CHAPTER 7

ALTERNATING CURRENT

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AC Voltage and AC Current

- A voltage that varies like a sine function with time is called *alternating voltage (ac voltage).*
- The electric current whose magnitude changes with time and direction reverses periodically is called the *alternating current (ac* current).

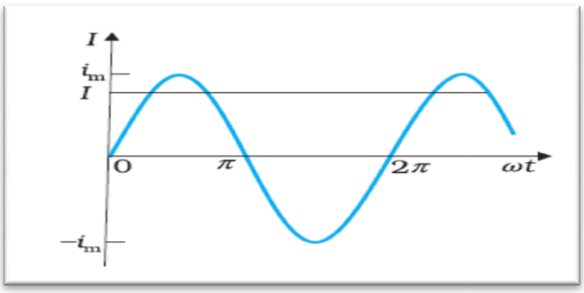
Advantages of AC:

- Easily stepped up or stepped down using transformer
- Can be regulated using choke coil without loss of energy
- Easily converted in to dc using rectifier (Pn - diode)
- Can be transmitted over distant places
- Production of ac is more economical

Disadvantages of ac

- Cannot used for electroplating - Polarity of ac changes
- ac is more dangerous
- It can't store for longer time

Representation of ac



- An ac voltage can be represented as

$$v = v_m \sin \omega t$$

- v- instantaneous value of voltage , v_m- peak value of voltage, ω - Angular frequency.

RMS Value (*effective current)*

- r.m.s. value of a.c. is the d.c. equivalent which produces the same amount of heat energy in same time as that of an a.c.
- It is denoted by I_{rms} *or I.*
- Relation between r.m.s. value and peak value is

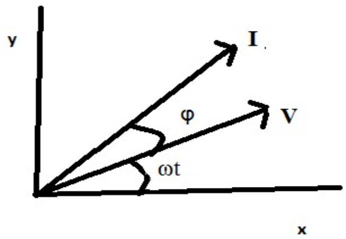
$$I_{rms} = \frac{i_m}{\sqrt{2}}$$

- The *r.m.s* voltage is given by

$$V_{rms} = \frac{V_m}{\sqrt{2}}$$

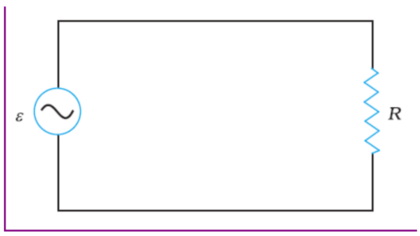
Phasors

- A phasor is a vector which rotates about the origin with angular speed ω.
- The vertical components of phasors V and I represent the sinusoidally varying quantities v and i.
- The magnitudes of phasors V and I represent the peak values v_m and i_m



- The diagram representing alternating voltage and current (phasors) as the rotating vectors along with the phase angle between them is called phasor diagram.

AC Voltage applied to a Resistor



- The ac voltage applied to the resistor is

$$v = v_m \sin \omega t$$

- Applying Kirchhoff's loop rule

$$v_m \sin \omega t = i R$$

$$i = \frac{v_m}{R} \sin \omega t$$

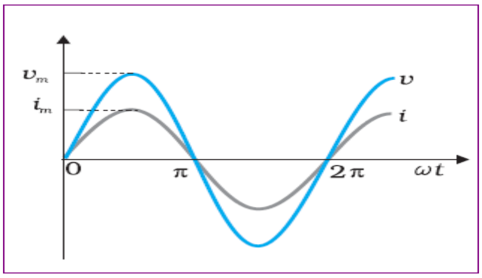
- Since R is a constant, we can write this equation as

$$i = i_m \sin \omega t$$

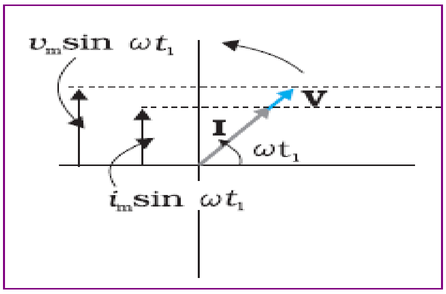
- Where peak value of current is

$$i_m = \frac{v_m}{R}$$

- Thus when ac is passed through a resistor *the voltage and current are in phase* with each other.



Phasor diagram



Instantaneous power

- The instantaneous power dissipated in the resistor is

$$p = i^2 R = i_m^2 R \sin^2 \omega t$$

Average power

- The average value of *p over a cycle is*

$$\bar{p} = < i^2 R > = < i_m^2 R \sin^2 \omega t >$$

or

$$\bar{p} = i_m^2 R < \sin^2 \omega t >$$

- Using the trigonometric identity,

$\sin^2 \omega t = 1/2\ (1 - \cos 2\omega t)$

$< \sin^2 \omega t > = (1/2)\ (1 - < \cos 2\omega t >)$

- Since $< \cos 2\omega t > = 0$

$$< \sin^2 \omega t > = \frac{1}{2}$$

- Thus

$$\bar{p} = \frac{1}{2} i_m^2 R$$

- In terms of r.m.s value

$$P = \bar{p} = \frac{1}{2} i_m^2 R = I^2 R$$

- Or

$$P = V^2 / R = I V \quad (\text{since } V = I R)$$

AC VOLTAGE APPLIED TO AN INDUCTOR

- Let the voltage across the source be

$$v = v_m \sin \omega t$$

- Using the Kirchhoff's loop rule

$$v - L \frac{di}{dt} = 0$$

- *Where L is the self-inductance*
- *Thus*

$$\frac{di}{dt} = \frac{v}{L} = \frac{v_m}{L} \sin \omega t$$

- Integrating

$$\int \frac{di}{dt} dt = \frac{v_m}{L} \int \sin(\omega t) dt$$

$$i = -\frac{v_m}{\omega L}\cos(\omega t) + \text{constant}$$

- Since the current is oscillating , the constant of integration is zero.
- Using

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

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

- Where

$$i_m = \frac{v_m}{\omega L}$$

- Or

$$i_m = \frac{v_m}{X_L}$$

- Where X_L- inductive reactance

Inductive reactance (X_L)

- The resistance offered by the inductor to an ac through it is called inductive reactance.
- It is given by

$$X_L = \omega L$$

- The dimension of inductive reactance is the same as that of resistance and its SI unit is ohm (Ω).
- The inductive reactance is directly proportional to the inductance and to the frequency of the current.

Phasor Diagram

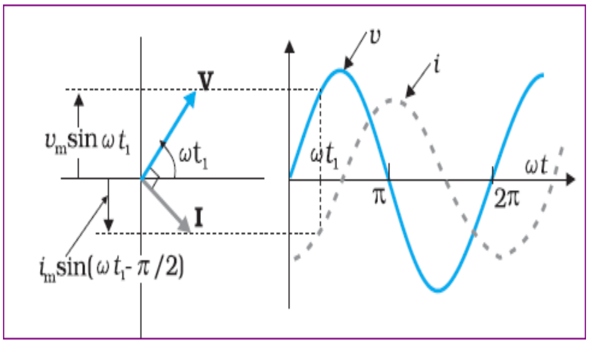
- We have the source voltage

$$v = v_m \sin\omega t$$

- The current

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

- Thus a comparison of equations for the source voltage and the current in an inductor shows that the current lags the voltage by π/2 or one-quarter (1/4) cycle.



Instantaneous power

- The instantaneous power supplied to the inductor is

$$p_L = iv = i_m \sin\left(\omega t - \frac{\pi}{2}\right) \times v_m \sin(\omega t)$$
$$= -i_m v_m \cos(\omega t)\sin(\omega t)$$
$$= -\frac{i_m v_m}{2}\sin(2\omega t)$$

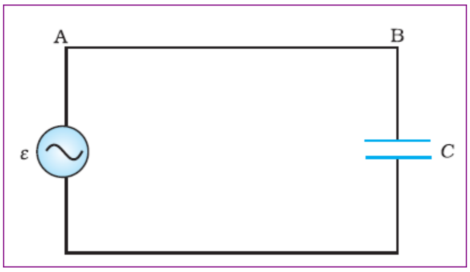
Average power

- The average power over a complete cycle in an inductor is

$$P_L = \left\langle -\frac{i_m v_m}{2}\sin(2\omega t)\right\rangle$$
$$= -\frac{i_m v_m}{2}\langle\sin(2\omega t)\rangle = 0,$$

- since the average of sin (2ωt) over a complete cycle is zero.
- Thus, the *average power supplied to an inductor over one complete cycle is zero.*

AC VOLTAGE APPLIED TO A CAPACITOR



- A capacitor in a dc circuit will limit or oppose the current as it charges.
- When the capacitor is connected to an ac source, it limits or regulates the current, but does not completely prevent the flow of charge.
- Let the applied voltage be

$$v = v_m \sin\omega t$$

- *The instantaneous voltage v across* the capacitor is

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

- Where q is the charge on the capacitor.
- Using the Kirchhoff's loop rule

$$v_m \sin\omega t = \frac{q}{C}$$

- Therefore

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

- Using the relation

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

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

- Where

$$i_m = \frac{v_m}{(1/\omega C)}$$

- Or

$$i_m = \frac{v_m}{X_C}$$

- Where X_C – capacitive reactance

Capacitive Reactance

- It is the resistance offered by the capacitor to an ac current through it.
- The dimension of capacitive reactance is the same as that of resistance and its SI unit is ohm (Ω).

Phasor Diagram

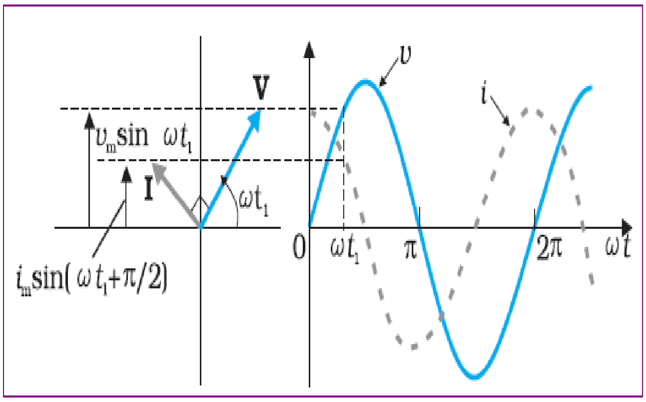
- The applied voltage is

$$v = v_m \sin\omega t$$

- The current is

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

- Thus the current leads voltage by π/2.



Instantaneous power

- The instantaneous power supplied to the capacitor is

$$p_c = i\,v = i_m \cos(\omega t) v_m \sin(\omega t)$$
$$= i_m v_m \cos(\omega t)\sin(\omega t)$$
$$= \frac{i_m v_m}{2}\sin(2\omega t)$$

Average power

- The average power is given by

$$P_C = \left\langle \frac{i_m v_m}{2} \sin(2\omega t) \right\rangle = \frac{i_m v_m}{2} \langle \sin(2\omega t) \rangle = 0$$

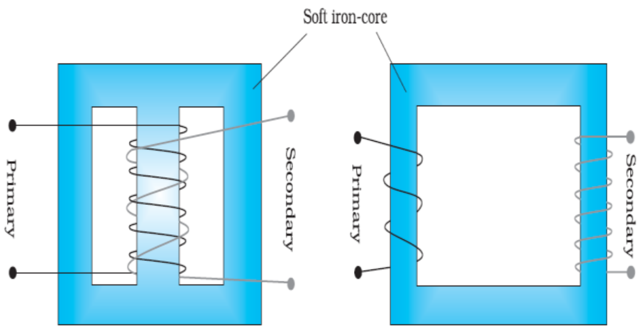
- Thus the average power over a cycle when an ac passed through a capacitor iszero.

TRANSFORMER

- It is a device used to change alternating voltage.
- It works using the principle of mutual induction.
- Works only in ac

Construction

- A transformer consists of two sets of coils, insulated from each other.
- They are wound on a soft-iron core, either one on top of the other.
- One of the coils called the ***primary coil*** *has* N_p *turns.*
- The other coil is called the ***secondary coil****; it has* N_s *turns.*
- The primary coil is the **input coil** and the secondary coil is the **output coil** of the transformer.



Theory / Transformer Equation

- 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.
- The induced emf or voltage ε_s *in the secondary with* N_s *turns is*

$$\varepsilon_s = -N_s \frac{d\phi}{dt}$$

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

$$\varepsilon_p = -N_p \frac{d\phi}{dt}$$

- Assuming

$\varepsilon_p = v_p$ and $\varepsilon_s = v_s$

- Therefore

$$v_s = -N_s \frac{d\phi}{dt}$$
$$v_p = -N_p \frac{d\phi}{dt}$$

- Thus

$$\frac{v_s}{v_p} = \frac{N_s}{N_p}$$

- For an ideal transformer input power and out put power are equal, therefore

$$i_p v_p = i_s v_s$$

- Thus

$$\frac{i_p}{i_s} = \frac{v_s}{v_p} = \frac{N_s}{N_p}$$

- This is the transformer equation.

Types of Transformers

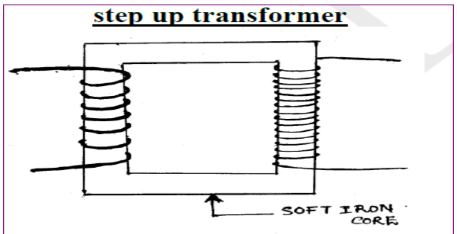
Step-up transformer

- We have

$$V_s = \left(\frac{N_s}{N_p}\right) V_p \quad \text{and} \quad I_s = \left(\frac{N_p}{N_s}\right) I_p$$

- Thus, if the secondary coil has a greater number of turns than the primary ($N_S > N_P$)*, the* ***voltage is stepped up*** ($V_S > V_P$)*. This type of* arrangement is called a ***step-up transformer.***
- In step up transformer, there is less current in the secondary than in the primary **(** $I_S < I_P$ **)**

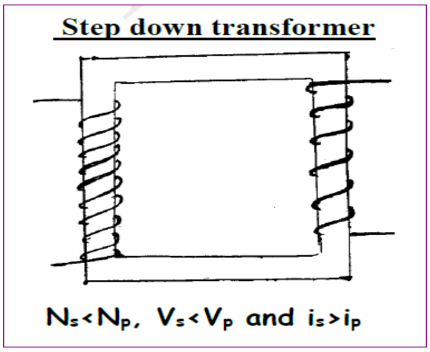
step up transformer



$N_s > N_p$, $V_s > V_p$ and $i_s < i_p$

Step-down transformer

- In a step-down transformer the secondary coil has less turns than the primary ($N_S < N_P$).
- Here $V_S < V_P$ **and** $I_S > I_P$**.** *That is, the* voltage is stepped down, or reduced, and the current is increased.



Working

- When an alternating voltage is applied to the primary, the resulting current produces an alternating magnetic flux which links the secondary and induces an emf in it.

- The value of the emf depends on the number of turns in the secondary.

Efficiency of a transformer

- The efficiency of a transformer is given by

$$\text{Efficiency, } \eta = \frac{\text{output power}}{\text{input power}}$$

Energy loss in transformers

Copper Loss

- As the current flows through the primary and secondary copper wires, electric energy is wasted in the form of heat.
- This is minimised by using thick wire.

Eddy current Loss (Iron Loss)

- The eddy currents produced in the soft iron core of the transformer produce heating.
- Thus electric energy is wasted in the form of heat.
- The effect is reduced by having a laminated core.

Magnetic flux leakage

- The entire magnetic flux produced by the primary coil may not be available to the secondary coil.
- Thus some energy is wasted.
- It can be reduced by winding the primary and secondary coils one over the other.

Hysteresis Loss

- Since the soft iron core is subjected to continuous cycles of magnetization, the core gets heated due to hysteresis.
- Minimised by using a magnetic material which has a low hysteresis loss.

Uses of a transformer

- 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.

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