Chapter 14

Alternating Current and Electromagnetic Waves

AVERAGE AND RMS VALUE OF AC

1. Mean or Average value for time interval '*t*'

$$E_{\text{mean}} = \frac{1}{t}\int_0^t E\,dt,\ I_{\text{mean}} = \frac{1}{t}\int_0^t I\,dt$$

The total charge flown in time '*t*' in a wire is $Q = I_{\text{mean}} \times t$

2. Root Mean Square (RMS) Value

RMS value of ac is equal to that value of dc, which when passed through a resistance for a given time interval will produce the same amount of heat as produced by the ac when passed through the same resistance for same time. RMS values are also known as **virtual or effective value.**

$$E_{\text{rms}}^2 = \frac{1}{t}\int_0^t E^2\,dt,\ I_{\text{rms}}^2 = \frac{1}{t}\int_0^t I^2\,dt$$

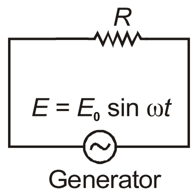
PHASOR AND AC CIRCUITS

Different ac Circuits

1. Resistive Circuit

$I = I_0 \sin \omega t$

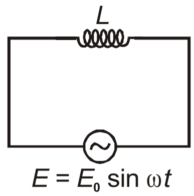
$$I_0 = \frac{E_0}{R}$$



2. Inductive Circuit

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

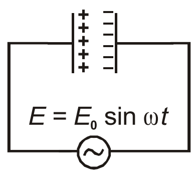
$$I_0 = \frac{E_0}{X_L},\ \text{where } X_L = \omega L = 2\pi f L$$



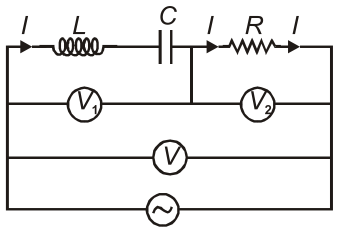
Capacitive Circuit

1. $I = I_0 \sin (\omega t + \pi/2)$

2. $I_0 = \dfrac{E_0}{X_C}$, where $X_C = \dfrac{1}{\omega C} = \dfrac{1}{2\pi f C}$



SERIES LCR CIRCUIT



$E = E_0 \sin \omega t$

$V = \dfrac{E_0}{\sqrt{2}}$ = rms value of applied voltage

V_1 = rms voltage across L-C = $V_L - V_C$

V_2 = rms voltage across R = V_R

Phase Relationship

⇒ I and V_R are in same phase in case of resistance.

⇒ V_L leads I by 90° in case of inductor.

⇒ V_C lags behind I by 90° in case of capacitor.

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

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

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

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

POWER CONSUMED IN AN A.C. CIRCUIT

$$P_{av} = \frac{1}{T}\int_0^T EIdt$$

If $E = E_0 \sin \omega t$ and $I = I_0 \sin (\omega t + \phi)$

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

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

$= E_v I_v \cos\phi$ [E_v = Virtual or rms voltage, I_v = Virtual or rms current]

$\cos\phi$ is known as power factor.

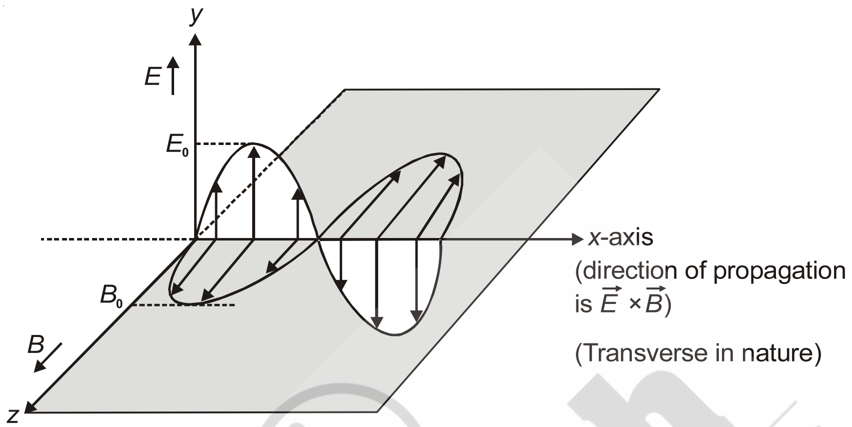
The inductor and capacitor are wattless components of ac circuit as their power consumption is zero.

ELECTROMAGNETIC WAVES

Electromagnetic waves are non-mechanical waves. They transport energy and momentum and carries information. They are transverse in nature and hence they can be polarised.

An electromagnetic wave is the one constituted by oscillating electric and magnetic fields which oscillate in two mutually perpendicular planes; the wave itself propagates in a direction, perpendicular to both the directions of oscillations of electric and magnetic fields.

Important Points Regarding Electromagnetic Waves Characteristics



1. Both electric and magnetic field vary in phase with each other.

2. $\vec{E}_y = E_0 \sin(\omega t - kx)\hat{j}$, $\vec{B}_z = B_0 \sin(\omega t - kx)\hat{k}$, speed $v = \dfrac{\omega}{k}$

3. In vacuum, $c = \dfrac{1}{\sqrt{\mu_0 \varepsilon_0}}$. In a medium $v = \dfrac{1}{\sqrt{\mu\varepsilon}}$.

   Refractive index of the medium $\mu = \dfrac{c}{v} = \sqrt{\mu_r \varepsilon_r}$.

4. $\dfrac{E}{B} = \dfrac{E_0}{B_0} = \dfrac{E_{rms}}{B_{rms}} = c$ (speed) $= \dfrac{\omega}{k}$

5. Average energy density $U_{av} = \dfrac{1}{2}\varepsilon_0 E_0^2 = \dfrac{1}{2}\dfrac{B_0^2}{\mu_0} = \dfrac{1}{4}\varepsilon_0 E_0^2 + \dfrac{1}{4}\dfrac{B_0^2}{\mu_0}$

6. Poynting vector $\vec{S}$ represents instantaneous intensity at a point

   $\vec{S} = \dfrac{\vec{E}\times\vec{B}}{\mu_0}$ or $S = \dfrac{EB}{\mu_0}$. Here $\vec{E}\times\vec{B}$ represents the direction of flow of energy.

7. **Intensity :** Average rate of flow of energy per unit time per unit area in the direction of wave propagation.

   $I = S_{av} = \dfrac{E_{rms}B_{rms}}{\mu_0} = \dfrac{1}{2}\dfrac{E_0 B_0}{\mu_0}$

   $I = c \times U_{av}$ or $U_{av} = \dfrac{I}{c}$

For a point source of power P, Intensity at a distance r from the source is $I = \frac{P}{4\pi r^2}$.

Now $U_{av} = \frac{I}{c} = \frac{P}{4\pi r^2 c}$

$$\Rightarrow \quad \frac{1}{2}\varepsilon_0 E_0^2 = \frac{P}{4\pi r^2 c} \quad \Rightarrow \quad E_0 = \sqrt{\frac{P}{2\pi r^2 c\,\varepsilon_0}}$$

$$B_0 = \frac{E_0}{c} = \sqrt{\frac{P\mu_0}{2\pi r^2 c}}$$

8. Radiation pressure (for normal incidence)
   (a) For perfectly absorbing surface $P = I/c$
   (b) For perfectly reflecting surface $P = 2I/c$
   (c) For all other surfaces $I/c < P < 2I/c$
   (d) For a surface of reflectance r

$$P = \frac{I}{c}(1+r)$$

9. The direction of wave propagation is always along $\vec{E}\times\vec{B}$ and E, B, c are always perpendicular.
10. Speed of electromagnetic waves only depends upon the medium. All the electromagnetic waves travels with equal speed (*i.e.* 3×10^8 m/s) in vacuum.
11. When a electromagnetic wave travels from one medium to another then its speed changes but frequency remains same.
12. Speed of electromagnetic waves in any medium = $\frac{c}{\mu}$ [where μ is the refractive index of the electromagnetic waves]

❑ ❑ ❑