# 7 ALTERNATING CURRENT

## Topic-1 Alternating Current

**Concepts covered:** Alternating current, peak and rms value, reactance and impedance

## Revision Notes

- An alternating current is a current whose magnitude changes continuously with time and direction reverses periodically.
- It is represented by sine curve or cosine curve
  $I = I_0 \sin \omega t$ or $I = I_0 \cos \omega t$,
  where, I is the instantaneous value of the current and $I_0$ is the peak value of the current.
- Frequency ($f$) of an alternating current is the number of cycles which get completed per second.

  i.e.,
  $$f = \frac{\omega}{2\pi}$$
- Average value of A.C. is defined as that value of direct current which sends the same charge in a circuit at the same time as it sent by the given alternating current in its half-time period.
  $$I_{av} = \frac{2I_0}{\pi} = 0.637\, I_0$$
- Root mean square or virtual or effective value of a.c. is defined as that value of a direct current which produces the same heating effect in a given resistor as is produced by the given alternating current when passed for the same time.
  $$I_{rms} = \frac{I_0}{\sqrt{2}} = 0.707 I_0$$
- Impedance is a quantity that measures the opposition of a circuit to the flow of current through it.
- $I_{rms}$ = 70.71% of $I_0$.
- $E_{rms}$ = 70.71% of $E_0$
- $I_{av}$ = 63.66% of $I_0$.
- $E_{av}$ = 63.66% of $E_0$
- The part of the impedance in which the phase difference between the current and emf is $\pi/2$ is called reactance.
- If the current lags behind emf by $\pi/2$, then the reactance is called inductive.
- If the emf lags behind the current by $\pi/2$, then the reactance is called capacitive.
- If the emf is in phase with the current, then the circuit is called resistive.
- Hot wire ammeter and voltmeters can be used both in a.c. as well as d.c. circuits.
- The non-sinusoidal complex waveform of an a.c. is obtained when a number of harmonic superpose on one another.

## Key Formulae

- $I_{av} = \frac{2I_0}{\pi} = 0.637 I_0$
- $I_{rms} = \frac{I_0}{\sqrt{2}}$
- $I_{rms}$ = 70.71% of $I_0$.

- $E_{rms}$ = 70.71% of $E_0$
- $I_{av}$ = 63.66% of $I_0$.
- $E_{av}$ = 63.66% of $E_0$
- Average power = $\frac{1}{2}E_0I_0\cos\phi = E_{rms}I_{rms}\cos\phi$
- Inductive reactance, $X_L = \omega L$
- Capacitance reactance, $X_C = \frac{1}{\omega C}$
- Net reactance, $X_L \sim X_C = X_L - X_C = \omega L - \frac{1}{\omega C}$

## Key Terms

- **Direct current:** It is that current which flows with a constant magnitude in the same fixed direction.
- **Phasor:** A rotating vector that represents a sinusoidally varying quantity is called a phasor.
- **Reactance:** The non-resistive opposition to the flow of A.C. is called reactance. It may be inductive reactance ($X_L$) or capacitive reactance ($X_C$).

## Topic-2

### LCR Series Circuit

**Concepts covered:** Reactance and impedance of different types of circuits, LC oscillations, LCR series circuit; Resonance; Power in a.c. circuits, Wattless current

## Revision Notes

- Sign for phase difference ($\phi$) between I and V for series LCR circuit.

  $\phi$ is positive, when $X_L > X_C$.
  $\phi$ is negative, when $X_L < X_C$.
  $\phi$ is zero, when $X_L = X_C$.
- The L.C.R. series circuit is said to be in resonance when $X_L = X_C$ i.e., when $\omega L = \frac{1}{\omega C}$.

  and $\omega = \frac{1}{\sqrt{LC}}$ is called resonant frequency.
- At series resonant frequency, $\omega_0 = \frac{1}{\sqrt{LC}}$, we have
  - $Z = R$ which is the minimum value of impedance.
  - When $\phi = 0$, i.e., I and E are in phase with each other.
  - $V_L$ is equal in magnitude and opposite to $V_C$.
  - Potential drop across C and L together is zero.
  - $E = V_R$.
  - The impedance is minimum i.e., $Z = R$ and $\omega_0 = \frac{1}{\sqrt{LC}}$.
- The $\phi$ varies, between – 90° to + 90°, with frequency. Also, $\phi = 0$ at resonant frequency, $\omega_0 = \frac{1}{\sqrt{LC}}$.

- **Power in a.c. circuit:** The power in LCR series circuit is given by

$$P = EI = E_0 I_0 \cos(\omega t - \phi).$$

- Power in an LCR series circuit consists of two components as follows,
  - Virtual power component $= \frac{1}{2} E_0 I_0 \cos(2\omega t - \phi)$.

    It has a frequency twice as that of a.c. Its value over the complete cycle is zero.
  - Real power component $= \frac{1}{2} E_0 I_0 \cos\phi$. The power is dissipated.
- Cos $\phi$ is called the power factor of the circuit.
  - $P = VI$ is called apparent power.
  - $P_x = VI\cos\phi$ is called active power.
  - $P_y = VI\sin\phi$ is called reactive power.
  - $P = \left[P_x^2 + P_y^2\right]^{1/2}$
- The average power i.e., energy dissipated in the LCR circuit:

$$P_a = \frac{E_0 I_0}{2} \cdot \cos\phi$$

$$\text{Power factor} = \cos\phi = \frac{\text{Resistance}}{\text{Impedance}} = \frac{\text{True power}}{\text{Apparent power}}$$

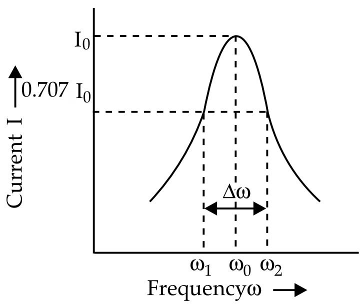
- Impedance for LCR series circuit

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

- At resonance: $X_L = X_C$ and $S_L = S_C$.

  Also $X = 0$ and $S = 0$

  and $Z = R$.
- At resonance, V is in phase with I.
- At series LCR resonance, the current is maximum and is given by $I_{max} = \frac{V}{R}$.
- **I vs. ω graph of a LCR circuit:**




- **Bandwidth:** The **bandwidth (*BW*)** of a resonant circuit is defined as difference in frequency below and above the resonant frequency for which the current is equal to or greater than 70.7% of its resonant value.
- **Q-factor:** ***Q factor*** is a measure of the quality of a resonance circuit represented by the letter $Q$. It is defined as the ratio of resonant frequency and bandwidth.

  $Q = \omega_0/\Delta\omega = \frac{1}{R}\sqrt{\frac{L}{C}}$

It may also calculated as: $Q = \frac{X_L}{R} = \frac{V_L}{V_R}$

At resonance, $V_R = V$ and $V_L = V_C$

$\therefore Q = \frac{v_L}{V} = \frac{V_C}{V}$

- LC circuit comprises of a fully charged capacitor and a totally de-energized Inductor. In such circuit, the inductor begins to absorb energy from the capacitor. Magnetic energy stored in inductor rises, causing the capacitor to discharge i.e., electric energy stored in capacitor decreases. When the Inductor is completely charged, the electrical energy of capacitor becomes zero. The Inductor now begins to charge the capacitor using the energy stored in it.

  This process repeats - transfer of energy from capacitor to the inductor and then back to the capacitor. This is LC oscillation. LC Oscillations are the continual flow of energy from one device to another.
- The maximum value of current in the LR circuit is V/R, where, V is applied emf.
- The maximum charge on the capacitor in RC circuit is VC.
- The current in RC circuit decays both while charging as well as discharging.

## Key Formulae

- Impedance for LCR series circuit

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

- At resonant frequency

  $Z = R, \omega_0 = \frac{1}{\sqrt{LC}}$

- Power factor $= \cos\phi = \frac{\text{Resistance}}{\text{Impedance}}$

  $= \frac{\text{True power}}{\text{Apparent power}}$

  $Q = (1/R)(L/C)$

## Key Terms

- **Resonant frequency:** The frequency at which the current amplitude $I_0$ attains a peak value is called natural or resonant frequency .
- **Acceptor circuit:** The series resonant circuit is also called an acceptor circuit.

## Mnemonics

**Concept :** Phase difference in pure capacitive and pure inductive circuit.
**Mnemonics:** LU**CC**I **L**eft **V**aroda. **IV**AN **L**eft **C**hennai.
**Interpretation:**
C : Capacitive Circuit
C : Current
L : Leads
V : Voltage
I : Inductive Circuit
V : Voltage
L : Leads
C : Current

## Topic-3 a.c. Generator

### Revision Notes

- The frequency of household a.c. in India is 50 hertz.
- The time period of a.c. is equal to the time taken by the a.c. generator coil to complete one rotation.
- Comparison of a.c. power supply and d.c. power supply:

  **Merits:**
  - The generation cost of a.c. is less than that of d.c.
  - It can be made available in a wide range of voltages using transformers.
  - The a.c. devices such as motors are mechanically more robust and stout than the d.c. devices.
  - The power loss in a.c. transmission is negligible as compared to that in d.c. transmission.
  - The a.c. can be easily converted to d.c. The reverse is not true.
  - For reducing alternating current, we can use choke coils in which the loss of energy is much less than that in the rheostat used for reducing d.c.

  **Demerits:**

  (i) The a.c. is more dangerous and fatal than d.c.

  (ii) The 220 V a.c. supply has the peak value of about 311 V, which can cause more severe shock to the persons coming in contact with it.

  (iii) The a.c. is transmitted mostly at the outer surface of the wire, so the conductor needs to be in the form of several stranded wires.

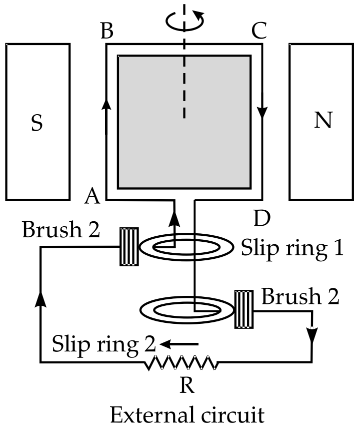
  (iv) The a.c. contains higher harmonics in addition to the fundamental frequency.

  (v) The a.c. cannot be used for electrolysis, electroplating, electrorefining, electro-typing, etc.

- **a.c. Generator:** It converts mechanical energy into electrical energy in the form of alternating current.

  **Construction:** The main parts of a.c. generator are: (i) field magnet, (ii) the armature (iii), the slip rings, (iv) the brushes.

  Field magnet is a strong horseshoe permanent magnet. The armature having a soft iron core, is rotated rapidly in the magnetic field between the poles of the field magnet. The armature is connected to two coaxial metallic slip rings. Brushes are made of carbon.




  (a) Initially,

$$e = \frac{d\phi}{dt}$$

$$e = BAN\omega \sin \omega t$$

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

Here, $e_0 = BAN\omega$

and $\omega = 2\pi f$

$e_0$ is called the peak value of induced emf.

### Key Formulae

- $$e = BAN\omega \sin \omega t$$

$$e = e_{0s} \sin \omega t$$

Here, $e_0 = BAN\omega$

and $\omega = 2\pi f$

## Mnemonics

**Concept :** Fleming's right hand rule is applicable for generator. Fleming's left hand rule is applicable for motors.
**Mnemonics:** **L**eft **H**anded **G**uy helped **R**ight **H**anded **M**am.

**Interpretation:**
L : Left
H : hand rule
G : Generators
R : Right
H : hand rule
M : Motors

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