = \frac{V_0}{\sqrt{2}} = 0.707 V_0 \quad \text{or} \quad V_{rms} = 70.7\% \text{ of } V_0$$

$$V_{av} = \frac{2V_0}{\pi} = 0.637 V_0 \quad \text{or} \quad V_{av} = 63.7\% \text{ of } V_0$$

Both AC voltage and AC current are represented by diagrams as shown in figure.





Inductive Reactance (X_L)

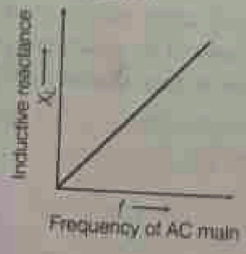
The effective resistance or opposition offered by the inductor to the flow of current is called inductive reactance and is denoted by X_L.

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

Also for a given inductor, $\boxed{X_L = (2\pi L) f}$

$\Rightarrow$ $X_L \propto f$ $(\because 2\pi L = \text{constant})$

where, L = self-inductance.



Capacitive Reactance (X_C)

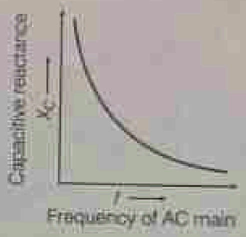
The opposing nature of capacitor to the flow of alternating current is called capacitive reactance.

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

For a given capacitor,

$$X_C = \left(\frac{1}{2\pi C}\right) \cdot \frac{1}{f} \Rightarrow X_C \propto \frac{1}{f} \quad (\because 1/2\pi C = \text{constant})$$

where, C = capacitance for AC.



Power in 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, $\cos \phi = \frac{R}{Z}$ = power factor for these two circuits and Z = impedance.

Average power consumption in pure inductive and pure capacitive circuit is equal to zero because phase difference, $\phi = \pi/2$

$\Rightarrow$ Power factor $= \cos \frac{\pi}{2} = 0$

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

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**. In other words, in an AC circuit, if $R = 0 \Rightarrow \cos \phi = \frac{R}{Z} = 0$ i.e. in resistance less circuit, the power consumed is zero.

Phasor Diagram

The representation of AC current and voltage (of same frequency) by rotating vectors is called phasor and the diagram representing these phasors is known as phasor diagram.

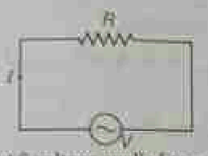
The length of the vector represents the maximum or peak value. The projection of the vectors on fixed axis gives the instantaneous value of alternating current and voltage.

Types of AC Circuits

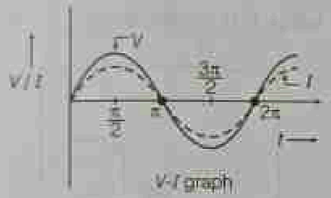
There are some basic types of AC circuits

AC Through Resistor

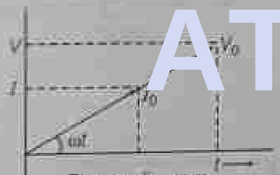
Suppose a resistor of resistance R is connected to an AC voltage with instantaneous value (V) is given by
$V = V_0 \sin \omega t$



An AC voltage applied to a resistor



V-I graph



Phasor diagram

Then,

(i) Voltage and current are in same phase.

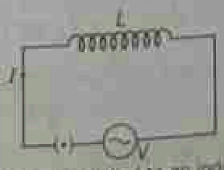
(ii) Maximum current, $I_0 = \frac{V_0}{R}$

(iii) $I_{rms} = \frac{V_{rms}}{R}$

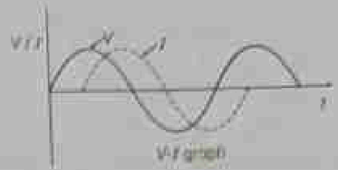
(iv) If $V = V_0 \sin \omega t$, then $I = I_0 \sin \omega t$.

AC Through Inductor

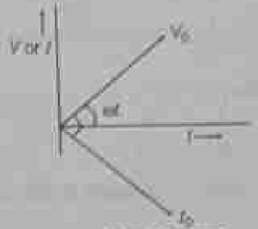
Suppose an inductor with self-inductance L is connected to AC voltage with instantaneous value V is given by
$E = E_0 \sin \omega t$



An AC voltage applied to an inductor



V-I graph



Phasor diagram

Then,

(i) Inductive reactance, $X_L = \omega L = 2\pi f L$

(ii) $I_0 = \frac{V_0}{X_L} = \frac{V_0}{\omega L}$

(iii) $I_{rms} = \frac{V_{rms}}{X_L} = \frac{V_{rms}}{\omega L} = \frac{V_0}{\omega L\sqrt{2}}$

(iv) Voltage leads the current by phase $\frac{\pi}{2}$

(v) If $V = V_0 \sin \omega t$, then $I = I_0 \sin\left(\omega t - \frac{\pi}{2}\right)$

(vi) Power factor, $\cos\phi = \cos\frac{\pi}{2} = 0$

(vii) Average power consumption,

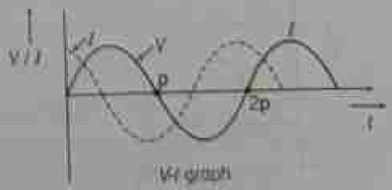
$P_{av} = V_{rms} I_{rms} \cos\phi = 0$

AC Through Capacitor

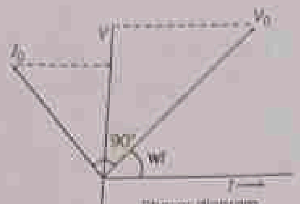
Suppose a capacitor with capacitance C is connected to an AC voltage instantaneous value V is given by

$V = V_0 \sin \omega t$

An AC source connected to a capacitor



V-I graph



Phasor diagram

Then,

(i) Capacitive reactance,

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

(ii) Capacitor offers infinite reactance in DC circuit as $f = 0$.

$\therefore \quad X_C = \infty$

(iii) $I_0 = \frac{V_0}{X_C} = \frac{V_0}{(1/\omega C)} = V_0 \omega C$

(iv) Voltage lags behind the current by phase $\frac{\pi}{2}$.

(v) If $V = V_0 \sin \omega t$, then $I = I_0 \sin\left(\omega t + \frac{\pi}{2}\right)$

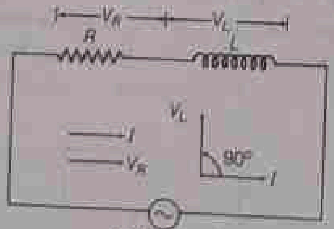
$$I_{\text{rms}} = \frac{I_0}{\sqrt{2}} = \frac{V_0}{1/\omega C \cdot \sqrt{2}} = \frac{V_{\text{rms}}}{1/\omega C} = \frac{V_{\text{rms}}}{X_C}$$

(vi) Power factor is minimum and equal to zero.

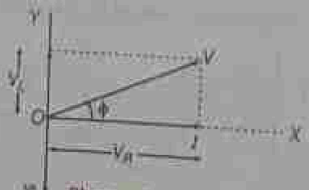
(vii) Average power consumption (during a complete cycle), $P_{\text{av}} = V_{\text{rms}} I_{\text{rms}} \cos \phi = 0$

L-R Series AC Circuit

L-R series AC circuit connected with AC voltage of instantaneous value V is show below.



AC Voltage (V)



Phasor diagram

Then,

(i) Impedance, $Z = \sqrt{R^2 + X_L^2}$

$= \sqrt{R^2 + \omega^2 L^2}$ $\quad [\because X_L = \omega L]$

$= V_{\text{rms}} / I_{\text{rms}}$

(ii) For the phase angle ϕ, $\tan \phi = \frac{X_L}{R} = \frac{\omega L}{R}$, voltage leads current by phase ϕ.

(iii) If $V = V_0 \sin \omega t$, then $I = I_0 \sin(\omega t - \phi)$

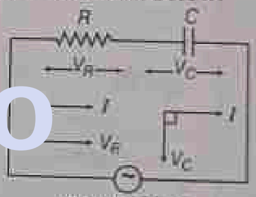
(iv) Power factor, $\cos \phi = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + X_L^2}}$

(v) Average power consumed,

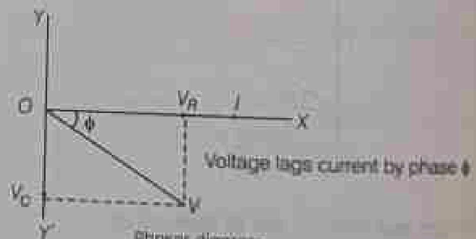
$$P_{\text{av}} = V_{\text{rms}} \times I_{\text{rms}} \times \cos \phi = V_{\text{rms}} \times I_{\text{rms}} \times \frac{R}{Z}$$

R-C Series AC Circuit

R-C series AC circuit connected with AC voltage of instantaneous value V is shown below.



AC Voltage (V)



Phasor diagram

Then, (i) Impedance, $Z = \frac{V_{\text{rms}}}{I_{\text{rms}}} = \sqrt{R^2 + X_C^2}$

$= \sqrt{R^2 + \frac{1}{\omega^2 C^2}}$ $\quad \left[\because X_C = \frac{1}{\omega C}\right]$

(ii) For the phase angle, $\tan \phi = \frac{X_C}{R} = \frac{1}{\omega CR}$

(iii) If $V = V_0 \sin \omega t$, then $I = I_0 \sin(\omega t + \phi)$

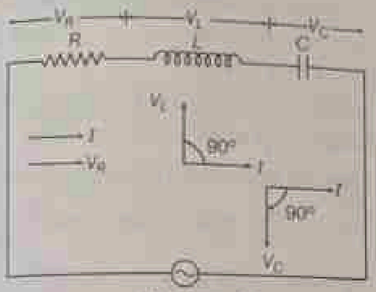
(iv) Power factor, $\cos \phi = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + X_C^2}}$

(v) Average power consumed,

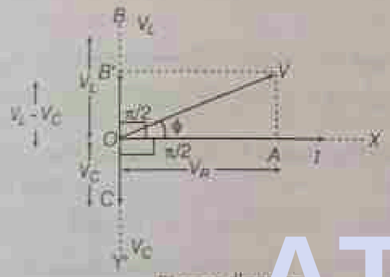
$$P_{\text{av}} = V_{\text{rms}} \times I_{\text{rms}} \times \cos \phi = V_{\text{rms}} \times I_{\text{rms}} \times R/Z$$

L-C-R Series AC Circuit

L-C-R series AC circuit connected with AC voltage (V) is given below.



AC voltage (V)



Phasor diagram

Then, (i) Impedance,

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \frac{V_{\text{rms}}}{I_{\text{rms}}}$$

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

(ii) If $X_L > X_C$, then V leads I by ϕ and if $X_L < X_C$, then V lags behind I by ϕ.

where, $\tan\phi = \frac{X_L - X_C}{R} = \frac{V_L - V_C}{V_R}$

$$= \frac{\omega L - \frac{1}{\omega C}}{R} = \frac{2\pi\nu L - \frac{1}{2\pi\nu C}}{R}$$

(iii) If net reactance is inductive, circuit behaves as L-R circuit.

(iv) If net reactance is capacitive, circuit behaves as C-R circuit.

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

(vi) If $I = I_0 \sin \omega t$, then $V = V_0 \sin(\omega t \pm \phi)$

(vii) Power factor = $\cos\phi = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + (X_L - X_C)^2}}$

(viii) Average power consumed,

$$P_{av} = V_{\text{rms}} \times I_{\text{rms}} \times \cos\phi = V_{\text{rms}} \times I_{\text{rms}} \times \frac{R}{Z}$$

Resonant L-C-R Series AC Circuit

(i) $X_L = X_C$

(ii) Impedance, $Z = Z_{\text{min}} = R$ i.e. circuit behaves as resistive circuit.

(iii) The phase difference between V and I is 0°.

(iv) Resonant angular frequency,

$$\omega_r = \frac{1}{\sqrt{LC}} \Rightarrow \nu_r = \frac{1}{2\pi\sqrt{LC}} \text{ Hz}$$

(v) Average power consumption P_{av} becomes maximum.

(vi) Current becomes maximum and

$$I_{\text{max}} = \frac{V_{\text{rms}}}{R}.$$

PYQs Previous Years Questions

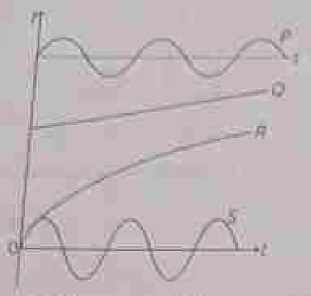
1 Mark Questions

Multiple Choice Questions

1. An ideal inductor is connected across an AC source of voltage. The current in the circuit **CBSE 2023**
(a) is ahead of the voltage in phase by π
(b) lags voltage in phase by π
(c) is ahead of voltage in phase by π/2
(d) lags voltage in phase by π/2

2. An AC voltage $V = V_0 \sin \omega t$ is applied to a series combination of a resistor R and an element X. The instantaneous current in the circuit is $I = I_0 \sin\left(\omega t + \frac{\pi}{4}\right)$. Then, which of the following is correct? **CBSE 2023**
(a) X is a capacitor and $X_C = \sqrt{2}\, R$
(b) X is an inductor and $X_L = R$
(c) X is an inductor and $X_L = \sqrt{2}\, R$
(d) X is a capacitor and $X_C = R$

3. The figure shows variation of current (I) with time (t) in four devices P, Q, R and S. The device in which an alternating current flows is **CBSE 2023**



(a) P (b) Q (c) R (d) S

4. A voltage signal is described by

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

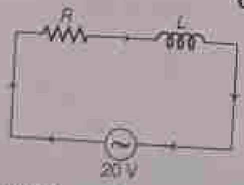
For a cycle. Its rms value is **CBSE 2023**

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

5. 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 2021-22**

(a) 39.70 kW (b) 26.70 kW
(c) 13.35 kW (d) zero

6. A 20 V AC is applied to a circuit of a resistance and a coil with negligible resistance. If the voltage across the resistance is 12V, the voltage across the coil is **CSBE SQP 2021-22**



(a) 16 V (b) 10 V (c) 8 V (d) 6 V

> **KEY idea**
>
> Voltage in resistance and inductance series circuit is given by $V = \sqrt{V_R^2 + V_L^2}$

7. The instantaneous values of emf and the current in a series AC circuit are $E = E_0 \sin \omega t$ and $I = I_0 \sin\left(\omega t + \frac{\pi}{3}\right)$ respectively, then it is **CSBE SQP 2021-22**

(a) Necessarily a RL circuit
(b) Necessarily a RC circuit
(c) Necessarily a LCR circuit
(d) Can be RC or LCR circuit

8. 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 **CSBE SQP 2021-22**

(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

9. The rms current in a circuit connected to a 50 Hz AC source is 15 A. The value of the current $\left(\frac{1}{600}\right)$ s after its value becomes zero is **CBSE 2022 (Term-I)**

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

10. In a circuit, the phase difference between the alternating current and the source voltage is $\frac{\pi}{2}$. Which of the following cannot be the element(s) of the circuit? **CBSE 2022 (Term-I)**

(a) Only C (b) Only L (c) L and R (d) L or C

11. The impedance of a series L-C-R circuit is **CBSE 2022 (Term-I)**

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

12. 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 2022 (Term-I)**

(a) $E_{rms} \cdot I_{rms}$ (b) $E_0 I_0$
(c) $\frac{E_0 I_0}{\sqrt{2}}$ (d) zero

13. 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 2022 (Term-I)**

(a) 5 V (b) 20 V (c) 25 V (d) 65 V

14. A circuit is connected to an AC source of variable frequency. As, the frequency of the source is increased, the current first increases and then decreases. Which of the following combinations of elements is likely to comprise the circuit? **CBSE 2022 (Term-I)**

(a) L, C and R (b) L and C (c) L and R (d) R and C

15. A 15 Ω 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 2022 (Term-I)**

(a) 100 μF (b) 127 μF (c) 142 μF (d) 160 μF

16. A 300 Ω resistor and a capacitor of $\left(\frac{25}{\pi}\right)$ μF are connected in series to a 200 V-50 Hz AC source. The current in the circuit is **CBSE 2022 (Term-I)**

(a) 0.1 A (b) 0.4 A (c) 0.6 A (d) 0.8 A

17. The power factor of a series L-C-R circuit at resonance will be **Delhi 2020**

(a) 1 (b) zero (c) $\frac{1}{2}$ (d) $\frac{1}{\sqrt{2}}$

18. An alternating current from a source is given by $I = 10 \sin 314t$. What is the effective value of current and frequency of source?

(a) 7.07 A, 50 Hz (b) 6.06 A, 50 Hz
(c) 7.07 A, 4 Hz (d) 6.06 A, 4 Hz

Assertion-Reason Questions

Directions (Q. Nos. 19-22) *In the following questions, two statements are given- one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below*

(a) If both Assertion and Reason are correct and Reason is the correct explanation of Assertion.
(b) If both Assertion and Reason are correct but Reason is not the correct explanation of Assertion.
(c) If Assertion is correct but Reason is incorrect.
(d) If both Assertion and Reason are incorrect.

19. **Assertion** The alternating current lags behind the emf by a phase angle of π/2, when AC flows through an inductor.

Reason The inductive reactance increases as the frequency of AC source decreases.

20. **Assertion** When the capacitor is connected to an AC source, it limits or regulates the current, but does not completely prevent the flow of charge.

Reason The capacitor is alternately charged and discharged as the current reverses each half-cycle.

21. **Assertion** Capacitor serves as a barrier for DC and offers an easy path to AC.

Reason Capacitive reactance is inversely proportional to frequency.

22. **Assertion** At resonance, power factor of L-C-R series circuit is 1.

Reason At resonance, $X_C = X_L$

Very Short Answer Questions

23. A series combination of an inductor (L), a capacitor (C) and a resistor (R) are connected across an AC source of emf of peak value E_0 and angular frequency (ω). Plot a graph to show variation of impedance of the circuit with angular frequency (ω). **Delhi 2020**

24. The power factor of an AC circuit is 0.5. What is the phase difference between voltage and current the circuit? **Foreign 2016**

KEY Idea

A capacitor permits alternating current (AC) and blocks direct current (DC) flowing through it.

25. Define capacitor reactance. Write its SI unit. **All India 2015**

26. Why is the use of AC voltage preferred over DC voltage? Give two reasons. **All India 2014**

27. When an AC source is connected across an inductor, show on a graph the nature of variation of the voltage and the current over one complete cycle. **Delhi 2012C**

28. The peak value of emf in AC is E_0. Write its (i) rms (ii) average value over a complete cycle. **Foreign 2011**

29. The current flowing through a pure inductance 2mH is, $I = (15 \cos 300t)$ A. What is the (i) rms and (ii) average value of current for a complete cycle? **Foreign 2011**

30. Define the term wattless current. **Delhi 2011**

31. A reactive element in an AC circuit causes the current flowing
(i) to lead in phase by π/2
(ii) to lag in phase by π/2 w.r.t. the applied voltage.
Identify the element in each case. **Delhi 2010C**

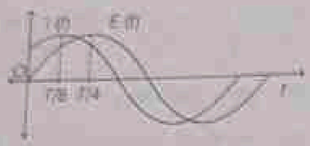
32. Define the term rms value of the current. How is it related to the peak value? **All India 2010C**

2 Marks Questions

33. A resistor R and an inductor L are connected in series to a source of voltage $V = V_0 \sin \omega t$. The voltage is found to lead current in phase by $\frac{\pi}{4}$. If the inductor is replaced by a capacitor C, the voltage lags behind current in phase by $\pi / 4$. When L, C and R are connected in series with the same source. Find the

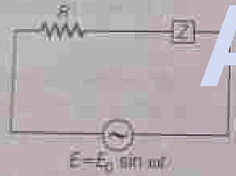
(i) average power dissipated
(ii) and instantaneous current in the circuit. **All India 2020**

34. The figure shows two sinusoidal curves representing oscillating supply voltage and current in an AC circuit. **CBSE SQP 2018-19**



Draw a phasor diagram to represent the current and supply voltage appropriately as phasors. State the phase difference between the two quantities.

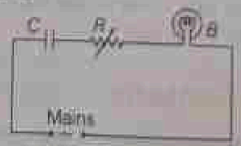
35. An alternating voltage $E = E_0 \sin \omega t$ is applied to a circuit containing a resistor R connected in series with a black box. The current in the circuit is found to be $I = I_0 \sin\left(\omega t + \frac{\pi}{4}\right)$. **CBSE SQP 2017-18**



(i) State whether the element in the black box is a capacitor or inductor.
(ii) Draw the corresponding phasor diagram and find the impedance in terms of R.

36. A capacitor C, a variable resistor R and a bulb B are connected in series to the AC mains in the circuit as shown. The bulb glows with some brightness. How will the glow of the bulb change if

(i) a dielectric slab is introduced between the plates of the capacitor keeping resistance R to be the same
(ii) the resistance R is increased keeping the same capacitance? **Delhi 2014**



37. A series L-C-R circuit is connected to an AC source of variable frequency. Draw a suitable phasor diagram to deduce the expressions for the amplitude of the current and phase angle. **Delhi 2014C**

38. Show that the current leads the voltage in phase by $\pi/2$ in an AC circuit containing an ideal capacitor. **Foreign 2014**

39. In a series L-C-R circuit, obtain the conditions under which
(i) the impedance of circuit is minimum and
(ii) wattless current flows in the circuit. **Foreign 2014**

40. A series L-C-R circuit is connected to an AC source (200 V, 50 Hz). The voltages across the resistor, capacitor and inductor are respectively, 200 V, 250 V and 250 V.
(i) The algebraic sum of the voltages across the three elements is greater than the voltage of the source. How is this paradox resolved?
(ii) Given the value of the resistance of R is 40 Ω, calculate the current in the circuit. **Foreign 2013**

41. A resistor R and an element X are connected in series to an AC source of voltage. The voltage is found to lead the current in phase by $\pi/4$. If X is replaced by another element Y, the voltage lags behind the current by $\pi/4$.
(i) Identify elements X and Y.
(ii) When both X and Y are connected in series with R to the same source, will the power dissipated in the circuit be maximum or minimum?
Justify your answer. **Foreign 2013**

42. Write the expression for the impedance offered by the series combination of resistor, inductor and capacitor connected to an AC source of voltage $V = V_0 \sin \omega t$. Show on a graph the variation of the voltage and the current with ωt in the circuit. **All India 2013C**

43. A bulb is connected in series with a capacitor. Predict your observation when this combination is connected in turn across
(i) AC source and
(ii) a DC battery. What change would your notice in each case if the capacitance of the capacitor is increased? **Delhi 2013C**

44. An alternating voltage given by $V = 140 \sin 314t$ is connected across a pure resistor of 50 Ω. Find
(i) the frequency of the source.
(ii) the rms current through the resistor. **All India 2012**

45. An alternating voltage given by $V = 280 \sin 50 \pi t$ is connected across a pure resistor of 40 Ω. Find
(i) the frequency of the source.
(ii) the rms current through the resistor. **All India 2012**

46. An alternating voltage given by $V = 70 \sin 100\pi t$ is connected across a pure resistor of 25 Ω. Find
(i) the frequency of the source.
(ii) the rms current through the resistor. **All India 2012**

47. A light bulb is rated 150 W for 220 V AC supply of 60 Hz. Calculate
(i) the resistance of the bulb
(ii) the rms current through the bulb. **All India 2012**

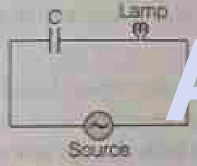
> **KEY Idea**
>
> Average power consumption in an AC calculated by using $P_{av} = V_{rms} I_{rms} \cos\phi$

48. Prove that an ideal capacitor in an AC circuit does not dissipate power. **Delhi 2011**

49. An electric lamp having coil of negligible inductance connected in series with a capacitor and an AC source is glowing with certain brightness.

How does the brightness of the lamp change on reducing the (i) capacitance, and (ii) the frequency ?

Justify your answer.



Delhi 2010

3 Marks Questions

50. A series *RL* circuit with $R = 10\,\Omega$ and $L = \left(\frac{100}{\pi}\right)$ mH is connected to an AC source of voltage, $V = 141 \sin(100\pi t)$, where V is in volts and t is in seconds. Calculate **CBSE 2023**
(i) impedence of the circuit
(ii) phase angle and
(iii) voltage drop across the inductor

51. 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**

52. 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**

53. A resistor of 30 Ω and a capacitor of $\frac{250}{\pi}$ μF are connected in series to a 200 V, 50 Hz AC source. Calculate (i) the current in the circuit and (ii) voltage drops across the resistor and the capacitor. (iii) Is the algebraic sum of these voltages more than the source voltage? If yes, solve the paradox. **CBSE 2023**

54. A series *LCR* circuit with $R = 20\,\Omega$, $L = 2$ H and $C = 50\,\mu$F is connected to a 200 V AC source of variable frequency. What is (i) the amplitude of the current and (ii) the average power transferred to the circuit in one complete cycle, at resonance?
(iii) Calculate the potential drop across the capacitor. **CBSE 2023**

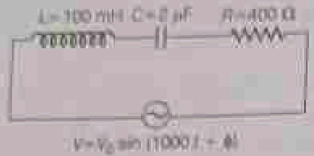
55. The current of 1 A flows through a coil when it is connected across a DC battery of 100 V. If DC battery is replaced by an AC source of 100 V and angular frequency 100 rad s^{-1}, the current reduces to 0.5 A. Find **CBSE 2023**
(i) impedance of the circuit,
(ii) self-inductance of coil and
(iii) phase difference between the voltage and the current.

56. An alternating voltage of 220 V is applied across a device X. A current of 0.22 A flows in the circuit and it lags behind the applied voltage in phase by $\pi/2$ radian. When the same voltage is applied across another device Y. The current in the circuit remains the same and it is in phase with the applied voltage.
(i) Name the devices X and Y and
(ii) calculate the current flowing in the circuit when the same voltage applied across series combination of X and Y. **CBSE 2023**

57. 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**

58. An AC source generating a voltage $E = E_0 \sin \omega t$ is connected to a capacitor C. Find the expression for the current I flowing through it. Plot a graph of E and I versus ωt to show that the current is ahead of the voltage by $\frac{\pi}{2}$. **CBSE SQP 2021-22**

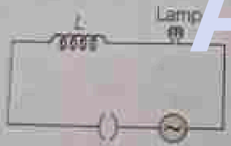
59. (i) Find the value of the phase difference between the current and the voltage in the series *L-C-R* circuit shown below. Which one leads in phase : current or voltage?



(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. **Delhi 2017**

60. (i) When an AC source is connected to an ideal inductor show that the average power supplied by the source over a complete cycle is zero.

(ii) 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.



All India 2016

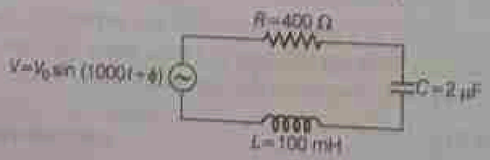
61. A 2 μF capacitor, 100 Ω resistor and 8 H inductor are connected in series with an AC source.

(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 *L-C-R* circuit for two different values of resistance R_1 and R_2 $(R_1 > R_2)$. **Foreign 2016**

62. Calculate the value of the additional capacitor which may be joined suitably to the capacitor *C* that would make the power factor of the circuit unity.



All India 2015

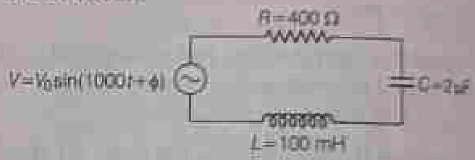
63. A circuit containing an 80 mH inductor and a 250 μF capacitor in series connected to a 240 V, 100 rad/s supply. The resistance of the circuit is negligible.

(i) Obtain rms value of current.

(ii) What is the total average power consumed by the circuit? **Delhi 2014**

64. A source of AC voltage $V = V_0 \sin \omega t$ is connected to a series combination of a resistor *R* and a capacitor *C*. Draw the phasor diagram and use it to obtain the expression for (i) impedance of the circuit and (ii) phase angle. **All India 2014**

65. (i) Determine the value of phase difference between the current and the voltage in the given series *L-C-R* circuit.



(ii) Calculate the value of additional capacitor which may be joined suitably to the capacitor *C* that would make the power factor of the circuit unity. **Delhi 2015**

66. An inductor *L* of inductance X_L is connected in series with a bulb *B* and an AC source. How would brightness of the bulb change when (i) number of turn in the inductor is reduced, (ii) an iron rod is inserted in the inductor and (iii) a capacitor of reactance $X_C = X_L$ is inserted in series in the circuit. Justify your answer in each case. **All India 2015**

67. A voltage $V = V_0 \sin \omega t$ is applied to a series *L-C-R* 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? **All India 2014**

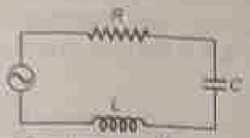
68. (i) For a given AC, $I = I_m \sin \omega t$, show that the average power dissipated in a resistor *R* over a complete cycle is $\frac{1}{2} I_m^2 R$.

(ii) A light bulb is rated at 100 W for a 220 V AC supply. Calculate the resistance of the bulb. **All India 2013**

69. (i) When an AC source is connected to an ideal capacitor, then show that the average power supplied by the source over a complete cycle is zero.

(ii) A lamp is connected in series with a capacitor. Predict your observations when the system is connected first across a DC and then an AC source. What happens in each case if the capacitance of the capacitor is reduced? **Delhi 2013C**

70. The figure shows a series L-C-R circuit with $L = 10$ H, $C = 40\,\mu$F, $R = 60\,\Omega$ connected to a variable frequency 240 V source. Calculate



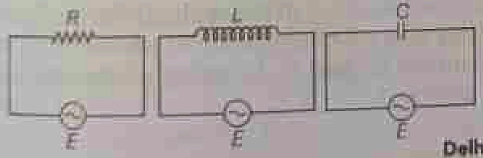
(i) the angular frequency of the source which derives the circuit at resonance.

(ii) the current at the resonating frequency.

(iii) the rms potential drop across the inductor at resonance. **Delhi 2012**

71. A series L-C-R circuit is connected to an AC source. Using the phasor diagram, derive the expression for the impedance of the circuit. Plot a graph to show the variation of current with frequency of the source, explaining the nature of its variation. **All India 2012**

72. Three electrical circuits having AC sources of variable frequency are shown in the figure. Initially the current flowing in each of these is same. If the frequency of the applied AC source is increased, how will the current flowing in these circuits be affected? Give the reason for your answer.



Delhi 2011C

73. A series L-C-R circuit is connected to a 220 V variable frequency AC supply. If $L = 20$ mH, $C = (800/\pi^2)\,\mu$F and $R = 110\,\Omega$.

(i) Find the frequency of the source for which average power absorbed by the circuit is maximum.

(ii) Calculate the value of maximum current amplitude. **Delhi 2010C**

74. An AC voltage $V = V_0 \sin \omega t$ is applied across a pure inductor L. Obtain an expression for the current I in the circuit and hence obtain the

(i) inductive reactance of the circuit and

(ii) the phase of the current flowing with respect to the applied voltage. **All India 2010C**

75. An AC voltage, $V = V_0 \sin \omega t$ is applied across a pure capacitor, C. Obtain an expression for the current I in the circuit and hence obtain the

(i) capacitive reactance of the circuit and

(ii) the phase of the current flowing with respect to the applied voltage. **All India 2010C**

5 Marks Questions

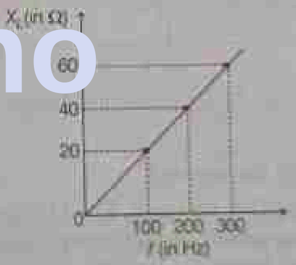
76. (i) Derive the expression for the current flowing in an ideal capacitor and its reactance when connected to an AC source of voltage $V = V_0 \sin \omega t$.

(ii) Draw its phasor diagram.

(iii) If resistance is added in series to capacitor what changes will occur in the current flowing in the circuit and phase angle between voltage and current. **CBSE SQP 2020-21**

77. (i) Show that an ideal inductor does not dissipate power in an AC circuit.

(ii) The variation of inductive reactance (X_L) of an inductor with the frequency (f) of the AC source of 100 V and variable frequency is shown in figure.



(a) Calculate the self-inductance of the inductor.

(b) When this inductor is used in series with a capacitor of unknown value and a resistor of $10\,\Omega$ at $300\ \text{s}^{-1}$, maximum power dissipation occurs in the circuit. Calculate the capacitance of the capacitor. **Delhi 2020**

78. (i) In a series L-C-R 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 L-C-R 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. **Delhi 2019**

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

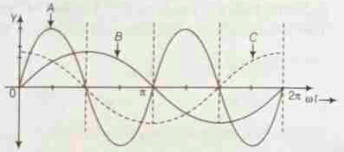
(i) Identify the device X and write the expression for its reactance.

(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**

80. 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 shown 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 the 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. **All India 2017**

81. 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 the condition called? **Delhi 2016**

82. (i) An AC source of voltage $V = V_0 \sin \omega t$ is connected across a series combination of an inductor, a capacitor and resistor. Use the phasor diagram to obtain the expression for

(a) impedance of the circuit and

(b) phase angle between the voltage and the current.

(ii) A capacitor of unknown capacitance, a resistor of 100 Ω and an inductor of self inductance $L = (4/\pi^2)$ henry are in series connected to an AC source of 200 V and 50 Hz. Calculate the value of the capacitance and the current that flows in the circuit when the current is in phase with the voltage. **All India 2013C**

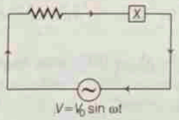
83. Derive an expression for the impedance of a series L-C-R circuit connected to an AC supply of variable frequency. Plot a graph showing variation of current with the frequency of the applied voltage. Explain briefly how the phenomenon of resonance in the circuit can be used in the tuning mechanism of a radio or a TV set. **Delhi 2001**

Explanations

1. (d)

2. (d) Given that, $V = V_0 \sin \omega t$

Instantaneous current,



$$I = I_0 \sin\left(\omega t + \frac{\pi}{4}\right)$$

$$= \frac{\pi}{4}$$

Then, $\tan\frac{\pi}{4} = \frac{X_C}{R} = 1 \Rightarrow X_C = R$

3. (d)

4. (a)

5. (c) Given that,

$$V_0 = 283 \text{ V}$$
$$f = 50 \text{ Hz}$$
$$R = 3\,\Omega$$

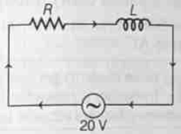
$$L = 25.48 \text{ mH}$$
$$C = 796\,\mu\text{F}$$

Power dissipated, $P = I^2 R$

$$I = \frac{I_0}{\sqrt{2}} = \frac{1}{\sqrt{2}}\left(\frac{V_0}{R}\right) = \frac{1}{\sqrt{2}} \times \frac{283}{3}$$
$$I = 66.7 \text{ A}$$
$$P = I^2 R = (66.7)^2 \times 3$$
$$P = 13.35 \text{ kW}$$

6. (a) Given, $V = 20$ V

$$V_R = 12 \text{ V}$$
$$V_L = ?$$



$$V = \sqrt{V_R^2 + V_L^2}$$
$$= \sqrt{I_{\text{eff}}^2 R^2 + I_{\text{eff}}^2 L^2}$$
$$20 = \sqrt{(12)^2 + V_L^2}$$

Or $(20)^2 = (12)^2 + V_L^2$

$$400 = 144 + V_L^2$$
$$V_L = \sqrt{400 - 144}$$
$$V_L = \sqrt{256} = 16 \text{ V}$$

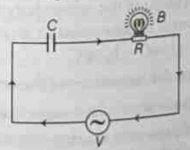
7. (b) Given, $E = E_0 \sin \omega t$

and $I = I_0 \sin\left(\omega t + \frac{\pi}{3}\right)$

Then, current lead the voltage in RC and LC Hence, it can be RC or LCR circuit.

8. (b) For capacitance C, $X_C = \frac{1}{\omega C}$

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



Which means when angular frequency ω increased, then impedance decreases and current increases, thus the bulb will glow brighter.

Concept Enhancer Capacitive reactance is inversely proportional to the angular frequency and capacitance.

9. (a) The value of AC current is

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

$$\Rightarrow \quad I = (I_{\text{rms}} \times \sqrt{2}) \sin\left(2\pi \times 50 \times \frac{1}{600}\right)$$

$$= 15 \times \sqrt{2} \times \sin\frac{\pi}{6} = 15 \times \sqrt{2} \times \frac{1}{2} = \frac{15}{\sqrt{2}} \text{ A}$$

10. (c)

11. (d) The impedance of a series L-C-R circuit is given by

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

12. (d) Given, $E = E_0 \sin \omega t$

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

The phase difference between current and voltage is $\phi = \frac{\pi}{2}$.

∴ Average power dissipated, $P = VI \cos\phi$

$$= V_0 I_0 \cos\frac{\pi}{2} = 0$$

Concept Enhancer The phase difference between the currrent and voltage is π/2, then average power dissipated will be zero.

13. (c) Given, $V_R = 20$ V, $V_L = 15$ V, $V_C = 30$ V

Here, $V_C > V_L$

∴ Resultant voltage in the circuit,

$$V = \sqrt{V_R^2 + (V_C - V_L)^2}$$
$$V = \sqrt{(20)^2 + (30-15)^2} = \sqrt{625} = 25 \text{ V}$$

14. (a)

15. (b) Given, $R = 15\,\Omega$, $L = 80 \text{ mH} = 80 \times 10^{-3}$ H

and $f = 50$ Hz

Since, voltage and current are in phase, so the circuit is in resonance.

∴ Resonant frequency, $f = \frac{1}{2\pi\sqrt{LC}}$

$$\Rightarrow \quad C=\frac{1}{f^2 4\pi^2 L}$$

$$=\frac{1}{(50)^2\times 4\times\pi^2\times 80\times 10^{-3}}=127\,\mu\text{F}$$

16. (b) Given, $R=300\,\Omega, C=\frac{25}{\pi}\,\mu\text{F}=\frac{25}{\pi}\times 10^{-6}\text{ F}$,

$$V=200\text{ V}, f=50\text{ Hz}$$

The capacitive reactance,

$$X_C=\frac{1}{2\pi fC}=\frac{1}{2\pi\times 50\times\frac{25}{\pi}\times 10^{-6}}=400\,\Omega$$

So, impedance of circuit, $Z=\sqrt{R^2+X_C^2}$

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

$$=500\,\Omega$$

Current in circuit, $I=\frac{V}{Z}=\frac{200}{500}=0.4\text{ A}$

17. (a) Power factor of a series L-C-R circuit is given as

$$\cos\phi=\frac{R\text{ (Resistance)}}{Z\text{ (Impedance)}}$$

As, at resonance, $Z=R \Rightarrow \cos\phi=1$

18. (a) Given, alternating current, $I=10\sin 314t$

As we know, $I=I_0\sin\omega t$

$$I_0=10$$

$$\omega=314$$

$$I_{\text{eff}}=\frac{I_0}{\sqrt{2}}=\frac{10}{\sqrt{2}}=7.07\text{ A}$$

Frequency of source, $f=\frac{\omega}{2\pi}=\frac{314\times 7}{2\times 22}$

$$f=\frac{2198}{44}=50\text{ Hz}$$

19. (c) The supply has voltage of $V=V_m\sin\omega t$ and the current through an inductor is

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

Thus, current lags behind the voltage or emf by $\pi/2$, when AC flows through an inductor.

The inductive reactance is directly proportional to the inductance and the frequency of the current as $X_L=\omega L=2\pi\nu L$. So, it increases as the frequency of AC source increases.

20. (a) When the capacitor is connected to an AC source, it limits or regulates the current, but does not completely prevent the flow of charge.

It is because, the capacitor is alternately charged and discharged as the current reverses each half cycle.

21. (a) Capacitive reactance is inversely proportional to frequency as $X_C=\frac{1}{\omega C}=\frac{1}{2\pi fC}$

As, DC does not have any frequency, i.e. $f=0$, hence $X_C=\infty$. So, no DC current flows through capacitor.

But AC varies like a sine function with some frequency, so it passes easily through capacitor. Hence, capacitor serves as a barrier for DC and offers an easy path to AC.

Common Mistake Some students get confused when frequency is related to DC and AC. They think frequency barriers occur in both AC and DC.

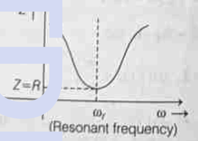
22. (a) At resonance, $X_C=X_L$ and $Z=R$.

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

23. Impedance of a series L-C-R circuit is given as

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

So, the graph between impedance and angular frequency (ω) of the circuit is as shown



24 Given, power factor $\cos\phi=0.5$

$$\cos\phi=\cos 60^\circ \Rightarrow \phi=60^\circ$$

Phase difference between voltage and current of the circuit is 60°.

25. Capacitor reactance is the resistance offered by a capacitor, when it is connected to an AC 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.

The SI unit of capacitor reactance is ohm (Ω).

26. 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.

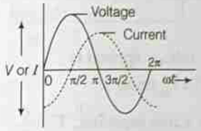
(ii) AC voltage can be stepped up and stepped down as per the requirement by using a transformer.

27. For an AC circuit having inductor, the current and voltage equation are shown below

$$V=V_0\sin\omega t$$

$$I=I_0\sin(\omega t-\pi/2)$$

The graphical variation of voltage and current are given below.



28. E_0 = peak value of emf in a complete cycle,

(i) rms value $(E_{\text{rms}})=E_0/\sqrt{2}$

(ii) average value (E) = zero

29. Given, current flowing through the inductor,

$$I=15\cos 300t$$

Comparing with $I=I_0\sin\omega t$

Here, peak value of current, $I_0=15\text{ A}$

(i) For complete cycle, rms value of current

$$I_{\text{rms}}=\frac{I_0}{\sqrt{2}}=\frac{15}{\sqrt{2}}\text{ A}$$

(ii) For complete cycle, average value of current is zero

i.e. $\quad I_{\text{av}}=0$

30. **Wattless Current** The current in an AC circuit w

average power consumption in AC circuit is zero, referred as wattless current.

31. (i) In case of pure capacitive circuit, the current le

in phase by $\pi/2$ with respect to the applied vol

So, the element will be a capacitor.

(ii) In case of pure inductive circuit, the current lag

phase by $\pi/2$ with respect to the applied voltag

So, the element will be an inductor.

32. It is defined as the value of Alternating Current (A

over a complete cycle which would generate same

amount of heat in a given resistor that is generated

dy current in the same resistor and in the same time during a complete cycle.It is also called virtual value or effective value of AC.

Let the peak value of the current be I_0

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

where, I_0 = peak value of AC.

Given, instantaneous voltage,

$$V=V_0\sin\omega t$$

As in both cases, the voltage and current differ by a phase of $\frac{\pi}{4}$. So, $\phi=\frac{\pi}{4}$.

(i) Average power dissipated,

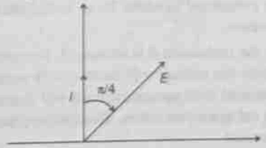
$$P_{\text{av}}=V_{\text{rms}}I_{\text{rms}}\cos\phi$$

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

$$=\frac{V_0I_0}{2}\cos\frac{\pi}{4}=\frac{V_0I_0}{2\sqrt{2}}$$

(ii) As R, L and C are in series, therefore at any instant through the three elements, AC has the same amplitude and phase, i.e. instantaneous current, $I=I_0\sin\omega t$.

Phasor diagram of given waveform.



The phase difference between the two quantities will given as equal length of phasors current leads voltage phase difference is $\frac{\pi}{4}$.

Given, alternating voltage, $E=E_0\sin\omega t$

Current in the circuit,

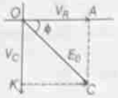
$$I=I_0\sin\left(\omega t+\frac{\pi}{4}\right)$$

(i) $E=E_0\sin\omega t$

$$I=I_0\sin\left(\omega t+\frac{\pi}{4}\right)$$

Current is leading by $\frac{\pi}{4}$. Hence, box must be the capacitor.

(ii) Phasor diagram,



$$\tan\phi = \frac{AK}{OA} = \frac{OC}{OA} = \frac{V_C}{V_R} = \frac{-I_0 X_C}{I_0 R} = \frac{-X_C}{R}$$

From diagram,

$$OK^2 = OA^2 + AK^2$$

$$= \sqrt{OA^2 + OC^2} = \sqrt{(I_0 R)^2 + (-I_0 X_C)^2}$$

than, $E_0 = I_0\sqrt{R^2 + X_C^2}$

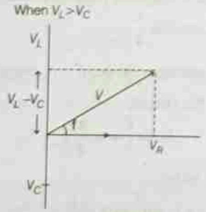
impedance, $Z = \sqrt{R^2 + X_C^2}$

$\therefore \qquad Z = \frac{E_0}{I_0}$

36. (i) As, the dielectric slab is introduced between the plates of the capacitor, its capacitance will increase. Hence, the potential drop across the capacitor will decrease, i.e. $V = \frac{Q}{C}$. As a result, the potential drop across the bulb will increase as they are connected in series. Thus, its brightness will increase.

(ii) As the resistance R is increased, the potential drop across the resistor will increase. As a result, the potential drop across the bulb will decrease as they are connected in series. Thus, its brightness will decrease.

37. (i) Phasor diagram for L-C-R series circuit is given as



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

$$\Rightarrow \qquad IZ = \sqrt{(IR)^2 + I^2(X_L - X_C)^2}$$

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

$\therefore$ Amplitude of current,

$$I_0 = \frac{V_0}{Z} = \frac{V\sqrt{2}}{Z}$$

$$I_0 = \frac{\sqrt{2[R^2 + (X_L - X_C)^2]}}{\sqrt{R^2 + (X_L - X_C)^2}}$$

From figure, $\tan\phi$

$$= \frac{V_L - V_C}{V_R} = \frac{IX_L - IX_C}{IR} = \frac{X_L - X_C}{R}$$

38. Let us consider a capacitor C connected to an AC source as shown below

Let the AC voltage applied is

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

and voltage across capacitor, $V = \frac{q}{C}$

Applying Kirchhoff's loop rule, we have

$$V_m \sin\omega t = \frac{q}{C} \Rightarrow q = CV_m \sin\omega t$$

Also, $\qquad I = \frac{dq}{dt}$

$$\Rightarrow \qquad \frac{d}{dt} C(V_m \sin\omega t)$$

$$I = \omega V_m \cos\omega t \qquad \text{...(i)}$$

We know that, $\cos\omega t = \sin(\omega t + \pi/2)$ ...(ii)

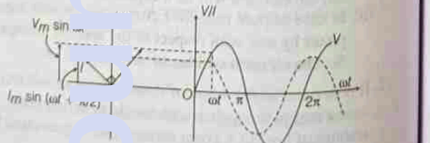
In the circuit.

$$V_m \quad I_m X_C = V_m \frac{1}{\omega C} \Rightarrow I_m = V_m \omega C \qquad \text{...(iii)}$$

Substituting the values of Eqs. (ii) and (iii) in Eq. (i), we get

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

The phasor diagram which shows the current lead the voltage in phase by 90° is given below



39. (i) The impedance of a series L-C-R circuit is give

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

Z will be minimum, when $\omega L = 1/\omega C$, i.e. wher circuit is under resonance. Hence, in this condi Z will be minimum and equal to R.

(ii) Average power dissipated through a series L-C circuit is given by

$$P_{av} = E_V I_V \cos\phi$$

where, E_V = rms value of alternating voltage

I_V = rms value of alternating current

and $\qquad \phi$ = phase difference between current and voltage

For wattless current, the power dissipated thro the circuit should be zero.

i.e. $\qquad \cos\phi = 0$

$$\Rightarrow \qquad \cos\phi = \cos\frac{\pi}{2}$$

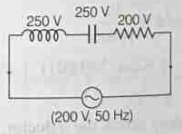
$$\Rightarrow \qquad \phi = \frac{\pi}{2}$$

Hence, the condition for wattless current is tha circuit is purely inductive or purely capacitive which the voltage and current differ by a phas angle of $\frac{\pi}{2}$, i.e. $\phi = \pm\frac{\pi}{2}$

40. (i) From given parameter, $V_R = 200\,\text{V}, V_L = 250\,\text{V}$ and $V_C = 250$ V. V_{eff} should be given as

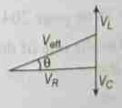
$$V_{\text{eff}} = V_R + V_L + V_C$$

$$= 200\,\text{V} + 250\,\text{V} + 250\,\text{V} = 700\,\text{V}$$



However, $V_{\text{eff}} > 200$ V of the AC source. This paradox can be solved only by using phasor diagram, as given below

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



Since, $V_L = V_C$

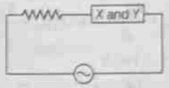
So, $\quad V_{\text{eff}} = V_R = 200\,\text{V}$

(ii) Given, $R = 40\,\Omega$, so current in the L-C-R circuit.

$$I_{\text{eff}} = \frac{V_{\text{eff}}}{R} = \frac{200}{40} = 5\,\text{A} \quad [X_L = X_C \text{ or } Z = R]$$

(i) In R-L series combination, voltage leads the current by phase $\phi = \frac{\pi}{4}$. It means element X is an inductor (with reactance equal to R). In R-C series combination, voltage lags behind the current by phase $\phi = \frac{\pi}{4}$. So, element Y is a capacitor (with reactance equal to R).

(ii) If both elements X and Y are connected in series with R, then power dissipation in the combination can be given as



$$P = V_{\text{rms}} \cdot I_{\text{rms}} \cdot \cos\phi$$

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

Here, $X_L = X_C = R$. So, $\cos\phi = 1$

Hence, $P = V_{\text{rms}} I_{\text{rms}}$ (Maximum)

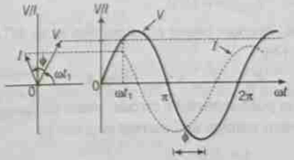
Impedance offered by series L-C-R circuit,

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

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

As, V_C and V_L are the voltages applied across capacitor C and inductor L. V_C or V_L may be greater than V.

The situation may be shown in figure, where $V_C > V$.



(i) We know that, capacitive reactance

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

On increasing capacitance, X_C will decrease and hence current will increase, therefore brightness of bulb will increase. As capacitance increases, capacitive reactance $(X_C = 1/\omega C)$ decreases, impedance Z decreases, hence current increases i.e. brightness of bulb will increase.

(ii) For DC source, frequency, $f = 0$.

$\therefore X_C$ becomes infinite, So, there will no flow of current and hence, bulb will not glow.

44. Given, $V = 140 \sin 314t$, $R = 50\,\Omega$

Comparing it with $V = V_0 \sin \omega t$

(i) Here, $\omega = 314$ rad/s

i.e. $2\pi f = 314$ $[\because \omega = 2\pi f]$

$\Rightarrow$ $f = 314/2\pi$

$$f = \frac{314}{2 \times 3.14} = 50\text{ Hz}$$

Frequency of AC, $\nu = 50$ Hz

(ii) As, $I_{\text{rms}} = \frac{V_{\text{rms}}}{R}$ and $V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$

Here, $V_0 = 140$ V

$$V_{\text{rms}} = \frac{140}{\sqrt{2}} \times \frac{\sqrt{2}}{\sqrt{2}} = 70\sqrt{2}\text{ V}$$

$$\therefore \quad I_{\text{rms}} = \frac{70\sqrt{2}}{R} = \frac{70\sqrt{2}}{50} = 1.9\text{ A or } 2\text{ A}$$

45. Refer to Sol. 44 on page 206. (25 Hz, 4.95 A)

46. Refer to Sol. 44 on page 206. (50 Hz, 1.98 A)

47. (i) $P = 150$ W, $V = 220$ V

Resistance of the bulb, $R = \frac{V^2}{P}$

$$R = \frac{220 \times 220}{150} = 322.7\,\Omega$$

(ii) As, $I_{\text{rms}} = \frac{V_{\text{rms}}}{R} = \frac{220}{322.7}$ $(V_{\text{rms}} = V = 220\text{ V})$

$\Rightarrow$ $I_{\text{rms}} = 0.68$ A

48. Since, average power consumption in an AC circuit is given by

$$P_{\text{av}} = V_{\text{rms}} \times I_{\text{rms}} \times \cos\phi$$

But in pure capacitive circuit, phase difference between voltage and current is given by

$$\phi = \pi/2$$

$$\therefore \quad P_{\text{av}} = V_{\text{rms}} \times I_{\text{rms}} \times \cos\frac{\pi}{2}$$

$$\Rightarrow \quad P_{\text{av}} = 0 \qquad \left(\because \cos\frac{\pi}{2} = 0\right)$$

Thus, no power is consumed in pure capacitive AC circuit.

49. When AC source is connected, the capacitor offers capacitive reactance $X_C = \frac{1}{\omega C} = \frac{1}{2\pi\nu C}$. The current flows in the circuit and the lamp glows.

(i) On reducing capacitance C, X_C increases so current in the circuit reduces. Therefore, the brightness of the bulb reduces.

(ii) On reducing frequency ν, X_C increases so current in the circuit reduces. Therefore, the brightness of the bulb reduces.

50. Given that, $R = 10\,\Omega$

$$L = \left(\frac{100}{\pi}\right)\text{mH}$$

Voltage, $V = 141 \sin (100\pi t)$

As we know, $V = V_0 \sin \omega t$

$$\omega = 100\,\pi$$

(i) Impedence,

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

$$\because X_L = 2\pi f \times L, \quad X_L = \omega_L$$

$$Z = \sqrt{(10)^2 + (100\pi)^2 \times \left(\frac{100}{\pi}\right)^2}$$

$$Z = \sqrt{(10)^2 + (100)^2 \times (100)^2}$$

$$Z = 10000\,\Omega$$

(ii) Phase angle ϕ,

$$\tan\phi = \frac{X_L}{R} \text{ or } \cos\phi = \frac{R}{Z}$$

$$\cos\phi = \frac{10}{10000}$$

$$\phi = \cos^{-1}(0.001)$$

$$\phi = 90°$$

(iii) Voltage drop across the inductor,

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

$$V_{\text{rms}} = \frac{141}{\sqrt{2}} = \frac{141}{1.41} = 100\text{ V}$$

51. Refer to solution 38 on page 204.

52. Power is defined as the rate of doing work.

$$P = \frac{dW}{dt} \quad \text{...(i)}$$

or Power is defined as the product of voltage and current

In AC circuit, both emf and current change continuously with respect to time. So, in it calculate average power in complete cycle

Instantaneous power, $P = EI$

$[\because E = E_0 \sin \omega t, I = I$

Here, E and I are instantaneous voltage an respectively. If the instantaneous power re constant for a small time dt, then small am work done in maintaining the current for a dt is

$$\frac{dW}{dt} = EI$$

$$\Rightarrow \quad dW = EI\,dt$$

Integrating Eq. (iii) on both sides, we get

$$\int dW = \int_0^T EI\,dt$$

Total work done or energy spent in mainta current over one full cycle,

$$W = \int_0^T E_0 \sin\omega t \cdot I_0 \sin(\omega t + \phi)dt$$

$$= E_0 I_0 \int_0^T \sin\omega t(\sin\omega t\cos\phi + \cos$$

$$= E_0 I_0 \Big[\cos\phi \int_0^T \sin^2\omega t\,dt$$

$$+ \sin\phi \int_0^T \sin$$

$$= E_0 I_0 \left[\cos\phi \int_0^T \left(\frac{1 - \cos 2\omega t}{2}\right)dt\right.$$

$$+ \frac{\sin\phi}{2}\int_0^T 2\sin$$

$$= \frac{E_0 I_0}{2}\left[\cos\phi\left(\int_0^T dt - \int_0^T \cos 2\omega t\right.\right.$$

$$+ \sin\phi \int_0^T$$

$$= \frac{E_0 I_0}{2}\left[\left(\cos\phi\,[t]_0^T - \int_0^T \cos 2\omega t\,dt\right.\right.$$

$$+ \sin\phi \int$$

But $\int_0^T \cos 2\omega t\,dt = 0$ or and

$$\int_0^T \sin 2\omega t\,dt = 0$$

$$\therefore \quad W = \frac{E_0 I_0 T}{2}\cos\phi$$

Average power associated in AC circuit,

$$P_{av} = \frac{W}{T} = \frac{E_0 I_0 T\cos\phi}{2T} = \frac{E_0 I_0}{2}\cos\phi$$

$$P_{av} = \frac{E_0}{\sqrt{2}} \cdot \frac{I_0}{\sqrt{2}}\cos\phi$$

or $$P_{av} = E_{\text{rms}} I_{\text{rms}} \cos\phi$$

$$= E_V I_V \cos\phi$$

Refer to text on page 191.

53. Given that, resistance, $R = 30\,\Omega$

Capacitor, $C = \frac{250}{\pi}\,\mu\text{F} = \frac{250}{\pi} \times 10^{-6}$ F

$$F = 50\text{ Hz}, V = 200\text{ V}$$

Capacitance of reactance,

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 50 \times \frac{250}{\pi} \times 10^{-6}}$$

$$X_C = 40\,\Omega$$

(i) Current in the circuit,

$$I_{\text{rms}} = \frac{V}{\sqrt{R^2 + X_C^2}} = \frac{200}{\sqrt{(30)^2 + (40)^2}}$$

$$I_{\text{rms}} = \frac{200}{\sqrt{900 + 1600}} = \frac{200}{50}$$

$$I_{\text{rms}} = 4\text{ A}$$

(ii) Voltage across resistor and capacitor,

$$V_R = I \times R = 4 \times 30 = 120\text{ V}$$

Capacitor voltage,

$$V_C = I \times X_C = 4 \times 40 = 160\text{ V}$$

$$V_T = V_R + V_C$$

$$= 120 + 160 = 280\text{ V}$$

(iii) However, $V_{\text{eff}} > 200$ V of the AC source. This paradox can be solved only by using phasor diagram.

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

$$= \sqrt{(120)^2 + (160)^2} = \sqrt{40000}$$

$$V = 200\text{ V}$$

54. At resonance, the frequency of the supply power equals the natural frequency of the given LCR circuit.

$R = 20\,\Omega$, $L = 2$ H

$C = 50\,\mu F = 50\times 10^{-6}\ F = 5\times 10^{-5}\ F$

AC supply voltage to the *LCR*, $V = 200$ V

Impedance of the circuit,

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

At resonance, $X_L = X_C$

$\therefore \quad Z = R = 20\,\Omega$

(i) Current in the circuit,

$$I = \frac{V}{Z} = \frac{200}{20} = 10\text{ A}$$

(ii) Average power transferred to the circuit in one complete cycle

$$P = VI = 200\times 10 \Rightarrow 2000\text{ W}$$

(iii) Potential drop across the capacitor

Frequency, $\nu = \frac{1}{2\pi\sqrt{LC}}$

$$\nu = 0.00159\text{ Hz}$$

$$V_C = I_{\text{rms}}\times X_C = 10\times 0199$$

$$V_C = 199\text{ V}$$

55. Given that,

Current $(I) = 1\text{A}, V = 100$ V

AC source = 100 V

Angular frequency, $\omega = 100$ rad/s

Current reduced = 0.5 A

Ohmic resistance, $R = \frac{V}{I} = \frac{100}{1} = 100\,\Omega$

(i) Impedance of coil,

$$Z_C = \frac{V_{\text{rms}}}{I_{\text{rms}}} = \frac{100}{0.5} = 200\,\Omega$$

Impedance of circuit, $Z^2 = R^2 + X_L^2$

$$X_L = \sqrt{Z^2 - R^2}$$

$$X_L = \sqrt{(200)^2 - (100)^1} = 173.2\,\Omega$$

(ii) Self-inductance of coil,

$$L = \frac{X_L}{2\pi f} = \frac{173.2}{2\times 3.14\times 100}$$

$$L = 0.275\text{ H}$$

(iii) Phase difference between voltage and current,

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

$$\phi = \tan^{-1}\left(\frac{173.2}{100}\right)$$

$$\phi = \tan^{-1}(1.732)$$

$$\phi = 60^\circ$$

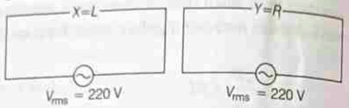
56. Given, voltage $(V) = 220$ V

Current $(I) = 22$ A

(i) *X* device is a inductor.

Y device is a resistance.

(ii)



Resistance, $R = \frac{V_{\text{rms}}}{I_{\text{rms}}} = \frac{220}{22} = 10\,\Omega$

We know, $R = X_L = 10\,\Omega$

When inductor and resistance are in the series, then

Current flowing, $I_{\text{rms}} = \frac{V_{\text{rms}}}{Z}$

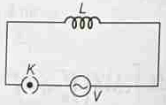
$$I_{\text{rms}} = \frac{V_{\text{rms}}}{\sqrt{R^2 + X_L^2}}$$

$$I_{\text{rms}} = \frac{220}{\sqrt{200}} = \frac{220}{14.14}$$

$$I_{\text{rms}} = 15.55\text{ A}$$

57. Suppo[illegible]ductor with self-inductance (*L*) is conne[illegible] an AC source with instantaneous emf (*V*), which is given by

$$V = V_0 \sin\omega t \qquad \text{...(i)}$$



Whe[illegible] closed, then current *I* begins to grow beca se [illegible] ic flux linked with it changes and induc[illegible] produces which opposes the applied emf. Acco[illegible]ling to Lenz's law,

$$e = -L\frac{dI}{dt} \qquad \text{...(i)}$$

where, *e* is induced emf and $\frac{dI}{dt}$ is the rate of change of current.

To m[illegible] the flow of current in the circuit, applie[illegible]ge must be equal and opposite to the indu[illegible]d emf [illegible]e.

$$V = -e$$

$$\therefore \quad V = -\left(-\frac{LdI}{dt}\right) = \frac{LdI}{dt} \quad \text{or} \quad dI = \frac{V}{L}dt$$

[f

Integrating the above equation on both side

$$\int dI = \int \frac{V}{L}dt$$

$$\Rightarrow \quad I = \int \frac{V_0 \sin\omega t}{L}dt \qquad [\because V$$

$$\Rightarrow \quad I = \frac{V_0}{L}\left[\frac{-\cos\omega t}{\omega}\right]$$

$$\Rightarrow \quad I = -\frac{V_0}{\omega L}\sin(\pi/2 - \omega t) \quad \left[\because \sin\left(\frac{\pi}{2} - \omega t\right.\right.$$

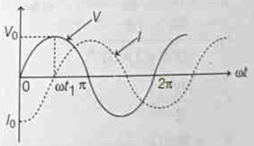
$$\Rightarrow \quad I = \frac{V_0}{\omega L}\sin(\omega t - \pi/2)$$

If $\sin(\omega t - \pi/2) = \text{maximum} = 1$, then $I = I_0$

where, peak value of current, $I_0 = \frac{V_0}{\omega L}$

$$\therefore \quad I = I_0 \sin(\omega t - \pi/2)$$

From Eqs. (i) and (iii), it is clear that in a pu inductor, the current lags behind the voltage phase angle of $\pi/2$ radians (90°) or the volta the current by a phase angle of $\pi/2$ radians



58. Refer to sol. 38 on page 204.

59. Given, $L = 100\text{ mH} = 100\times 10^{-3}\text{H}$,

$C = 2\,\mu F = 2\times 10^{-6}\ F, \quad \omega = 1000$ rad/s and

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

[where, ϕ is phase difference between cur voltage]

$$\omega L = 1000\times 100\times 10^{-3} = 100\,\Omega$$

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

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

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

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

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

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

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

where, C_1 is the total capacitance.

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

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

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

Additional capacitance C' required in parallel

$$= C_1 - C \Rightarrow 10\,\mu F - 2\,\mu F = 8\,\mu F\ )$$

60. (i) As, $P_{av} = V_{\text{rms}} I_{\text{rms}} \cos\phi$

In ideal inductor, current I_{rms} lags behind applied voltage V_{rms} by $\pi/2$.

$\therefore \quad \phi = \pi/2$

so, $\quad P_{av} = V_{\text{rms}} I_{\text{rms}} \cos\pi/2$

or $\quad P_{av} = V_{\text{rms}} I_{\text{rms}} \times 0$

or $\quad P_{av} = 0$

(ii) Brightness of the lamp decreases. It is because when iron rod is inserted inside the inductor, its inductance *L* increases, thereby its inductive reactance X_L will also increase and hence, impedance *Z* of the circuit will increase.

As, $I_{\text{rms}} = V_{\text{rms}}/Z$, so this decreases the current I_{rms} in the circuit and hence, the brightness of lamp will decrease.

Concept Enhancer The average value of sin ωt, cos ωt, sin 2ωt, cos 2ωt, etc., is zero because it is positive in first half of the cycle and negative in rest half of cycle.

61. (i) To draw maximum current from a series *L-C-R* circuit, the circuit at particular frequency

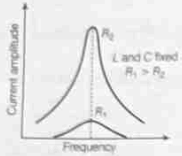
$X_L = X_C$.

$$\nu = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\times 3.14\sqrt{8\times 2\times 10^{-6}}} = 39.80\text{ Hz}$$

This frequency is known as the series resonance frequency.

(ii) $I_0 = \frac{V}{R} = \frac{200}{100} = 2\text{ A}$

(iii)



62. For unity power factor,

$$X_L = X_C$$
$$\omega L = 1/\omega C'$$

where, $C' = C + C''$

$$C' = \frac{1}{\omega^2 L} = \frac{1}{(1000)^2 \times 100 \times 10^{-3}}$$
$$= 10^{-5}\text{ F} = 10\ \mu\text{F}$$

As $\quad C' = C + C''$

$$C'' = C' - C = 10 - 2 = 8\mu\text{F}$$

So, required capacitor is 8 μF which is added in parallel with the given capacitor.

63. (i) Here, $L = 80\text{ mH}, C = 250\text{ mF}, \omega = 100\text{ rad/s}$

$$V_{\text{rms}} = 240\text{ V}$$

Impedance, $Z = |X_L - X_C| = \left|\omega L - \frac{1}{\omega C}\right|$

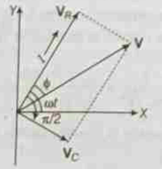
$$= \left|100 \times 80 \times 10^{-3} - \frac{1}{100 \times 250 \times 10^{-3}}\right|$$
$$= \left|8 - \frac{1}{25}\right| = 7.96$$
$$I_{\text{rms}} = \frac{V_{\text{rms}}}{\text{Reactance}} = \frac{240}{7.96} = 30.15\text{ A}$$

(ii) For L-C circuit, phase difference is $\frac{\pi}{2}$. Hence, the total average power consumed by circuit is zero.

64. (i) Applied AC voltage, $V = V_0 \sin \omega t$ ...(i)

Phasor diagram for given R-C circuit is shown.

From diagram, by parallelogram law of vector addition, $\mathbf{V}_R + \mathbf{V}_C = \mathbf{V}$



Using pythagoras theorem, we get

$$V^2 = V_R^2 + V_C^2 = (IR)^2 + (IX_C)^2$$
$$\Rightarrow \quad V^2 = I^2(R^2 + X_C^2)$$
$$I = V/\sqrt{R^2 + X_C^2} = V/Z$$

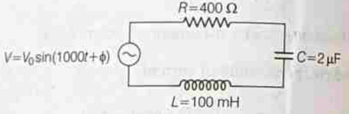
where, $Z = \sqrt{R^2 + X_C^2} = \sqrt{R^2 + 1/\omega^2 C^2}$

(ii) The phase angle φ between resultant voltage and current is given by

$$\tan\phi = \frac{V_C}{V_R} = \frac{IX_C}{IR} = \frac{X_C}{R} = \frac{1/\omega C}{R} = \frac{1}{\omega RC}$$

Common Mistake Sometimes students may think, that we can write $V_R = IR$, $(V_0)_R = I_0 R$, $(V_0)_L = I_0 X_L$ and $(V_0)_C = I_0 X_C$ but cannot write (for instantaneous voltages).

65. (i) Given, figure



Given,

$$V = V_0 \sin(1000t + \phi) \Rightarrow \omega = 1000\text{ Hz}$$
$$R = 400\Omega, C = 2\ \mu\text{F}, L = 100\text{ mH}$$

∴ Capacitive reactance, $X_C = \frac{1}{\omega C}$

$$\Rightarrow \quad X_C = \frac{1}{1000 \times 2 \times 10^{-6}}$$
$$\Rightarrow \quad X_C = \frac{10^3}{2}$$
$$\Rightarrow \quad X_C = 500\Omega$$

Inductive reactance, $X_L = \omega L$

$$\Rightarrow \quad X_L = 1000 \times 100 \times 10^{-3} \Rightarrow X_L = 100\Omega$$

So, we can see that $X_C > X_L$

Phase difference, $\tan\phi = \frac{X_L - X_C}{R}$

$$\tan\phi = \frac{100 - 500}{400} \Rightarrow \tan\phi = \frac{-400}{400} \Rightarrow \tan\phi = -1$$
$$\tan\phi = -\tan\left(\frac{\pi}{4}\right) \Rightarrow \phi = -\frac{\pi}{4}$$

⇒ tan φ is negative.

Hence, the voltage lags behind the current by a phase angle φ. The AC circuit is capacitance dominated circuit.

This is the required value of the phase between the current and the voltage in series L-C-R circuit.

(ii) Suppose, new capacitance of the circu

Thus, to have power factor unity

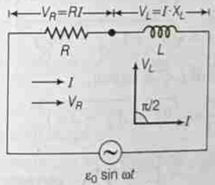
$$\cos\phi' = 1 = \frac{R}{\sqrt{R^2 + (X_L - X_C')^2}}$$
$$\Rightarrow R^2 = R^2 + (X_L - X_C')^2$$
$$\Rightarrow X_L = X_C' \quad \text{or} \quad \omega L = \frac{1}{\omega C'}$$
$$\Rightarrow \omega^2 = \frac{1}{LC'} \quad \text{or} \quad (1000)^2 = \frac{1}{LC'} (\because$$
$$\Rightarrow C' = \frac{1}{L \times 10^6} = \frac{1}{100 \times 10^{-3} \times 10^6}$$
$$= \frac{10}{10^6} = \frac{1}{10^5} = 10^{-5}$$
$$\Rightarrow C' = 10^{-5}\text{ F} = 10 \times 10^{-6}\text{ F} = 10\mu\text{F}$$

As, $C' > C$. Hence, we have to add an a capacitor of capacitance 8 μF (10μF−2 parallel with previous capacitor.

66. The inductive reactance $(X_L)\omega L$

where, ω = angular frequency of AC sourc

and $\quad L$ = inductance of the inductor.



Series L-R circuit

The net resistance of the circuit is given by

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

where, R = resistance of the bulb.

(i) We know that, if the number of turns in inductor decreases, then inductance L d So, the net resistance of the circuit decre the current through the circuit increases, the brightness of the bulb.

(ii) If the soft iron rod is inserted in the indu the inductance L increases. Therefore, th through the bulb will decrease, decreasin brightness of the bulb.

$$I_{\text{rms}} = \frac{\varepsilon_{\text{rms}}}{X_L}$$

(iii) If the capacitor of reactance, $X_C = X_L$ is connected in series with the circuit, then

$$Z = \sqrt{(X_L - X_C)^2 + R^2}$$
$$\Rightarrow \quad Z = R \qquad [\because X_L = X_C]$$

This is a case of resonance. In this case, the maximum current will flow through the circuit. Hence, the brightness of the bulb will increase to maximum.

67. Refer to Sol. 52 on pages 206 and 207.

(i) If $\phi = 90°$, then no power is dissipated even though the current flows through the circuit.

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

This current is called wattless current. The resistance of the circuit is zero which is shown below.

$$\because \quad \tan\phi = \left(\frac{X_L - X_C}{R}\right)$$
$$\Rightarrow \quad \tan\phi = \frac{\omega L - 1/\omega C}{R} = \infty \quad (\because \tan 90° = \infty)$$
$$\Rightarrow \quad R = 0$$

(ii) If $\phi = 0°$, then maximum power is dissipated in the circuit.

$$P_{\text{av}} = \text{maximum}$$
$$\tan\phi = \frac{X_L - X_C}{R} = 0 \qquad (\because \tan 0° = 0)$$
$$\Rightarrow \quad X_L = X_C \qquad \text{(Resonance)}$$

68. (i) The average power dissipated,

$$\overline{P} = (I^2 R) = (I_m^2 R \sin^2 \omega t) = I_m^2 R (\sin^2 \omega t)$$
$$\therefore (\sin^2 \omega t) = \frac{1}{2}[1 - (\cos 2\omega t)] = \frac{1}{2}$$
$$(\because \cos 2\omega t = 0)$$
$$\therefore \quad \overline{P} = \frac{1}{2} I_m^2 R$$

(ii) Power of the bulb, $P = 100\text{ W}$ and voltage,

$$V = 220\text{ V}$$

The resistance of the bulb is given as

$$R = \frac{V^2}{P} = \frac{(220)^2}{100} = 484\,\Omega$$

69. (i) When a source of AC is connected to a capacitor of capacitance C_1, the charge on it grows from zero to maximum steady value Q_0.

The energy stored in a capacitor is, $\quad E = \frac{1}{2} CV_0^{\ 2}$

where, V_0 is maximum potential difference across the plates of the capacitor.

The alternating voltage applied is

$$V = V_0 \sin \omega t$$

and the current leads the emf by a phase angle of $\pi/2$.

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

$\therefore$ Work done over a complete cycle is

$$W = \int_0^T VI dt = \int_0^T (V_0 \sin \omega t)(I_0 \cos \omega t)\, dt$$

$$= \frac{V_0 I_0}{2} \int_0^T 2 \sin \omega t \cos \omega t \, dt$$

$$W = \frac{V_0 I_0}{2} \int_0^T \sin 2\,\omega\, t\, dt$$

$$W = \frac{V_0 I_0}{2} \left[-\frac{\cos 2\omega t}{2\omega} \right]_0^T = 0$$

$$\therefore \quad P_{av} = \frac{W}{T} = 0$$

(ii) When DC source is connected, the condenser is charged but no current flows in the circuit. Therefore, the lamp does not glow. No change occurs even when capacitance of capacitor is reduced.

When AC source is connected, the capacitor offers capacitive reactance $X_C = 1/\omega C$. The current flows in the circuit and the lamp glows. On reducing C_1, X_C increases. Therefore, the glowing of the bulb reduces.

70. Given, $L = 10\,\text{H}, C = 40\,\mu\text{F}$,
$R = 60\,\Omega, V_{\text{rms}} = 240\,\text{V}$

(i) Resonating angular frequency,

$$\omega_r = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{10 \times 40 \times 10^{-6}}}$$

$$\omega_r = \frac{1}{20 \times 10^{-3}} = 50 \text{ rad/s}$$

(ii) Current at resonating frequency,

$$I_{\text{rms}} = \frac{V_{\text{rms}}}{Z} = \frac{V_{\text{rms}}}{R} \quad (\because \text{At resonance}, Z = R)$$

$$= 240 / 60 = 4 \text{ A}$$

(iii) Inductive reactance, $X_L = \omega L$

At resonance, $X_L = \omega_r L = 50 \times 10 = 500\,\Omega$

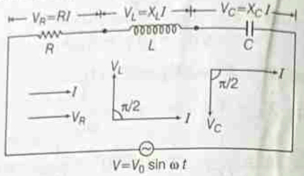
Potential drop across to inductor,

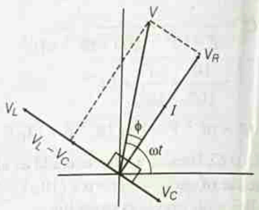
$$V_{\text{rms}} = I_{\text{rms}} \times X_L = 4 \times 500 = 2000 \text{ V}$$

71. 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 difference across L, C and R respectively.





But, $\quad V_R = IR, V_L = IX_L$,

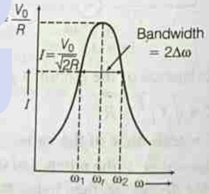
$$V_C = IX_C$$

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

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

Impedance [illegible] L-C-R circuit,

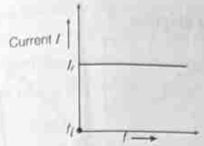
$$Z = \frac{V}{I} = \sqrt{R^2 + (X_L - X_C)^2}$$



Common Mistake In phase diagram, we represent alternating voltage and current as rotating vectors, but these quantities are scalar quantities, not vector themselves.

72. Let initially I, current is flowing in all the three circuits. If frequency of applied AC source is increased, then the change in current will occur in the following manner.

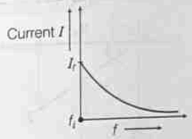
(i) **Circuit containing resistance R only** T not be any effect in the current on chang frequency of AC source.



where, f_i = initial frequency of AC sou
There is no effect on current with the in
frequency.

(ii) **AC circuit containing inductance onl** increase of frequency of AC source in reactance increase as $I = \frac{V_{\text{rms}}}{X_L} = \frac{V_{\text{rms}}}{2\pi f L}$

For given circuit, $I \propto 1/f$



Current decreases with the increase of

(iii) **AC circuit containing capacitor only**

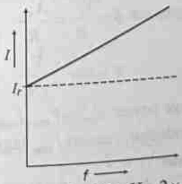
$$X_C = 1/\omega C = 1/2\pi f C$$

Current, $I = V_{\text{rms}} / X_C = V_{\text{rms}} / \frac{1}{2\pi f C}$

$$I = 2\pi f C V_{\text{rms}}$$

For given circuit, $I \propto f$

Current increases with the increase of



73. Given, $V_{\text{rms}} = 220\,\text{V}, L = 20\,\text{mH} = 2 \times 10^{-2}$

$$R = 110\,\Omega,$$

$$C = \frac{800}{\pi^2}\,\mu\text{F} = \frac{800}{\pi^2} \times 10^{-6}\,\text{F}$$

(i) Average power observed by L-C-R se circuit is maximum when circuit is in r

$\therefore$ Resonant frequency,

$$\omega_r = \frac{1}{\sqrt{LC}} \Rightarrow \nu_0 = \frac{1}{2\pi\sqrt{LC}}$$

$$= \frac{1}{2\pi\sqrt{2 \times 10^{-2} \times \frac{800}{\pi^2} \times 10^{-6}}}$$

$$\nu_0 = \frac{1000}{2 \times 4} = 125\,\text{s}^{-1}$$

$$\nu_0 = 125\,\text{s}^{-1}$$

(ii) As, $I_{\text{rms}} = \frac{V_{\text{rms}}}{Z} = \frac{220}{110} = 2\,\text{A}$

$\because \quad Z = R = 110\,\Omega$

$\therefore$ Maximum current amplitude,

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

74. The rate of change of flux will give the value of emf.

(i) Let an alternating voltage, $V = V_0 \sin \omega t$ is applied across pure inductor of inductance L. The magnitude of induced emf is given by $e = L\, dI / dt$

For the circuit,

Magnitude of induced emf = Applied voltage

i.e. $\quad L\frac{dI}{dt} = V_0 \sin \omega t$

or $\quad dI = \frac{V_0}{L} \sin \omega t \, dt$

On integrating both sides, we get

$$I = \frac{V_0}{L}\int \sin \omega t \, dt$$

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

or $\quad I = -\frac{V_0}{\omega L} \cos \omega t$

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

$\therefore \quad I = \frac{V_0}{X_L} \sin\left(\omega t - \frac{\pi}{2}\right) \quad \text{...(i)}$

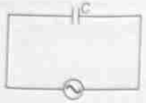
$\because \quad \frac{V_0}{\omega L} = I_0$ = peak value of AC

$$I = I_0 \sin\left(\omega t - \frac{\pi}{2}\right) \quad \text{...(ii)}$$

$\therefore$ Inductive reactance, $X_L = \omega L \quad$ ...(iii)

(ii) From Eqs. (ii) and (iii), it is clear that current lags behind the voltage by phase $\pi/2$.

75. (i) Let alternating voltage, $V = V_0 \sin \omega t$ is applied across a capacitor C. At any instant, the potential difference across the capacitor is equal to applied voltage.



$$V = V_0 \sin \omega t \quad \text{...(i)}$$

$\therefore V$ = Potential difference across the capacitor

$$= \frac{q}{C}$$

$\Rightarrow \quad q = CV \quad$ or $\quad q = CV_0 \sin \omega t$

$\therefore \quad \frac{dq}{dt} = \omega C V_0 \cos \omega t$

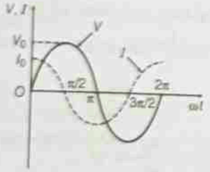
or $\quad I = \frac{V_0}{(1/\omega C)} \cos \omega t$

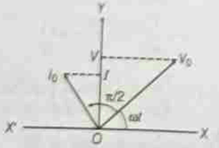
or $\quad I = I_0 \sin\left(\omega t + \frac{\pi}{2}\right) \quad$ ...(ii)

where, $I_0 = \frac{V_0}{(1/\omega C)} = \frac{V_0}{X_C}$

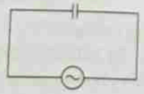
Capacitive reactance, $X_C = \frac{1}{\omega C}$

(ii) From Eqs. (i) and (ii), current leads the voltage by phase $\pi/2$.





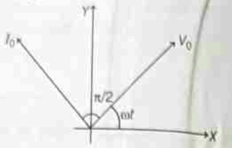
76. (i) Refer to sol. 75(i) on page 214.



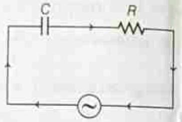
(ii) As, $V = V_0 \sin \omega t$

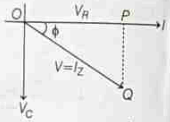
then $I = I_0 \sin\left(\omega t + \frac{\pi}{2}\right)$

Phasor diagram



(iii) If resistance is added in series to capacitor. The vector sum of two voltage drop is equal to applied voltage.





$$V_R = I \times R$$
$$V_C = I \times X_C$$

In ΔOPQ,

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

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

Current $I = \frac{V}{\sqrt{R^2 + X_C^2}}$

Phase angle, $\tan \phi = \frac{V_C}{R} = \frac{X_C}{R}$

$$\phi = \tan^{-1} \frac{X_C}{R}$$

77. (i) [illegible], average power, $P_{av} = V_{rms} I_{rms} \cos \phi$

In ideal inductor, current I_{rms} lags behind applied voltage V_{rms} by $\pi/2$.

i.e. $\quad \phi = \pi/2$

$$P_{av} = V_{rms} I_{ms} \cos \pi/2$$
$$P_{av} = V_{ms} I_{ms} \times 0$$

or $\quad P_{av} = 0$

Thus, an ideal inductor does not dissipate power in [illegible] circuit.

(ii) (a) As we know,

Inductive reactance, $X_L = (2\pi f)L$

where, L is the self-inductance of the indu

Since, the above equation is in the form, y

where, $\quad y = X_L, x = f$ and $m = 2\pi L$.

So, from the given graph, we get

Slope of the X_L *versus* f graph,

$$m = \frac{\Delta y}{\Delta x}$$
$$= \frac{(60-40)}{(300-200)} = \frac{20}{100} = 0.2$$

$\Rightarrow \quad m = 2\pi L = 0.2$

or $\quad L = \frac{0.2}{2\pi} = 0.0318 \text{ H}$

(b) Let the capacitance of a capacitor be C.

Since, the given circuit will become a s

L-C-R circuit. So, its power dissipation

maximum, if $\phi = 0$.

$\Rightarrow \quad \tan \phi = \frac{\omega L - 1/\omega C}{R} = 0 \quad$ [∵tan 0

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

$\Rightarrow \quad C = \frac{1}{\omega^2 L} = \frac{1}{(2\pi f)^2 L}$

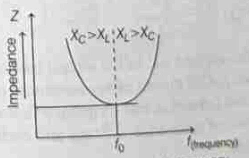
Given, $\quad f = 300 \text{ s}^{-1}$

Substituting the values of f and L in t

equation, we get

$$C = \frac{1}{(2\pi \times 300)^2 \times 0.0318}$$
$$= 8.859 \times 10^{-6} \text{ F} = 8.86 \mu\text{F}$$

78. (i) Refer to Sol. 71 on page 212.



Variation of impedance with frequency

(ii) At resonance, $X_L = X_C$,

At resonance, voltage across inductor i

voltage across capacitor in magnitude

both are in opposite polarities.

Hence, phase difference between V_L ar

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 impedence increases and hence value of current decreases.

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

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

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

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

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

$\Rightarrow \quad L^2 = \sqrt{12}$

or $\quad L = 1.101 \text{ H}$

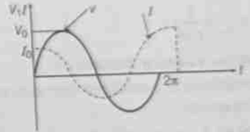
79. (i) Given, $V = V_0 \sin \omega t$

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

As it is clear that, the current leads the voltage by a phase angle $\frac{\pi}{2}$.

∴ The device X is a capacitor.

(ii)



(iii) The reactance of the capacitance is given as

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

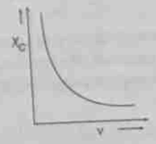
where, ω = angular frequency

and $\quad C$ = capacitance of capacitor.

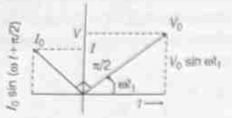
$\therefore \quad X_C = \frac{1}{2\pi \nu C}$

where, ν = frequency of AC or $X_C \propto \frac{1}{\nu}$

∴The graphical representation between reactance of capacitance and frequency is given as



(iv) **Phasor diagram**



80. (i) Device X is a capacitor.
As, the current is leading voltage by $\pi/2$ rad.

(ii) Curve A represents power,
Curve B represents voltage and
Curve C represents current.

As, $V = V_0 \sin \omega t$

Current, $I = I_0 \cos \omega t$

As, in the case of capacitor,

$I = I_0 \sin\left(\omega t + \frac{\pi}{2}\right)$ [current is leading voltage]

Average power,

$$P = V_{\text{rms}} \times I_{\text{rms}} \times \cos\phi = \frac{V_0 \cos\phi}{2}$$

where, ϕ = phase difference

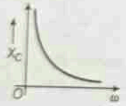
(iii) As, X_C = capacitive reactance

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

where, ω is angular frequency.

So, reactance or impedance decreases with increase in frequency.

Graph of X_C *versus* ω is shown below,



(iv) For a capacitor fed with an AC supply

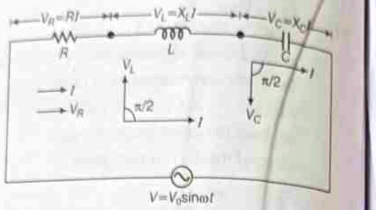
$$V = \frac{q}{C}$$

or $q = CV = CV_0 \sin \omega t$

$\therefore$ $I = \frac{dq}{dt} = \frac{V_0}{X_C} \sin\left(\omega t + \frac{\pi}{2}\right)$

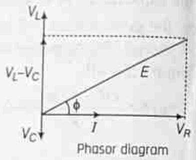
81. If I is the current in the circuit containing inductor of inductance L, capacitor of capacitance C and resistor of resistance R in series, then the voltage drop across the inductor is

$$V_L = I \times X_L$$



which leads current I by phase angle of $\pi/2$, and voltage drop across the capacitor is $V_2 = I \times X_C$.

which lags behind current I by phase angle of $\pi/2$, and voltage drop across the resistor is $V_R = IR$ which is in phase with current I. So, the net voltage E across the circuit is (using phasor diagram)



Phasor diagram

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

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

where, $Z = \sqrt{R^2 + (X_L - X_C)^2}$ is known as impedance. Phase angle between voltage and current is given by $\tan\phi = \frac{V_L - V_C}{V_R} = \frac{X_L - X_C}{R}$.

A series L-C-R circuit has its natural angular frequency, $\omega = \frac{1}{\sqrt{LC}}$ and natural (resonating) frequency, $\nu = \frac{1}{\sqrt{LC}}$.

When the applied AC in the circuit has this frequency, the series L-C-R circuit offers minimum impedance i.e. only R and current at this frequency flows maximum. In the case of resonance, voltage and current are in same phase.

Above mentioned condition is known as condition of resonance. In this condition

(i) Inductive and capacitive reactances are equal

$$X_L = X_C$$

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

$$\Rightarrow \quad \omega = \frac{1}{\sqrt{LC}} \qquad [\because \omega = 2\pi$$

$$\Rightarrow \quad \nu = \frac{1}{2\pi\sqrt{LC}}$$

(ii) Potential drop across inductor and capacitor are equal, $V_L = V_C$

Concept Enhancer At resonance, the potential difference across inductor and capacitor are equal and 180° out of phase. Therefore, cancel out. Hence, applied emf is merel overcome the resistance opposition only.

82. (i) Refer to Sol. 81 on pages 216 and 217.

(ii) $L = \frac{4}{\pi^2}$ H, $\nu = 50$ Hz, $R = 100\Omega$, $V = 200$ V

$$X_L = X_C \text{ or } \omega L = 1/\omega C$$

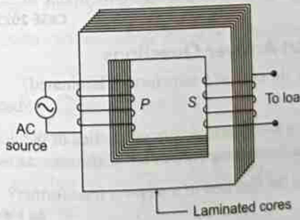
$$C = \frac{1}{\omega^2 L} = \frac{1}{4\pi^2\nu^2 \times L} = \frac{1}{4\pi^2 \times 50 \times 50 \times \frac{4}{\pi^2}}$$

TOPIC 2

AC Devices

Transformer

It is a device which converts high voltage AC into low voltage AC and *vice-versa*. It is based upon the princi mutual induction. When a variable current is passed thr one of the two inductively coupled coils, an induced em set up in other coil.



Working

When an alternating current is passed through the pri coil, the magnetic flux through the iron core changes which does two things, produces emf in the primary and an induced emf is set up in the secondary coil . I assume that the resistance of primary coil is negligib then the back emf will be equal to the voltage applie the primary coil.

$$= \frac{1}{2500 \times 16} = \frac{1}{40000}$$

$$= 2.5 \times 10^{-5} \text{ F} = 25 \,\mu\text{F}$$

$$I = \frac{V}{Z} = \frac{V}{R} = \frac{200}{100} = 2 \text{ A}$$

efer to Sol. 71 on page 212.

he receiving antenna picks up the frequencies ransmitted by different stations and a number of oltage appears in L-C-R circuit corresponding to ifferent frequencies. But maximum current flows in ircuit for that AC voltage which have got the frequency is equal to resonant frequency of circuit

i.e. $\nu = \frac{1}{2\pi\sqrt{LC}}$

For higher quality factor resonance, the signal received from other stations becomes weak due to sharpness of resonance. Thus, signal of desired frequency or program is tunned in.

$$\boxed{V_1 = -N_1 \frac{d\phi}{dt}} \quad \text{and} \quad \boxed{V_2 = -N_2 \frac{d\phi}{dt}}$$

ere, N_1 and N_2 are number of turns in the primary and secondary coil respectively, while V_1 and V_2 are their tages, respectively.

$$\frac{\text{Output emf}}{\text{Input emf}} = \frac{V_2}{V_1} = \frac{N_2}{N_1}$$

ergy Losses in a Transformer

ere are some energy losses in a transforms

(i) **Eddy Current Loss** Eddy current in iron core of transformer facilitate the loss of energy in the form of heat.

ii) **Flux Leakage** Total fluxes linked with primary do not completely pass through the secondary which denotes the loss in the flux or flux leakage.

iii) **Copper Loss** Due to heating, energy loss takes place in copper wires of primary and secondary coils.

iv) **Hysteresis Loss** The energy loss takes place in magnetising and demagnetising the iron core over every cycle.

(v) **Humming Loss** The magnetostriction effect leads to set the core in vibration which in turn produced the sound and we know that sound is also a form of energy. This loss is referred as humming loss. The humming can reduce the mechanical strength of the transformer.

Types of Transformer

There are two types of transformers which are given as below

(i) **Step-up transformer** ($N_2 > N_1$) It converts low alternating voltage into high alternating voltage.

(ii) **Step-down transformer** ($N_2 < N_1$)

It converts high alternating voltage into low alternating voltage.

Important Points Related to Transformer

- For an ideal transformer,
  Input power = Output power

$$V_1 I_1 = V_2 I_2$$

$$\Rightarrow \quad V_1 / V_2 = I_2 / I_1$$

- Transformation ratio (r)

$$\boxed{r = N_S / N_P = V_S / V_P = I_P / I_S}$$

where, N_P and N_S are the number of turns in primary and secondary coils. V_P and V_S are alternative voltage in primary and secondary coils.
I_P and I_S are current in primary and secondary coils.

- Long distance power transmission takes place at high alternating voltage so as to minimise losses in the form of heat, therefore, step-up transformers are used at power stations and step-down transformers at receiving ends.
- Efficiency of transformer,

$$\boxed{\eta = \frac{\text{Output power}}{\text{Input power}} \times 100}$$

PYQs Previous Years Questions

1 Mark Questions

Multiple Choice Questions

1. The core of a transformer is laminated to reduce the effect of **CBSE 2022 (Term-II)**
   (a) flux leakage (b) copper loss
   (c) hysteresis loss (d) eddy current

2. Which among the following, is not a cause for power loss in a transformer
   (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. **CBSE SQP 2021-22**

Assertion-Reason Questions

Direction (Q. No. 3) *In the following question, two statements are given- one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to this question from the codes (a), (b), (c) and (d) as given below.*

(a) If both Assertion and Reason are correct and Reason is the correct explanation of Assertion.
(b) If both Assertion and Reason are correct but Reason is not the correct explanation of Assertion.
(c) If Assertion is correct but Reason is incorrect.
(d) If both Assertion and Reason are incorrect.

3. **Assertion** A step-up transformer cannot be used as a step-down transformer.
   Reason A transformer works only in one direction.
   CBSE 2022 (Term-I)

Very Short Answer Questions

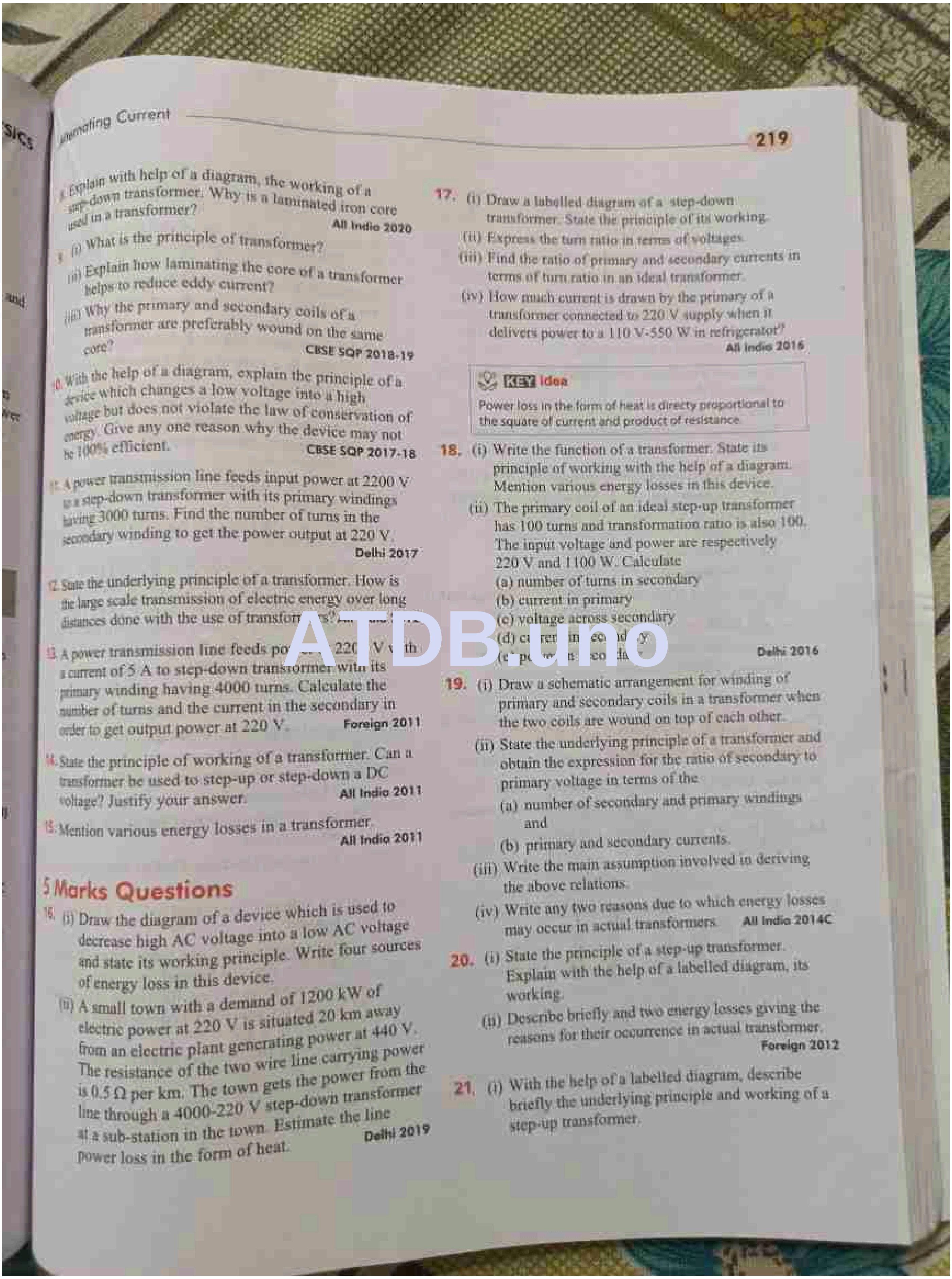
4. Why is the core of a transformer laminated? **Delhi 2013C**

5. Mention two characteristic properties of the material suitable for making core of a transformer. **All India 2012**

6. What is the function of a step-up transformer? **All India 2011C**

2 Marks Questions

7. The primary coil having N_P turns of an ideal transformer is supplied with alternating voltage V_P. Obtain an expression for the voltage V_s induced in its secondary coil having N_s turns. Mention two main sources of power loss in real transformers. **CBSE 2023**



8. Explain with help of a diagram, the working of a step-down transformer. Why is a laminated iron core used in a transformer?
All India 2020

9. (i) What is the principle of transformer?
(ii) Explain how laminating the core of a transformer helps to reduce eddy current?
(iii) Why the primary and secondary coils of a transformer are preferably wound on the same core?
CBSE SQP 2018-19

10. With the help of a diagram, explain the principle of a device which changes a low voltage into a high voltage but does not violate the law of conservation of energy. Give any one reason why the device may not be 100% efficient.
CBSE SQP 2017-18

11. 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.
Delhi 2017

12. State the underlying principle of a transformer. How is the large scale transmission of electric energy over long distances done with the use of transformers? [illegible]

13. A power transmission line feeds [illegible] 220 V with a current of 5 A to step-down transformer with its primary winding having 4000 turns. Calculate the number of turns and the current in the secondary in order to get output power at 220 V.
Foreign 2011

14. State the principle of working of a transformer. Can a transformer be used to step-up or step-down a DC voltage? Justify your answer.
All India 2011

15. Mention various energy losses in a transformer.
All India 2011

5 Marks Questions

16. (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 loss 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 wire line carrying power is 0.5 Ω 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.
Delhi 2019

17. (i) Draw a labelled diagram of a step-down transformer. State the principle of its working.
(ii) Express the turn ratio in terms of voltages.
(iii) Find the ratio of primary and secondary currents in terms of turn ratio in an ideal transformer.
(iv) How much current is drawn by the primary of a transformer connected to 220 V supply when it delivers power to a 110 V-550 W in refrigerator?
All India 2016

KEY Idea

Power loss in the form of heat is directy proportional to the square of current and product of resistance.

18. (i) Write the function of a transformer. State its principle of working with the help of a diagram. Mention various energy losses in this device.
(ii) The primary coil of an ideal step-up transformer has 100 turns and transformation ratio is also 100. The input voltage and power are respectively 220 V and 1100 W. Calculate
(a) number of turns in secondary
(b) current in primary
(c) voltage across secondary
(d) current in secondary
(e) power in secondary
Delhi 2016

19. (i) Draw a schematic arrangement for winding of primary and secondary coils in a transformer when the two coils are wound on top of each other.
(ii) State the underlying principle of a transformer and obtain the expression for the ratio of secondary to primary voltage in terms of the
(a) number of secondary and primary windings and
(b) primary and secondary currents.
(iii) Write the main assumption involved in deriving the above relations.
(iv) Write any two reasons due to which energy losses may occur in actual transformers.
All India 2014C

20. (i) State the principle of a step-up transformer. Explain with the help of a labelled diagram, its working.
(ii) Describe briefly and two energy losses giving the reasons for their occurrence in actual transformer.
Foreign 2012

21. (i) With the help of a labelled diagram, describe briefly the underlying principle and working of a step-up transformer.

(ii) Write any two sources of energy loss in a transformer.

(iii) A step-up transformer converts a low input voltage into a high output voltage. Does it violate law of conservation of energy? Explain. **Delhi 2011**

22. 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 relation related to the currents in the two coils.

How is the transformer used in large scale transmission and distribution of electrical energy over the long distances? **All India 2010**

23. A step-up down transformer operated on a 2.5 kV line. It supplies a load with 20 A. The ratio of the primary winding to the secondary is 10 : 1. If the transformer is 90% efficient, calculate

(i) the power output

(ii) the voltage and

(iii) the current in the secondary. **Foreign 2010**

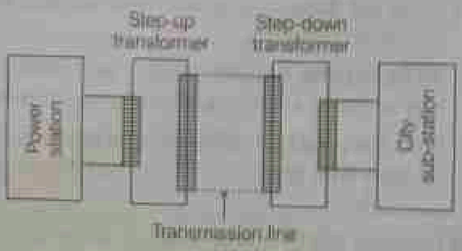
KEY idea

Percentage efficiency of transfomer is determine by using, $\frac{\text{Output power}}{\text{Input power}} \times 100$

Case Based Question (4 Marks) (For Complete Chapter)

Direction (Q.No. 24) *This question is Case Study based question. Read the following paragraph and answer the questions.*

24. Read the following paragraph and answers the questions



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. There 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-

(i) Which of the following statement is true? [1]
  (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

(ii) If the secondary coil has a greater number of turns than the primary [1]
  (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

(iii) We need to step-up the voltage for power transmission, so that [1]
  (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

(iv) 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 [1]
  (a) 4 (b) 40 (c) 400 (d) 4000

Explanations

1. (d) The core of a transformer is laminated to reduce the effect of eddy currents. These are the current produced in metal parts due to changing magnetic field.

2. (d) In transformer, primary coil is made up of a very thick copper wire due to which primary coil has very low resistivity. Therefore, power low is negligible.

3. (d) A transformer works in both direction. So, a step-up transformer can be used as a step-down transformer by connecting input to secondary windings and taking output from primary windings.

4. The core of transformer is laminated to reduce the energy losses due to eddy currents, for increasing the efficiency.

5. The characteristic properties of the material suitable for making core of a transformer are as follow
   (i) Low retentivity or coercivity.
   (ii) Low hysteresis loss or high permeability and susceptibility.

6. Step-up transformer converts low alternating voltage into high alternating voltage. The secondary coil of step-up transformer has a greater number of turns than the primary coil ($N_s > N_p$).

7. We consider an ideal transformer in which the primary coil has negligible resistance and all the flux in the core links both primary and secondary windings. Let ϕ be the flux in each turn in the core at time t due to current in the primary when a voltage V_p is applied to it.

Then, the induced emf or voltage E_s, in the secondary with N_s turns is

$$E_s = -N_s \frac{d\phi}{dt} \quad \text{...(i)}$$

The alternating flux ϕ also induces an emf, called back emf in the primary. This is

$$E_p = -N_p \frac{d\phi}{dt} \quad \text{...(ii)}$$

But $E_p = V_p$. If this was not, so the primary current would be infinite, since the primary has zero resistance (as considered). If the secondary is an open circuit or the current taken from it is small, then to a good approximation.

$$E_s = V_s$$

where, V_s is the voltage across the secondary.

Therefore, Eqs. (i) and (ii) can be written as

$$V_s = -N_s \frac{d\phi}{dt} \quad \text{...(iii)}$$

and $$V_p = -N_p \frac{d\phi}{dt} \quad \text{...(iv)}$$

From Eqs. (iii) and (iv), we have

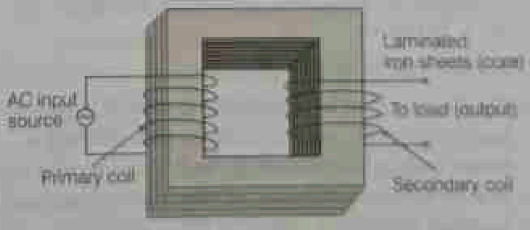
$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

Two main sources of power loss in real transformers.

(i) **Flux leakage** There is always some leakage of flux that is not all of the flux due to primary passes through the secondary. This is due to poor design of the core or the air gaps in the core. It can be reduced by winding the primary and secondary coils one over the other.

(ii) **Resistance of the windings** The wire used for the windings has some resistance and so, energy is also lost due to heat produced in the wire (I^2R). In high current, low voltage windings, energy losses are minimised by using thick wire.

8. Step-down transformer convert high voltage (low current) into low voltage (high current). It works on the principle of mutual induction. It is shown below.



Step-down transformer

In step-down transformer, number of turns in secondary coil is less than number of turns in primary coil, hence voltage induced in secondary coil is less than voltage given to primary coil.

Core to transformer is laminated to reduce eddy current and thus, increase efficiency.

9. (i) **Principle of transformer** A transformer is based on the principle of mutual induction, i.e. whenever the amount of magnetic flux linked with a coil changes, an emf is induced in the neighbouring coil. This changing flux sets up an induced emf in the secondary coil, also self induced emf in primary coil.

(ii) The alternating magnetic flux induces eddy currents in the iron core and cause heating. The effect is reduced by having a laminated core.

(iii) For maximum sharing of magnetic flux and magnetic flux per turn to be the same in both primary and secondary coils of a transformer and preferably wound on the same core .

10. Refer to text on pages 217 and 218 (Transformer).

A transformer is not 100% efficient as all the electrical energy in the primary coil is not transferred to the secondary coil. Some of it lost due to resistance in the winding and also due to magnetic effect.

11. Given, input power $(V_p) = 2200$ V

Number of turns $(N_p) = 3000$

Output power $(V_s) = 220$ V

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

$$\Rightarrow \quad \frac{220}{2200} = \frac{N_s}{3000}$$

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

$\therefore$ Number of turns in the secondary winding,
$N_s = 300$ turns.

12. Refer to Sol. 9 (i) on page 222.

Electric power is transmitted over long distances at high voltage. So, step-up transformers are used at power stations to increase the voltage whereas a series of step-down transformers at customer end are used to decrease the voltage upto 220 V.

13. $V_p = 2200$ V, $I_p = 5$ A, $N_p = 4000$

$V_s = 220$ V, $N_s = ?\, I_s = ?$

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

$$\frac{220}{2200} = \frac{5}{I_s} = \frac{N_s}{4000}$$

$$\frac{220}{2200} = \frac{5}{I_s}$$

$$\Rightarrow \quad \frac{1}{10} = \frac{5}{I_s}$$

$$\Rightarrow \quad I_s = 50 \text{ A}$$

$$\frac{5}{I_s} = \frac{N_s}{4000}$$

$$\Rightarrow \quad \frac{5}{50} = \frac{N_s}{4000} \Rightarrow N_s = 400$$

14. Refer to Sol. 9 (i) on page 222 (For principle of working of transformer).

No, transformer cannot be used to change DC voltage because DC voltage is constant and cannot change flux linked with primary or secondary coils. Due to low resistance of primary winding, a heavy DC current will flow through it, causing overheating in winding and finally transformer will burn.

15. For energy losses in transformer are

(i) Eddy current loss	(ii) Flux leakage
(iii) Copper loss	(iv) Hysteresis loss
(v) Humming loss	

16. (i) Refer to text on pages 217 and 218 (Transformer)

(ii) Given, power = 1200 kW,

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

$V_p = 4000, V_s = 220$ V, distance = 20 km

Power $= I_p V_p$

$1200 \times 1000 = I_p \times 4000 \Rightarrow I_p = 300$ A

Power loss $= (I_p)^2 \times R$ (2 lines)

$$= (300)^2 \times 0.5 \times 20 \times 2$$

$$= 18 \times 10^5 \text{ W}$$

17. (i) Refer to Sol. 8 on page 221.

(ii) $\varepsilon_s / \varepsilon_p = N_s / N_p$

(iii) For an ideal transformer, $P_{\text{in}} = P_{\text{out}}$

$$\varepsilon_p I_p = \varepsilon_s I_s$$

$$\Rightarrow \quad I_p / I_s = \varepsilon_s / \varepsilon_p = N_s / N_p$$

(iv) $P_{\text{in}} = P_{\text{out}} = 550$ W

$$\Rightarrow \quad \varepsilon_p I_p = 550$$

$$220 \times I_p = 550$$

$$\Rightarrow \quad I_p = 550/220 = 5/2 = 2.5 \text{ A}$$

18. (i) Transformer is a device which converts high voltage AC into low voltage AC and *vice-versa*. Refer to text on page 217. (For working principle & diagram)

There are number of energy losses in a transformer.

(a) **Copper losses** due to Joule's heating produced across the resistances of primary and secondary coils. It can be reduced by using copper wires.

(b) **Hysteresis losses** due to repeated magnetisation and demagnetization of the core of transformer. It is minimised by using soft iron core, as area of hysteresis loop for soft iron is small and hence energy loss also becomes small.

(c) **Iron losses** due to eddy currents produced in soft iron core. It is minimised by using laminated iron core.

(d) **Flux losses** due to flux leakage or incomplete flux linkage and can be minimised by proper coupling of primary and secondary coils.

(ii) Here, $N_p = 100$, $N_s / N_p = 100$

$\varepsilon_p = 220$ V, $P_{in} = 1100$ W

(a) $N_p = 100$

$\therefore N_s = 10000$

(b) $I_p = P_{in} / \varepsilon_p$

$= 1100/220 = 5$ A

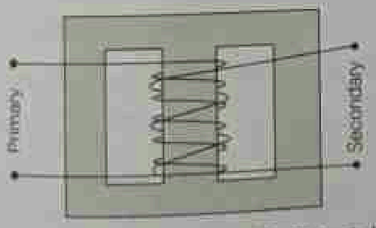
(c) $\varepsilon_s = N_s / N_p \times \varepsilon_p$

$= 100 \times 220 = 22000$ V

(d) $I_s = \frac{P_{out}}{\varepsilon_s} = \frac{1100}{22000} = \frac{1}{20}$ A $(\because P_{out} = P_{in})$

(e) $P_s = P_{out} = P_{in} = 1100$ W

(i) The schematic arrangement of a transformer is shown as below



(ii) Refer to Sol. 9 (i) on page 222 (Principle of transformer).

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

(a) $\therefore \quad V_1 = -N_1 \frac{d\phi}{dt}$

and $V_2 = -N_2 \frac{d\phi}{dt}$

where, N_1 and N_2 are number of turns in the primary and the secondary coils respectively while V_1 and V_2 are their voltages respectively.

(b) But for ideal transformers, $V_1 I_1 = V_2 I_2$

$V_1 / V_2 = I_2 / I_1$

(iii) **Main assumptions**

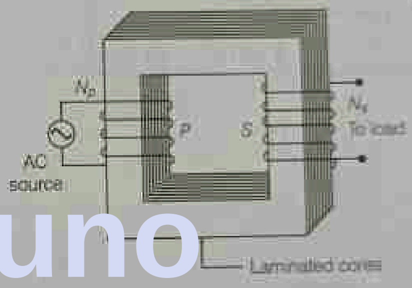
(a) The primary resistance and current are small.

(b) The flux linked with primary and secondary coil is same. There is no leakage of flux from the core.

(c) secondary current is small.

(iv) Refer to text on pages 217 and 218. (Energy losses in a transformer)

20. (i)



$N_s > N_p$

Refer to text on pages 217 and 218 (Transformer).

(ii) Refer to Sol. 18 (i) on pages 222 and 223.

21. (i) Refer to text on pages 217 and 218 (Transformer).

(ii) Refer to text on pages 217 and 218 (Energy losses in a transformer).

(iii) No, it does not violate the law of conservation of energy because voltage increase is accompanied by decrease in current.

In step-up transformer the current decreases by the same proportion as the voltage increases. When voltage increases n times, the current reduce $1/n$ times.

22. Refer to text on pages 217 and 218 (Transformer).

Step-up transformers are used at generating stations so as to transmit the power at high voltage to minimise the loss in the form of heat, whereas series of step-down transformers are used at receiving ends.

23. Given, input voltages, $V_p = 2.5 \times 10^3$ V

Input current, $I_p = 20$ A

Also, $N_p / N_s = 10/1$

$\Rightarrow$ $N_s / N_p = 1/10$ ...(i)

Percentage efficiency $= \frac{\text{Output power}}{\text{Input power}} \times 100$

$$\Rightarrow \quad \frac{90}{100} = \frac{\text{Output power}}{V_p \, I_p}$$

(i) Output power $= \frac{90}{100} \times (V_p \, I_p)$

$$= \frac{90}{100} \times 2.5 \times 10^3 \times 20 = 4.5 \times 10^4 \text{ W}$$

(ii) $V_s / V_p = N_s / N_p$

$\Rightarrow$ $V_s = N_s / N_p \times V_p$

Voltage, $V_s = \frac{1}{10} \times 2.5 \times 10^3 =$ 2[illegible]0 V

(iii) $V_s I_s = 4.5 \times 10^4$ W

Current, $I_s = \frac{4.5 \times 10^4}{V_s} = \frac{4.5 \times 10^4}{250}$

$\Rightarrow$ $I_s = 180$ A

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

(ii) (a) The voltage is stepped-up and arrangement called a step-up transformer.

i.e. $\frac{N_s}{N_p} = \frac{E_s}{E_p}$

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

(iv) (c) Given, power input,

$$= 2300 \text{ W}$$

Turns, $N = 400$

Output power $= 230$ W

As we know,

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

$$\Rightarrow \quad N_2 = \frac{400 \times 230}{2300}$$

$$N_2 = 400$$