CHAPTER 7

ALTERNATING CURRENT

Syllabus

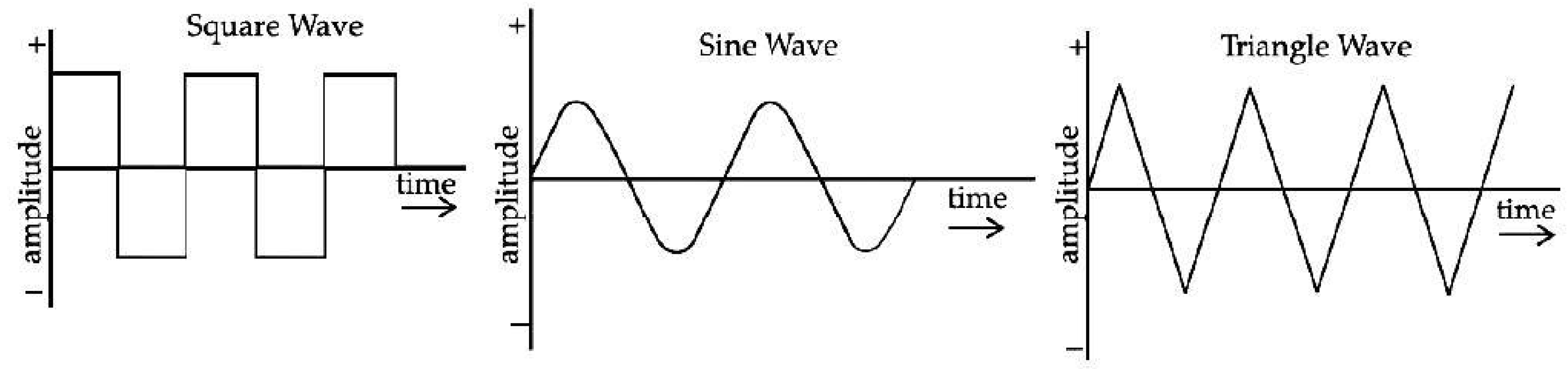
- *Alternating currents, peak and RMS value of alternating current/voltage; reactance and impedance; LC oscillations (qualitative treatment only).*
- *LCR series circuit, resonance; power in A.C. circuits.*
- *AC generator and transformer.*

Revision Notes

Alternating Current

Alternating current

- Alternating current changes continuously in magnitude and periodically in direction.
- It is represented by sine curve or cosine curve as $I = I_0 \sin wt$ or $I = I_0 \cos wt$ where, I_0 is peak value of current and I is instantaneous value of current.
- Frequency of an alternating current supply f, is defined as the number of cycles completed per second. It is measured in Hertz (Hz). In India, the frequency is 50 Hz.
- The time period T, of an alternating supply, is time taken to complete one cycle.
- The behaviour of ohmic resistance R in ac circuit is the same as in dc circuit.
- Alternating current can be produced by using a device called as an alternator.
- AC waveforms are:



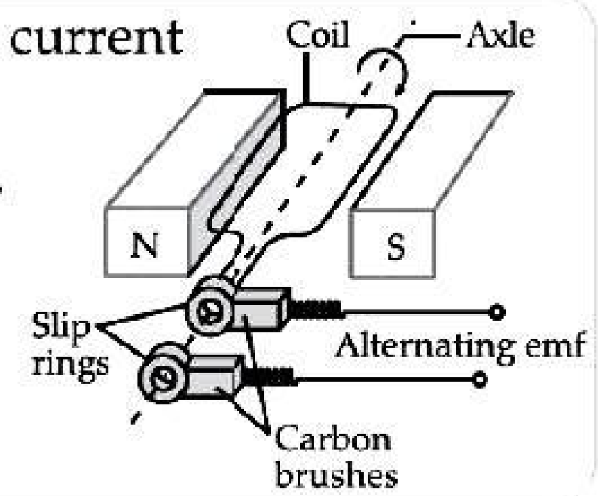
Peak and *rms* value of alternating current/voltage:

- Root mean square or *rms* is the root mean square of voltage or current in an *ac* circuit for one complete cycle denoted by V_{rms} or I_{rms}.
- *Rms* value is the standard way of measuring alternating current and voltage as it gives the *dc* equivalent values.
- *Rms* value of *ac* is also called effective value or virtual value of *ac* represented as I_{rms}, I_{eff} or I_v shown as

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

Alternating Current

- **AC Current**
  - Direction of current changes alternatively
    - $i = i_0 \sin\omega t$
    - $v = v_0 \sin\omega t$
  - RMS value or root mean square value
    - $i_{rms} = i_0/\sqrt{2}$
    - $v_{rms} = v_0/\sqrt{2}$
  - Mean value or Average value
    - $i_{mean} = 2i_0/\pi$
    - $v_{rms} = 2v_0/\pi$
  - Peak value or Maxm value
    - $i_0 = \sqrt{2}\, i_{rms}$
    - $v_0 = \sqrt{2}\, v_{rms}$
- **Contribution**
  - In 1883, Nikola Tesla inverted fixer AC motor, AC generator and AC transmission technology.
- **A C Generator**
  - A device generating alternating current having elements magnet, Armature and graphite Brushes
  - emf induced through coil
  - $E = NBA\,\omega \sin\omega t$
  - $i = E/R = NBA\,\omega \sin \omega t/R$



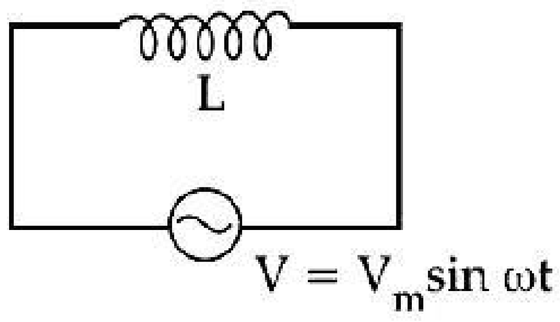
- **Transformer**
  - It is used to obtain a high AC voltage from a Low–voltage AC source or vice–versa
  - Efficiency of a transformer
    - η = output power/Input power
    - 99% efficiency can easily achieved
  - Turnsratio
    - $\frac{E_s}{E_p} = \frac{I_p}{I_s} = \frac{N_s}{N_p} = K$
- **Power in AC Circuit**
  - $P = E_{rms} i_{rms} \cos\phi = \frac{E_0}{\sqrt{2}} \times \frac{i_0}{\sqrt{2}} \cos\phi = \frac{1}{2} E_0 i_0 \cos\phi$
- **Impedance**
  - The ratio of emf applied and the current produced in an AC circuit
  - $Z = E_0/i_0$ Ohm
- **Reactance**
  - The hindrance offered by inductor or capacitor or both to the flow of AC (c_1 or c_2)
- **A C Circuits**
  - Inductive (L) circuit
    - $i = i_0 \sin\left(\omega t - \frac{\pi}{2}\right)$
    - Phase difference b/w $V \& I$, $\phi = \pi/2$
    - Power factor $\cos(\phi) = 0$
    - Voltage leads current by $\pi/2$
    - $P = 0$
  - Capacitive (C) circuit
    - $i = i_0 \sin\left(\omega t + \frac{\pi}{2}\right)$
    - $\phi = \pi/2$ or $-\pi/2$
    - Power factor $\cos\phi = 0$
    - Power $(P) = 0$
    - Current leads the voltage by $\pi/2$
  - Resistive (R) circuit
    - $i = i_0 \sin(\omega t)$
    - $\phi = 0°$
    - $\cos\phi = 1$
    - $P = V_0 I_0/2$
    - Current & voltage both are in same phase
  - R–C circuit
    - $i = i_0 \sin(\omega t + \phi)$
    - $Z = \sqrt{R^2 + X_c^2}$
    - $X_c = 1/\omega C$
    - $\tan\phi = 1/\omega CR$
    - $i_0 = E_0/Z$
    - Power factor $\cos\phi = \frac{R^2}{\sqrt{R^2 + X_c^2}}$
    - current leading.
  - L–C circuit
    - $i = i_0 \sin\left(\omega t \pm \frac{\pi}{2}\right)$
    - $X = X_L - X_C$
    - $\phi = \pi/2$
    - Power factor = 0, Either voltage or current leading
  - L–R circuit
    - $i = i_0 \sin(\omega t + \phi)$
    - $Z = \sqrt{R^2 + X_L^2}$
    - $X_L = \omega L$
    - $\tan\phi = \omega L/R$
    - $i_0 = E_0/Z$
    - power factor = R/Z
    - voltage is leading
  - L–C–R circuit
    - $i = i_0 \sin(\omega t \pm \phi)$
    - $Z = \sqrt{R^2 + (X_c - X_L)^2}$
    - $X = X_c - X_L$
    - $= \left(\frac{1}{\omega c} - \omega L\right)$
    - $\tan\phi = \left(\frac{1}{\omega c} - \omega L\right)/R$, $i_0 = \frac{E_0}{Z}$

Trace the Mind Map
- First Level
- Second Level
- Third Level

- *Rms* voltage value is the square root of averages of the squares of instantaneous voltages in a time varying waveform.

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

- AC voltage applied to pure inductive circuits:



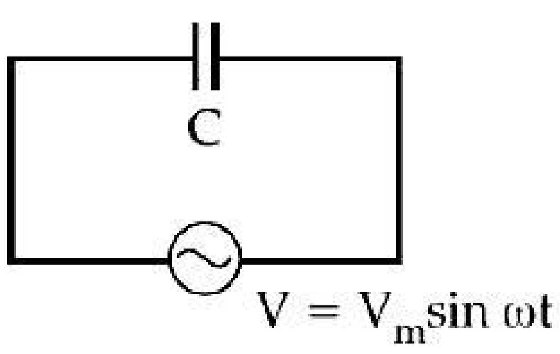
$$V = V_m \sin \omega t$$

$$i = i_m \left(\sin \omega t - \frac{\pi}{2} \right)$$ [which shows current lags the voltage by $\frac{\pi}{2}$]

$$\text{Average } P_L = \frac{i_m V_m}{2} [\sin (2\omega t)] = 0$$ [Since average of sin $2\omega t$ over a complete cycle is zero]

Thus the average power supplied to an inductor over one complete cycle is zero.

AC applied to pure capacitive circuit:



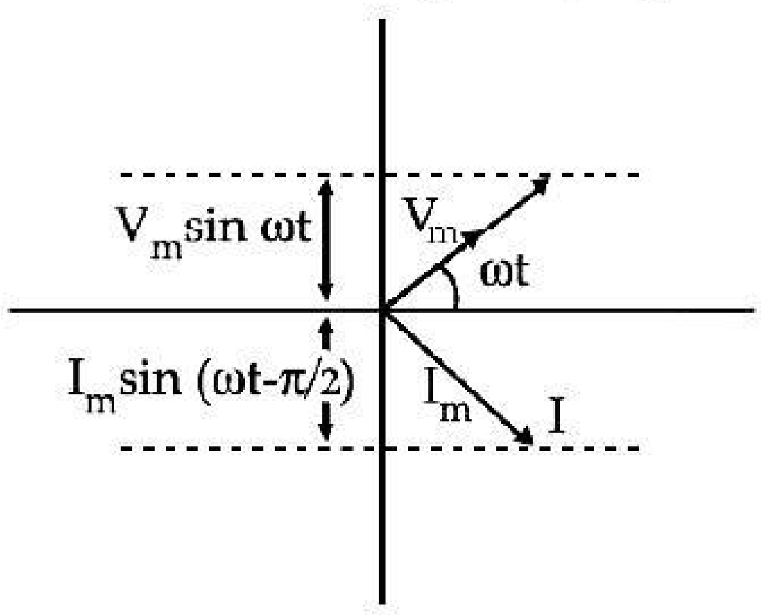
$$V = V_m \sin \omega t$$

$$I = I_m \sin \left(\omega t + \frac{\pi}{2} \right)$$ [which shows current leads the voltage by $\frac{\pi}{2}$]

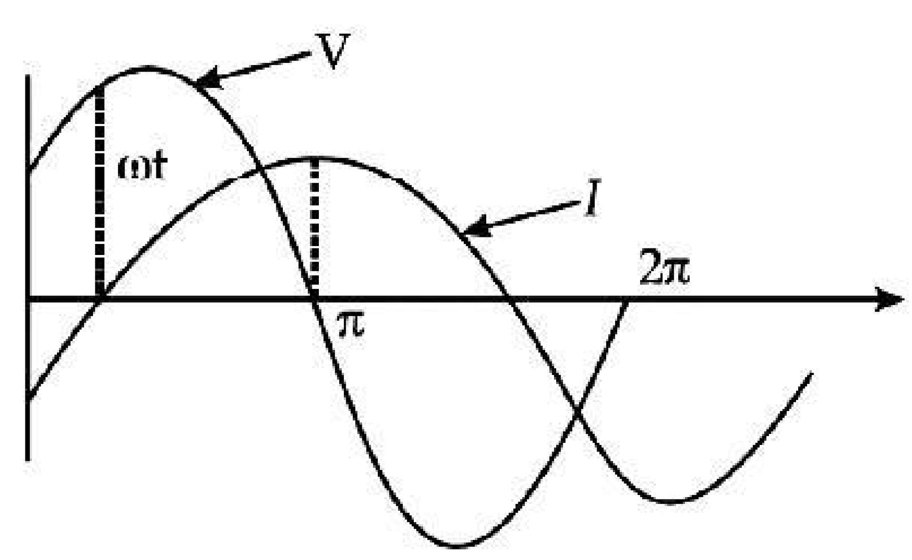
$$\text{Average } P_C = \frac{I_m V_m}{2} \sin(2\omega t) = 0$$ [Since average of sin $2\omega t$ over a complete cycle is zero]

Thus the average power supplied to an capacitor over one complete cycle is zero.

- **Phasor-diagram:** A phasor diagram represents sinusoidal *ac* current and sinusoidal voltage in a circuit along with the phase difference between current and voltage. The length of phasor is proportional to the instantaneous values of V and I and the maximum length is proportional to V_0 and I_0.



Phasor diagram of purely Inductive circuit



Graphical representation of V **and** i **versus** ωt.

Reactance and Impedance

- When an *ac* current is passed through a resistance, a voltage drop is produced which is in phase with the current and is measured in ohms (Ω).
- Reactance is the inertia against the motion of electrons where an alternating current after passing through it produces a voltage drop which is 90° out of phase with the current.
- Reactance is shown by "X" and is measured in ohms (Ω).
- Reactance is of two types: inductive and capacitive.
- Inductive reactance is linked with varying magnetic field that surrounds a wire or a coil carrying a current.
- Inductive reactance (X_L) is the resistance offered by an inductor and is given by $X_L = \omega L = 2\pi f L$
- Through a pure inductor, alternating current lags behind the alternating *emf* by phase angle of 90°.
- Capacitive reactance is linked with changing electric field between two conducting surfaces separated from each other by an insulating medium.
- Capacitive reactance (X_C) is the resistance offered by a capacitor and is given by

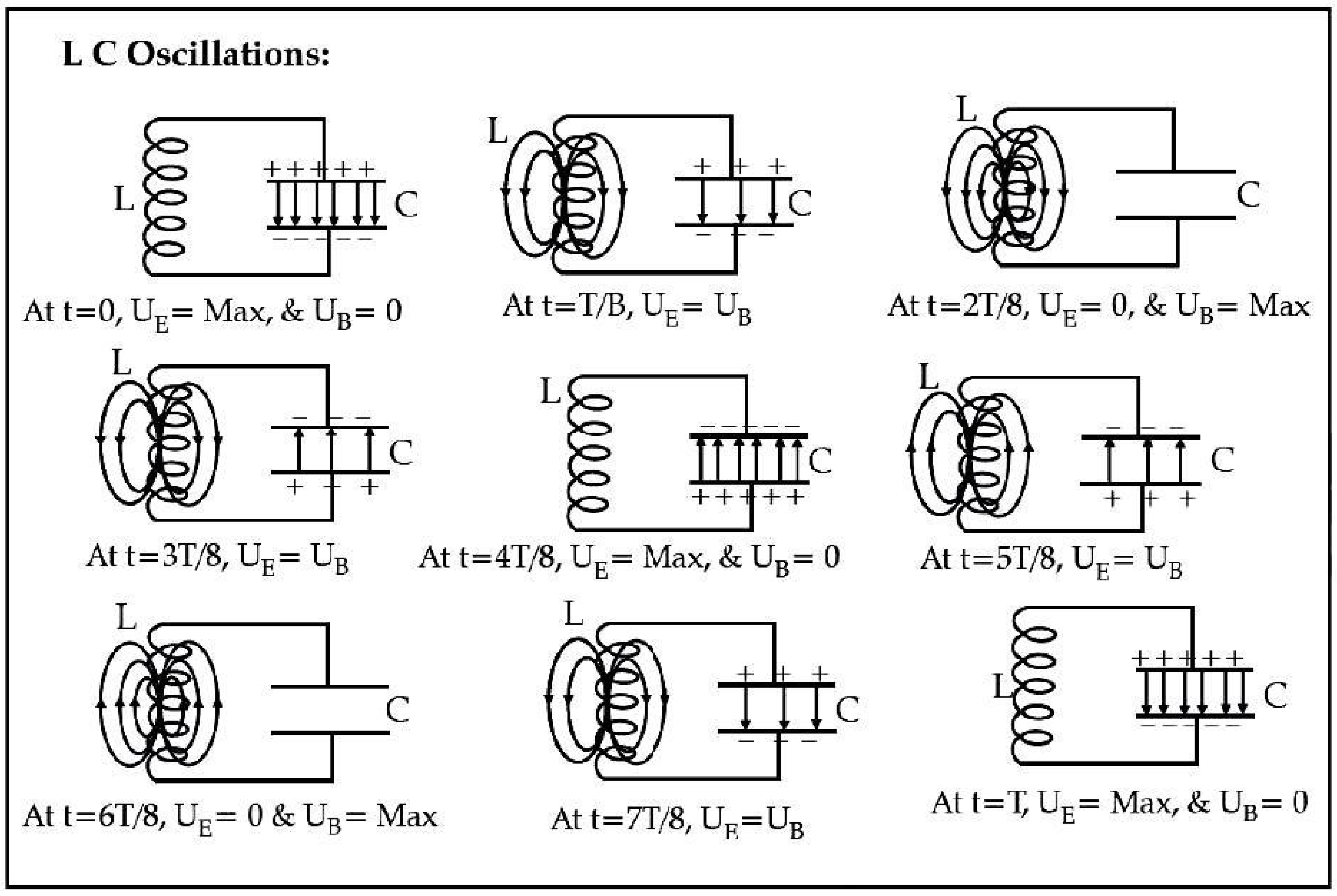
$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

- Through a pure capacitor, alternating current leads the alternating *emf* by a phase angle of 90°.
- Impedance is the comprehensive expression of all forms of opposition to electron flow, including resistance and reactance, where an alternating current after passing through it produces a voltage drop between 0° and 90° which will be out of phase with current given as,

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

where, Z = Impedance of circuit, R = Resistance, X = Reactance

***LC* Oscillations (qualitative treatment only)**



- *LC* circuit comprises of inductor and capacitor connected in series where energy from the cell is given to capacitor which keeps on oscillating between inductor and capacitor.
- When *ac* voltage is applied to the capacitor, it keeps on charging and discharging continuously.
- When capacitor is fully charged, it starts discharging and charge gets transferred to the inductor which is connected to capacitor.
- Due to change in current, there is change in magnetic flux of the inductor in the circuit, which induces an *emf* in the inductor.
- The *emf* is given by $e = -L\frac{dI}{dt}$ which opposes the growth of the current.
- When capacitor gets completely discharged, all the energy stored in it, gets stored in the inductor as a result of which, inductor starts charging the capacitor and energy stored in the capacitor starts increasing.
- As there is no current in the circuit, energy in the inductor is zero, so total energy of *LC* circuit will be

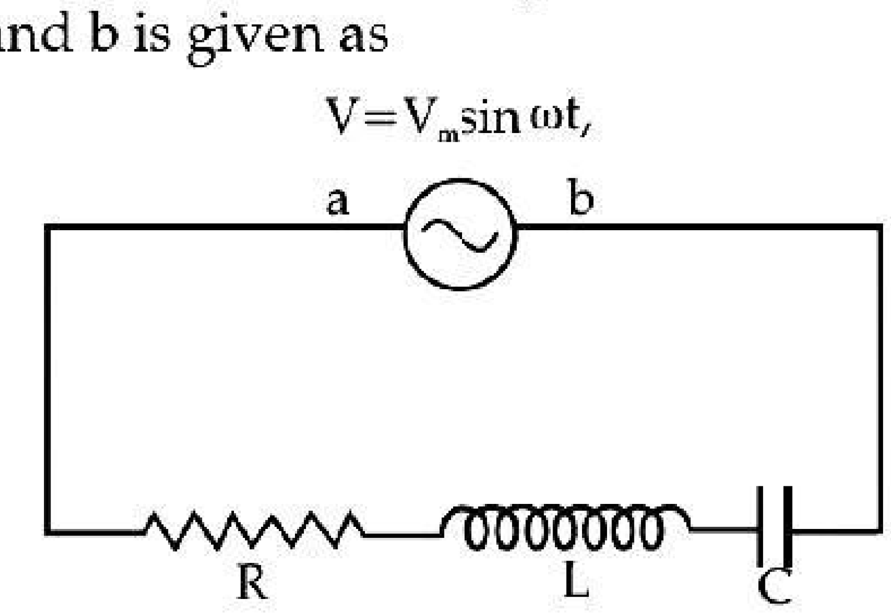
$$U_E = \frac{1}{2}.\frac{q^2}{C}$$

- Band Width: It is the range of angular frequencies over which the average power is greater than ½ the maximum value of average power.
- **Impedance:** In an *ac*, the impedance is analogous to resistance in a *dc* circuit that measures the combined effect of resistance, capacitive reactance and inductive reactance.

LCR Series Circuit

***LCR* series circuit**

- In an LCR series circuit with resistor, inductor and capacitor, the expression for the instantaneous potential difference between the terminals a and b is given as



- The potential difference in this will be equal to the sum of the magnitudes of potential differences across R, L and C elements as

$$V = V_m \sin \omega t = RI + L\frac{dI}{dt} + \frac{1}{C}q$$

where, q is the charge on capacitor.

- The steady state situation will be

$$i = \frac{V_m}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}} \sin(\omega t - \phi) \text{ and } i_m = \frac{V_m}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)}}$$

where, $$\phi = \tan^{-1}\frac{\omega L - \frac{1}{\omega C}}{R}$$

- From the equation, steady-state current varies sinusoidal with time, so steady-state current can be written as $I = I_m \sin(wt - f)$
- In an LCR circuit:

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

Here, Z = Impedance of the circuit, X = Reactance of the circuit, X_L and X_C = Inductive and Capacitive reactance.

- For steady-state currents, maximum current I_m is related to maximum potential difference V_m by

$$I_m = \frac{V_m}{Z}$$

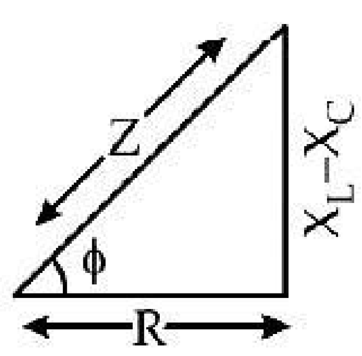
- Total effective resistance of LCR circuit is called Impedance (Z) of the circuit given as

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

- The angle by which alternating voltage leads the alternating current in LCR circuit is given by

$$\tan\phi - \frac{X_L - X_C}{R}$$

- In an LCR circuit, impedance triangle is a right-angled triangle in which base is ohmic resistance R, perpendicular is reactance $(X_L - X_C)$ and hypotenuse is impedance (Z)



- When a condenser of capacity C charged to certain potential is connected to inductor L, energy stored in C oscillates between L and C where frequency of energy oscillations is given by

$$X_L = X_C \text{ or } f = \frac{1}{2\pi\sqrt{LC}}$$

- In LCR circuit, if there is no loss of energy, then total energy in L and C at every instant will remain constant.
- Sign for phase difference (f) between I and E for a series LCR circuit:

ϕ is positive, when $X_L > X_C$.
ϕ is negative, when $X_L < X_C$.
ϕ is zero, when $X_L = X_C$.
$\phi = \pi/2$, when $\omega = \infty$.
$\phi = -\pi/2$, when $\omega = 0$.

Resonance

- Circuit in which inductance L, capacitance C and resistance R are connected in series and the circuit admits maximum current, such circuit is called as series resonant circuit.
- The necessary condition for resonance in LCR series circuit is: $V_C = V_L$

$$X_L = X_C \text{ which gives } \omega^2 = \frac{1}{LC} \text{ or } f = \frac{1}{2\pi\sqrt{LC}}$$

- In this, frequency of ac fed to circuit will be equal to natural frequency of energy oscillations in the circuit under conditions,

$$Z = R$$

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

- The sharpness of tuning at resonance is measured by Q factor or quality factor of the circuit given as

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

- At series LCR resonance or acceptor circuit, current is maximum.

$$I_{\max} = \frac{E}{R}$$

Power in AC circuits

- When the current is out of phase with the voltage, the power indicated by the product of the applied voltage and the total current gives apparent power.
- If the instantaneous values of the voltage and current in an ac circuit are given by

$$E = E_0 \sin \omega t$$
$$i = i_0 \sin (\omega t - \phi)$$

where ϕ is the phase difference between voltage and the current. Then, the instantaneous power

$$P_{in} = E \times i = E_0 i_0 \sin \omega t . \sin (\omega t - \phi)$$

or average power

$$P_{avg} = \frac{1}{2} E_0 i_0 \cos\phi$$

$$= \frac{E_0}{\sqrt{2}} \times \frac{i_0}{\sqrt{2}} \cos\phi = V_{rms} \times I_{rms} \times \cos\phi$$

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

- Power factor ($\cos \phi$) is important in power systems as it shows how closely the effective power equals the apparent power which is given as:

$$\cos\phi = \frac{\text{Effective power}}{\text{Apparent power}}$$

- The value of power factor varies from 0 to 1.
- The instantaneous rate at which energy is supplied to an electrical device by ac circuit is

$$P = VI$$

- Average power in LCR where, $X_L = X_C$ over a complete cycle in a non-inductive circuit or pure resistive circuit is given as $P = V_0 I_0$ or $I_0^2 R$

AC Generator and Transformer

***AC* generator**

- An alternator is an electrical machine which converts mechanical energy into alternating electrical energy.
- Alternator or a synchronous generator has a stator and rotor.
- It is similar to the basic working principle of a dc generator.
- It works on the principle of electromagnetic induction where a coil gets rotated in uniform magnetic field, sets an induced emf given as:

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

Transformer

- Transformer is an electrical device used for changing the alternating voltages.

  It is based on the phenomenon of mutual induction.
- The main use of transformer is in transmission of ac over long distances at extremely high voltages which reduces the energy losses in transmission.
- It comprises of two sets of coils which are insulated from each other and are wound on soft-iron core.
- In this, one of the coil is called as primary (input coil) having N_p turns while other coil is secondary (output coil) having N_s turns, so we have

$$\frac{E_s}{E_p} = \frac{I_p}{I_s} = \frac{N_s}{N_p} = k$$

- Transformer Ratio:

$$E_s = \left(\frac{N_s}{N_p}\right)E_p \text{ and } I_s = \left(\frac{N_p}{N_s}\right)I_p$$

$\frac{N_s}{N_p} = \frac{V_s}{V_p}$ is defined as the transformer ratio.

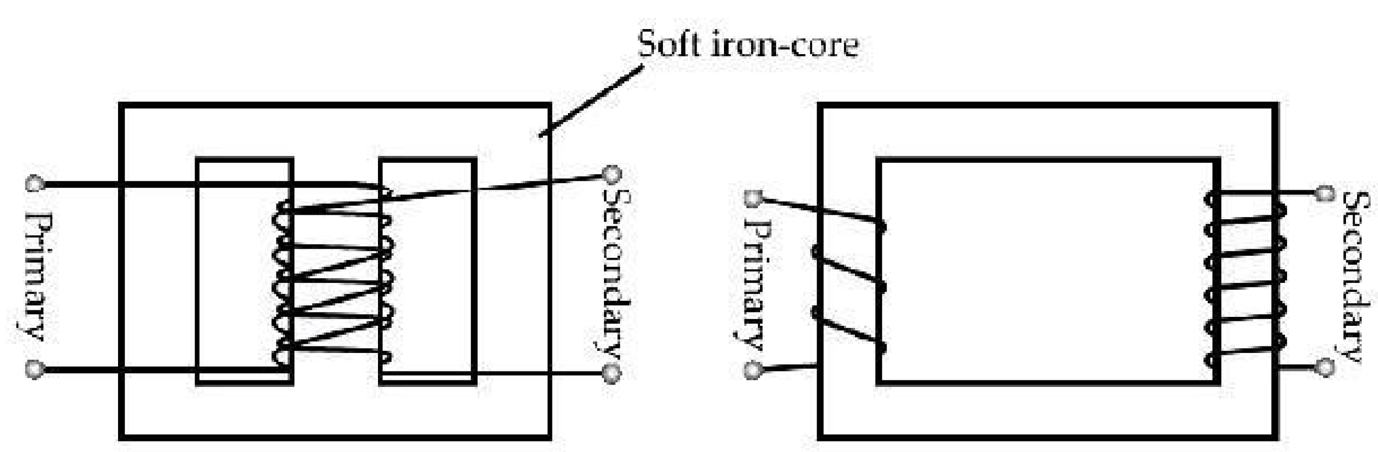
The value of turns ratio of a transformer $\frac{N_p}{N_s} = \frac{V_p}{V_s} = n$

- Step-up transformer: If secondary coil has more number of turns than primary ($N_s > N_p$), voltage gets stepped up ($V_s > V_p$).

  In this, there is less current in secondary as compared to primary ($\frac{N_s}{N_p} > 1$ and $I_s < I_p$).

  The value of transformer ratio $k > 1$
- Step-down transformer: In this, the secondary coil has less number of turns than primary ($N_s < N_p$). In this, $V_s < V_p$ and $I_s > I_p$ as voltage gets stepped down or reduced with increase in current.

  In this, value of transformer ratio $k < 1$
- The main use of transformers is in stepping up voltage for power transmission.
- Electric power can be transmitted efficiently at high voltages than at low voltages due to less (I^2R) heat loss in a high voltage / low current transmission.
- Efficiency of transformer:



$$\eta = \frac{\text{Output power}}{\text{Input power}}$$

$$\eta = \frac{E_s I_s}{E_p I_p}$$

- Inspite of heavy power losses, the efficiency in a transformer is usually above 90%.
- An ideal transformer is 100% efficient as it delivers all energy it receives.
- Real transformer is not 100% efficient and at full load, its efficiency lies between 94% to 96%.
- A transformer operating with constant voltage and frequency with very high capacity, efficiency results as 98%.
- Energy losses in transformers:
  1. Flux Leakage
  2. Resistance of windings
  3. Eddy currents
  4. Hysteresis

Mnemonics

Concept: In pure inductive and capacitive circuit

Mnemonics: Chocolate Cookies are Very Interesting !

Interpretation:

Chocolate: Current leads

Cookies are: in Capacitive circuit

Very: Voltage leads

Interesting !: in Inductive circuit

Key Formulae

- *rms* value for current $I_{rms} = \frac{I_0}{\sqrt{2}}$
- *rms* value for voltage $V_{rms} = \frac{V_0}{\sqrt{2}}$
- Power $P = V_{rms} I_{rms}$
- In a purely inductive circuit if, $V = V_m \sin \omega t$

$$i = i_m \sin\left(\omega t - \frac{\pi}{2}\right), \quad \text{where } i_m = \frac{V_m}{X_L} \text{ and } X_L = \omega L$$

$$(P_{avg})_L = 0$$

- In a purely capacitive circuit if, $V = V_m \sin \omega t$

$$i = i_m \sin\left(\omega t + \frac{\pi}{2}\right) \quad \text{where, } i_m = \frac{V_m}{X_C} \text{ and } X_C = \frac{1}{\omega C}$$

- $$\text{Average Power} = \frac{1}{2} V_0 I_0 \cos\phi = V_{rms} I_{rms} \cos\phi \quad (\text{where, } \cos\phi = \frac{R}{Z} \text{ is power factor})$$
- $$Z = \sqrt{R^2 + (X_L - X_C)^2}$$
- $$\text{Induced emf} = e = -L\frac{dI}{dt}$$
- Energy in *LC* circuit, $U_E = \frac{1}{2}\frac{q^2}{C}$
- Impedance for a series *LCR* circuit,

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

- Average power, $P = \frac{E_0 I_0}{2} \cos\phi = V_{rms} I_{rms} \cos\phi$
- Quality factor $Q = \frac{1}{R}\sqrt{\frac{L}{C}}$

For transformer:

- $$\frac{E_s}{E_p} = \frac{I_p}{I_s} = \frac{N_s}{N_p} = k$$
- $$V_s = \left(\frac{N_s}{N_p}\right) V_p \text{ and } I_s = \left(\frac{N_p}{N_s}\right) I_p$$
- The value of transformer ratio is greater than 1 for step up transformer and less than 1 for step-down transformer.
- $$\eta = \frac{E_s I_s}{E_p I_p}$$
- $$\%\text{Efficiency} = \frac{\text{Output power}}{\text{Input power}} \times 100\%$$

$$= \frac{\text{Input power} - \text{Losses}}{\text{Input power}} \times 100\%$$

For generator:

- $e = e_0 \sin \omega t = NBA\omega \sin \omega t$
- $I = \frac{e}{r} = \frac{NBA\omega \sin \omega t}{R}$

STAND ALONE MCQs (1 Mark each)

Q. 1. If the rms current in a 50 Hz AC circuit is 5 A, the value of the current 1/300 s after its value becomes zero is

(A) $5\sqrt{2}$ A (B) $5\sqrt{\frac{3}{2}}$ A

(C) $\frac{5}{6}$ A (D) $\frac{5}{\sqrt{2}}$ A

Ans. Option (B) is correct.

> *Explanation:* Here, I_{rms} = 5 A, n = 50 Hz and $t = \frac{1}{300}$ s
>
> I_0 = Peak value $= \sqrt{2} I_{rms} = \sqrt{2} \times 5 = 5\sqrt{2}$ A
>
> Now, $I = I_0 \sin \omega t = 5\sqrt{2} \sin 2\pi vt$
>
> $= 5\sqrt{2} \sin 2\pi \times 50 \times \frac{1}{300} = 5\sqrt{\frac{3}{2}}$ A

Q. 2. An alternating current generator has an internal resistance R_g and an internal reactance X_g. It is used to supply power to a passive load consisting of a resistance R_g and a reactance X_L. For maximum power to be delivered from the generator to the load, the value of X_L is equal to

(A) zero (B) X_g

(C) $-X_g$ (D) R_g

Ans. Option (C) is correct.

> *Explanation:* As internal resistance of generator is already equal to external resistance *Rg*. So to deliver maximum power, *i.e.*, to make reactance equal to zero, the reactance in external circuit will be $-X_g$. In order to deliver maximum power, the generator to the load, the total reactance must be equal to zero, *i.e.*, $X_L + X_g = 0$, $X_L = -X_g$.

Q. 3. When a voltage measuring device is connected to AC mains, the meter shows the steady input voltage of 220 V. this means

(A) input voltage cannot be AC voltage, but a DC voltage.

(B) maximum input voltage is 220 V.

(C) The meter reads not v but (v^2) and is calibrated to read $\sqrt{(v^2)}$.

(D) The pointer of the meter is stuck by some mechanical defect.

Ans. Option (C) is correct.

> *Explanation:* The voltmeter in AC circuit reads value $<v^2>$ and meter is calibrated to rms value $<v^2>$ which is multiplied by $\sqrt{2}$ to get V_{rms}. In other words, voltmeter connected to the AC main read root mean square value of AC voltage, *i.e.*, $\sqrt{<v^2>}$.

Q. 4. When frequency of applied alternating voltage very high then

(A) A capacitor will tend to become SHORT

(B) An inductor will tend to become SHORT

(C) Both (A) and (B)

(D) No one will become short

Ans. Option (A) is correct.

> *Explanation:* $X_C = 1/2\pi fC$
>
> So, as f increases, X_C becomes smaller and smaller. For very high value of f, X_C will be too small which may be considered as SHORT.

Q. 5. Relation between r.m.s. voltage and instantaneous voltage of an AC

(A) $V_0 = V_{RMS}/\sqrt{2}$ (B) $V_{RMS} = V_0/\sqrt{2}$

(C) $V_{RMS} = 0.707V_0$ (D) Both (C) and (D)

Ans. Option (D) is correct.

> *Explanation:* $V_{rms} = V_0/\sqrt{2} = 0.707V_0$

Q. 6. The heat produced in a given resistance in a given time by the sinusoidal current $I_0 \sin \omega t$ will be the same as heat produced by a steady current of magnitude

(A) $0.707\ I_0$ (B) $1.412\ I_0$

(C) I_0 (D) $\sqrt{I_0}$

Ans. Option (A) is correct.

> *Explanation:* Heat produced by AC is
>
> Heat produced by DC is I^2R
>
> $I^2_{RMS} = I^2R$
>
> $\therefore I = I_{rms} = I_0/\sqrt{2} = 0.707I_0$

Q. 7. An A.C. source is connected to a resistive circuit. Which of the following statements is true?

(A) Current leads the voltage in phase

(B) Current lags the voltage in phase

(C) Current and voltage are in same phase

(D) Either (A) or (B) depending on the value of resistance.

Ans. Option (A) is correct.

> *Explanation:* In a pure resistive circuit, current and voltage are always in phase.

Q. 8. In which of the following circuit power dissipation is maximum?

(A) Pure capacitive circuit

(B) Pure inductive circuit

(C) Pure resistive circuit

(D) LR or CR circuit

Ans. Option (C) is correct.

> *Explanation:* Since in pure resistive circuit the current and voltage are in phase, the power dissipation is maximum.

Q. 9. To reduce the resonant frequency in an *L-C-R* series circuit with a generator

(A) the generator frequency should be reduced.

(B) another capacitor should be added in parallel to the first.
(C) the iron core of the inductor should be removed.
(D) dielectric in the capacitor should be removed.

Ans. **Option (B) is correct.**

Explanation: The resonant frequency of L-C-R series circuit is $v_o = \frac{1}{2\pi\sqrt{LC}}$

So to reduce resonant frequency, we have either to increase L or to increase C.

To increase capacitance, another capacitor must be connected in parallel with the first.

Q. 10. Which of the following combinations should be selected for better tuning of an L-C-R circuit used for communication?

(A) R = 20 Ω, L = 1.5 H, C = 35 μF
(B) R = 25 Ω, L = 2.5 H, C = 45 μF
(C) R = 15 Ω, L = 3.5 H, C = 30 μF
(D) R = 25 Ω, L = 1.5 H, C = 45 μF

Ans. **Option (C) is correct.**

Explanation: Quality factor (Q) of an L-C-R circuit is given by,

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

Tuning of an L-C-R circuit depends on quality factor of the circuit. Tuning will be better when quality factor of the circuit is high.

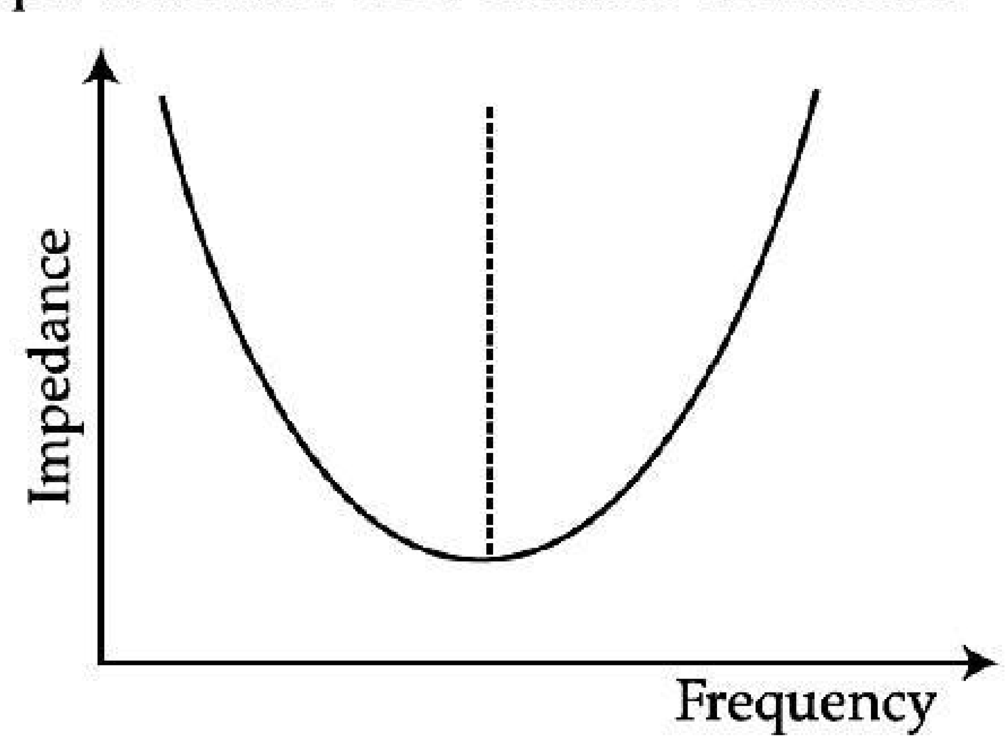
For Q to be high, R should be low, L should be high and C should be low. Therefore, option (C) is most suitable.

Q. 11. With increase in frequency of an A.C. supply, the impedance of a series L-C-R circuit

(A) remains constant.
(B) increases.
(C) decreases.
(D) decreases at first, becomes minimum and then increases.

Ans. **Option (D) is correct.**

Explanation: The frequency vs. impedance graph of a series LCR circuit is as follows:



With increase in frequency, the impedance decreases at first, becomes minimum and then increases.

Q. 12. The sharpness of tuning of a series LCR circuit at resonance is measured by Q factor of the circuit which is given by

(A) $Q = \frac{1}{R}\sqrt{\frac{L}{C}}$ (B) $Q = \frac{1}{R}\sqrt{\frac{C}{L}}$

(C) $Q = \frac{1}{L}\sqrt{\frac{R}{C}}$ (D) $Q = \frac{1}{C}\sqrt{\frac{R}{L}}$

Ans. **Option (A) is correct.**

Explanation: Q factor of a series LCR circuit is given by $Q = \frac{1}{R}\sqrt{\frac{L}{C}}$

Q. 13. At resonance, the impedance in series LCR circuit is

(A) maximum. (B) zero.
(C) infinity. (D) minimum.

Ans. **Option (D) is correct.**

Explanation: Impedance of a series LCR circuit is $Z = \sqrt{R^2 + (X_C - X_L)^2}$

At resonance, $X_C = X_L$

So, Z is minimum.

Q. 14. The power factor of series LCR circuit at resonance is

(A) 0.707 (B) 1
(C) 0.5 (D) 0

Ans. **Option (B) is correct.**

Explanation: At resonance, LCR circuit behaves as purely resistive circuit. For purely resistive circuit, power factor is 1.

Q. 15. When a capacitor C is charged to a certain potential and connected to an inductor L, then frequency of energy oscillation is given by

(A) $\frac{1}{2\pi\sqrt{LC}}$ (B) $\frac{1}{\sqrt{LC}}$

(C) $\frac{2\pi}{\sqrt{LC}}$ (D) $\frac{1}{2\pi}\sqrt{\frac{L}{C}}$

Ans. **Option (A) is correct.**

Explanation: When a capacitor C is charged to a certain potential and connected to an inductor L, energy stored in C oscillates between L and C.

$$X_L = X_C$$

$$\therefore \quad f = \frac{1}{2\pi\sqrt{LC}}$$

Q. 16. The output of a step-down transformer is measured to be 24 V when connected to a 12 W Light bulb. The value of the peak current is

(A) $1/\sqrt{2}$ A (B) $\sqrt{2}$ A
(C) 2 A (D) $2\sqrt{2}$ A

Ans. **Option (A) is correct.**

Explanation: Given,

Power associated with secondary, P_s = 12 W

Secondary voltage, V_s=24 V

Current in the secondary, $I_s = \frac{P_s}{V_s} = \frac{12}{24} = 0.5\ A$

Peak value of the current in the secondary,

$I_0 = I_s\sqrt{2} = (0.5)(1.414) = 0.707$ or $\frac{1}{\sqrt{2}}$ A.

Q. 17. The underlying principle of transformer is
(A) resonance.
(B) mutual induction.
(C) self induction.
(D) none of the above.

Ans. Option (B) is correct.

> ***Explanation:*** The transformer is based on the principle of mutual induction which state that due to continuous change in current in the primary coil, an emf is induced across the secondary soil.

Q. 18. The core of a transformer is laminated as
(A) it improves the ratio of voltage in the primary and secondary may be increased.
(B) it checks rusting of the core may be stopped.
(C) it reduces energy losses due to eddy currents.
(D) it increases flux linkage.

Ans. Option (C) is correct.

> ***Explanation:*** Laminated core means a layered core instead of a single solid core. Eddy currents are current loops generated by changing magnetic fields. They flow in a plane perpendicular to the magnetic field.
>
> Laminated magnetic core reduces eddy currents. For this reason, electrically isolated laminations are utilized to manufacture transformers.

Q. 19. If rotational velocity of an armature is doubled, emf generated in a generator will be
(A) half. (B) two times.
(C) four times. (D) unchanged.

Ans. Option (B) is correct.

> ***Explanation:*** emf generated = NBA $\omega \sin \omega t$
>
> As ω becomes double, emf generated also becomes double.

Q. 20. Quantity that remains unchanged in a transformer is
(A) voltage. (B) current.
(C) frequency. (D) none of these.

Ans. Option (C) is correct.

> ***Explanation:*** Transformer does not change the frequency of the applied AC.

Q. 21. _______ increases in step-down transformer.
(A) Voltage (B) Current
(C) Power (D) Current density

Ans. Option (B) is correct.

> ***Explanation:*** Since $V_P/V_S = I_S/I_P$, so as as voltage reduces, the current increases in a step-down transformer.

Q. 22. The efficiency of transformer is very high because
(A) There is no moving part
(B) It uses AC only
(C) It uses the copper wire for the coils
(D) None of the above

Ans. Option (A) is correct.

> ***Explanation:*** Transformer is a static device which transforms power from one circuit to other through electromagnetic induction. In electrical transformer as there are no moving parts, no friction. Losses in the transformer are very less compared to any other rotating machine, hence efficiency of transformers will be very high which is about 95% to 98%.

ASSERTION AND REASON BASED MCQs (1 Mark each)

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

(A) Both A and R are true and R is the correct explanation of A
(B) Both A and R are true but R is NOT the correct explanation of A
(C) A is true but R is false
(D) A is false and R is true

Q. 1. Assertion (A): An alternating current does not show any magnetic effect.
Reason (R): Alternating current changes direction with time.

Ans. Option (D) is correct.

> ***Explanation:*** Current or moving charged particle creates magnetic field irrespective of direct current or alternating current. So assertion is false. Alternating current changes direction with time. So, the reason is true, but cannot explain the assertion.

Q. 2. Assertion (A) : Capacitor blocks *dc* and allows *ac* to pass.
Reason (R): Capacitive reactance is inversely proportional to frequency.

Ans. Option (A) is correct.

> ***Explanation:*** Capacitive reactance = $\frac{1}{2\pi f C}$
>
> So, as f (frequency) increases, reactance decreases.
>
> For *dc*, frequency = 0, hence capacitor offers infinite reactance. So, it blocks dc.
>
> For *ac*, frequency ≠ 0, hence capacitor offers low reactance and allows ac to pass.
>
> Hence assertion and reason both are true. Assertion is properly explained by reason.

Q. 3. Assertion (A): V_{RMS} value of an alternating voltage $V = 4\sqrt{2} \sin 314t$ is 4 volt.
Reason (R): Peak value of the alternating voltage is $4\sqrt{2}$ volt.

Ans. Option (B) is correct.

Explanation: Given alternating voltage $V = 4\sqrt{2}\sin 314t$.

Where peak value = $V_0 = 4\sqrt{2}$ volt.

$V_{RMS} = V_0/\sqrt{2} = 4$ volt.

Hence both assertion and reason both are true. But the reason does not properly explain the assertion.

Q. 4. Assertion (A): Both *ac* and *dc* can be measured by hot wire instrument.

Reason (R): Hot wire instrument is based on the principal of magnetic effect of current.

Ans. Option (C) is correct.

Explanation: In both *ac* and *dc*, heat generated is proportional to the square of current. Polarity change of *ac* is immaterial in the case of heat generation. Hence they can be measured by hot wire instrument. Hence, the assertion is true.

Hot wire instruments are based on the principle of heating effect of current. Hence the reason is false.

Q. 5. Assertion (A): The dimension of L/R is time.

Reason (R): Time constant (L/R) should be increased to reduce the rate of increase of current through a solenoid.

Ans. Option (B) is correct.

Explanation: For a solenoid, the magnitude of induced emf

$$e = L\frac{di}{dt}$$

$$i = \frac{e}{R} = \left(\frac{L}{R}\right)\left(\frac{di}{dt}\right)$$

$$\frac{di}{dt} = \frac{i}{\frac{L}{R}}$$

In left hand side of the above equation, denominator is time. So, in right hand side, the denominator should be time. So, dimension of L/R is time.

So, the assertion is true.

If L/R increases, *di/dt* decreases.

So, reason is also true.

But reason cannot properly explain the assertion.

Q. 6. Assertion (A): At resonance, the current becomes minimum in a series LCR circuit.

Reason (R): At resonance, voltage and current are out of phase in a series LCR circuit.

Ans. Option (D) is correct.

Explanation: At resonance, $X_L = X_C$, so the circuit impedance becomes minimum and resistive and hence the current becomes maximum. So, the assertion is false.

At resonance, $X_L = X_C$, so the circuit impedance becomes resistive. In resistive circuit voltage and current are always in same phase. Hence, reason is also false.

Q. 7. Assertion (A): When capacitive reactance is less than the inductive reactance in a series LCR circuit, e.m.f. leads the current.

Reason (R): The angle by which alternating voltage leads the alternating current in series RLC circuit is given by $\tan\varphi = \frac{X_L - X_C}{R}$.

Ans. Option (A) is correct.

Explanation: The angle by which alternating voltage leads the alternating current in series RLC circuit is given by $\tan\varphi = \frac{X_L - X_C}{R}$.

If $X_C < X_L$, then $\tan\varphi$ is positive. φ is also positive. So, e.m.f. leads the current.

Assertion and reason both are true. Reason properly explains the assertion.

Q. 8. Assertion (A): Quality factor of a series LCR circuit is $Q = \frac{1}{R}\sqrt{\frac{L}{C}}$

Reason (R): As bandwidth decreases, Q increases in a resonant LCR circuit.

Ans. Option (B) is correct.

Explanation: Quality factor of a series LCR circuit is $Q = \frac{1}{R}\sqrt{\frac{L}{C}}$. Assertion is true.

Quality factor is also defined as $Q = \frac{\text{Resonant frequency}}{\text{Bandwidth}}$. So, as bandwidth decreases, Q increases. So, reason is also true. But reason does not explain the assertion.

Q. 9. Assertion (A): Principle of operation of AC generator is electromagnetic induction.

Reason (R): Resistance offered by inductor for AC is zero.

Ans. Option (B) is correct.

Explanation: Principle of operation of AC generator is electromagnetic induction. The assertion is true.

Resistance offered by inductor = $2\pi f L$. For AC, $f \neq 0$. So, $2\pi f L \neq 0$. So, the reason is false.

Q. 10. Assertion (A): An alternator is a machine which converts mechanical energy into electrical energy.

Reason (R): When a coil rotates in a magnetic field an e.m.f. is induced in it.

Ans. Option (A) is correct.

Explanation: Alternator is basically a generator in which a coil rotates in a strong magnetic field and according to laws of electromagnetic induction e.m.f. is generated. So, assertion and reason both are true and reason explains the assertion.

Q. 11. Assertion (A): A transformer does not work on DC.

Reason (R): DC neither change direction nor magnitude.

Ans. Option (A) is correct.

Explanation: Transformer has two coils. If current fluctuates in one coil, e.m.f. is induced in the other coil. For DC supply current does not change, so there is no induced e.m.f. Hence both assertion and reason are true and reason explains the assertion.

Q. 12. Assertion (A): A step-up transformer converts input low AC voltage to output high AC voltage.

Reason (R): It violate the law of conservation of energy.

Ans. Option (C) is correct.

Explanation: Step-up transformer means it converts input low AC voltage to output high AC voltage. So, the assertion is true.

For step up transformer, $V_{OUT} / V_{IN} > 1$, but simultaneously $I_{OUT} / I_{IN} < 1$ and $P_{IN} = P_{OUT}$ (ideally). Hence, the law of conservation of energy is not violated.

CASE-BASED MCQs

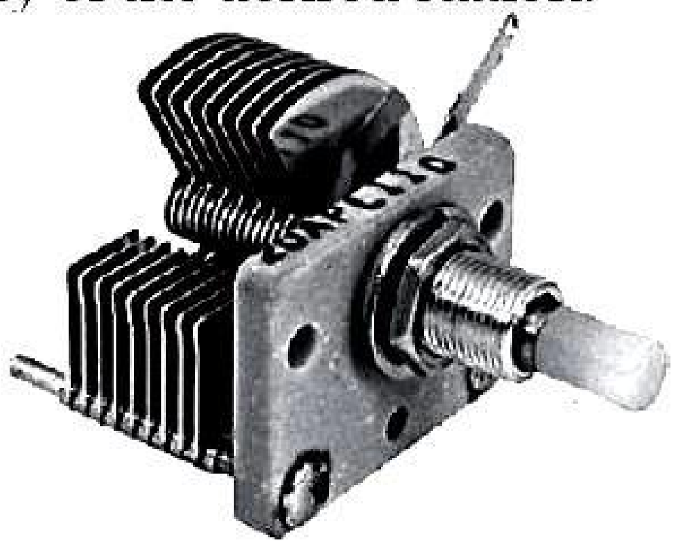
Attempt any 4 sub-parts out of 5. Each sub-part carries 1 mark.

I. Read the following text and answer the following questions on the basis of the same:

Tuning a radio set: In essence the simplest tuned radio frequency receiver is a simple crystal set. Desired frequency is tuned by a tuned coil / capacitor combination, and then the signal is presented to a simple crystal or diode detector where the amplitude modulated signal, is demodulated. This is then passed straight to the headphones or speaker. In radio set there is an LC oscillator comprising of a variable capacitor (or sometimes a variable coupling coil), with a knob on the front panel to tune the receiver.

Capacitor used in old radio sets is gang capacitor. It consists of two sets of parallel circular plates one of which can rotate manually by means of a knob. The rotation causes overlapping areas of plates to change, thus changing its capacitance. Air gap between plates acts as dielectric.

The capacitor has to be tuned in tandem corresponding to the frequency of a station so that the LC combination of the radio set resonates at the frequency of the desired station.



When capacitive reactance (X_C) is equal to the inductive reactance (X_L), then the resonance occurs and the resonant frequency is given by $\omega_0 = \frac{1}{\sqrt{LC}}$ current amplitude becomes maximum at the resonant frequency. It is important to note that resonance phenomenon is exhibited by a circuit only if both L and C are present in the circuit. Only then do the voltages across L and C cancel each other (both being out of phase) and the Current amplitude is $\frac{V_m}{R}$, the total source voltage appearing across R.

This means that we cannot have resonance in a RL or RC circuit.

Q. 1. Name the phenomenon involved in tuning a radio set to a particular radio station.

(A) Stabilization **(B)** Rectification

(C) Resonance **(D)** Reflection

Ans. Option (C) is correct.

Explanation: Phenomenon involved in tuning a radio set to a particular radio station is resonance.

The capacitor has to be tuned in tandem corresponding to the frequency of a station. So, that the LC combination of the radio set resonates at the frequency of the desired station.

Q. 2. Resonance may occur in:

(A) RL circuit.

(B) RC circuit.

(C) LC circuit.

(D) circuit having resistor only.

Ans. Option (C) is correct.

Explanation: A simple radio receiver is a simple crystal set with a coil and capacitor combination. Desired frequency is tuned by tuning the coil - capacitor combination. Tuning means to make capacitive reactance (X_C) equal to the inductive reactance (X_L), so that the resonance occurs.

Q. 3. Resonance frequency is equal to:

(A) $\frac{1}{LC}$ **(B)** $1/\sqrt{LC}$

(C) $\sqrt{\frac{L}{C}}$ **(D)** $\sqrt{\frac{C}{L}}$

Ans. Option (B) is correct.

Explanation: The resonant frequency is given by $\omega_0 = 1/\sqrt{LC}$

Q. 4. Resonance occurs only when:

(A) $X_C = R$ **(B)** $X_L = R$

(C) $X_L = X_C$ **(D)** $X_C > X_L$

Ans. Option (C) is correct.

Explanation: At resonance, capacitive reactance (X_C) is equal to the inductive reactance (X_L). Circuit is totally resistive and the current amplitude becomes maximum.

Q. 5. Capacitor used in radio set for tuning is a:

(A) parallel plate capacitor.
(B) spherical capacitor.
(C) paper capacitor.
(D) electrolytic capacitor.

Ans. Option (A) is correct.

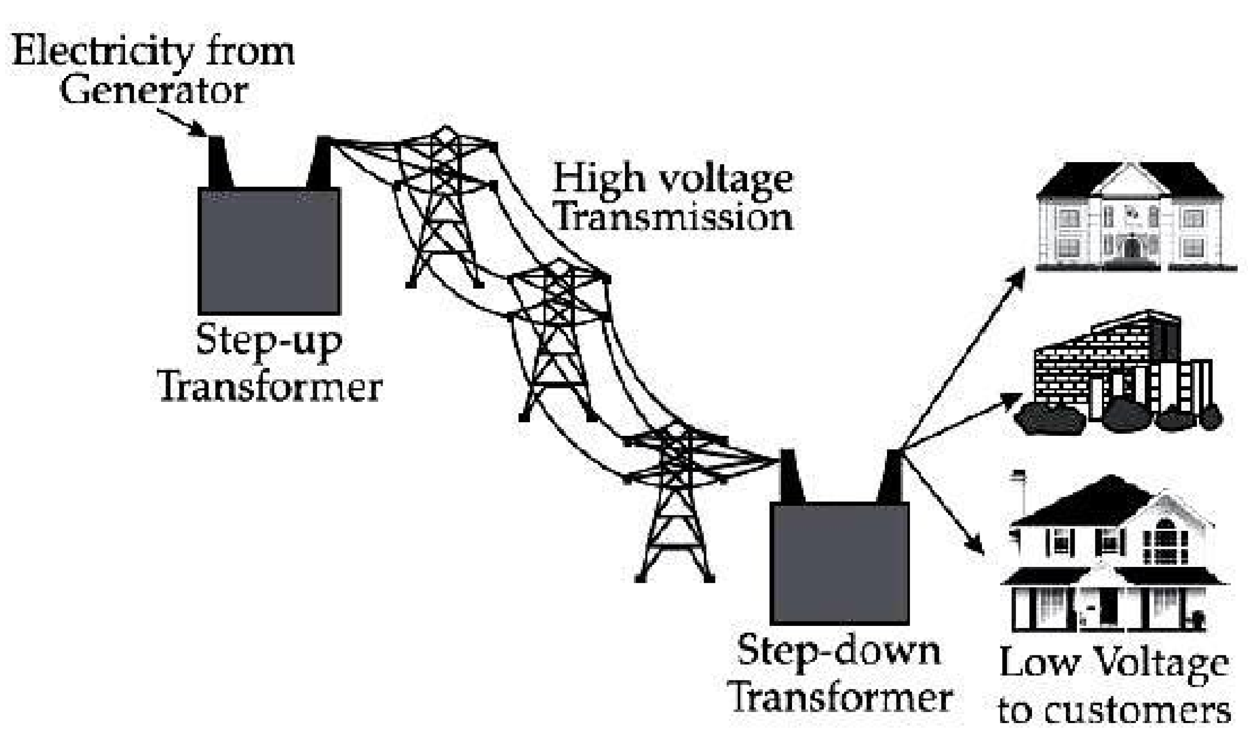
> ***Explanation:*** Capacitor used in old radio is a parallel plate capacitor. It consists of two sets of parallel circular plates , one of which can rotate manually by means of a knob. The rotation causes overlapping areas of plates to change, thus changing its capacitance.

II. Read the following text and answer the following questions on the basis of the same:

At power plant, a transformer increases the voltage of generated power by thousands of volts so that it can be sent of long distances through high-voltage transmission power lines. Transmission lines are bundles of wires that carry electric power from power plants to distant substations.

At substations, transformers lower the voltage of incoming power to make it acceptable for high-volume delivery to nearby end-users.

Electricity is sent at extremely high voltage because it limits so-called line losses. Very good conductors of electricity also offer some resistance and this resistance becomes considerable over long distances causing considerable loss.



At generating station, normally voltage is stepped up to around thousands of volts. Power losses increase with the square of current. Therefore, keeping voltage high current becomes low and the loss is minimized.

Another option of minimizing loss is the use of wires of super-conducting material. Super-conducting materials are capable of conducting without resistance, they must be kept extremely cold, nearly absolute zero, and this requirement makes standard super-conducting materials impractical to use. However, recent advances in super-conducting materials have decreased cooling requirement. In Germany recently 1 km super-conducting cable have been installed connecting the generating station and the destination. It has eliminated the line loss and the cable is capable of sending five times more electricity than conventional cable. Using super-conducting cables Germany has also get rid of the need of costly transformers.

Transformers generate waste heat when they are in operation and oil is the coolant of choice. It transfers the heat through convection to the transformer housing, which has cooling fins or radiators similar to heat exchangers on the outside.

Flush point is a very important parameter of transformer oil. Flashpoint of an oil is the temperature at which the oil ignites spontaneously. This must be as high as possible (not less than 160º C from the point of safety).

Fire point is the temperature at which the oil flashes and continuously burns. This must be very high for the chosen oil (not less than 200º C).

Q. 1. Which of the following statement is true for long distance transmission of electricity?

(A) Step-down transformer is used at generating station and step-up transformer is used at destination substation.

(B) Step-down transformers are used at generating station and destination substation.

(C) Step-up transformers are used at generating station and destination substation.

(D) None of the above

Ans. Option (D) is correct.

> ***Explanation:*** At power plant, a step-up transformer increases the voltage of generated power by thousands of volts, so that it can be sent of long distances through high-voltage transmission power lines.
>
> At substations, step-down transformers lower the voltage of incoming power to make it acceptable for high-volume delivery to nearby end-users.

Q. 2. Super-conducting transmission line has the following advantages:

(A) Resistance being zero, there is no I^2R loss.

(B) There is no requirement of costly step-up and step-down transformers.

(C) Cable is capable of sending more electricity.

(D) All of the above

Ans. Option (D) is correct.

> ***Explanation:*** Super-conducting materials are capable of conducting without resistance. So, this eliminates the line loss and the cable is capable of sending more electricity than conventional cable. Using super-conducting cables, one can get rid of the need of costly transformers.

Q. 3. Why does stepping up voltages reduce power loss?

(A) Since resistance of conductor decreases with increase of voltage

(B) Since current decreases with increase of voltage

(C) Both of the above

(D) None of the above

Ans. Option (B) is correct.

> ***Explanation:*** At generating station, normally voltage is stepped up to around thousands of volts. Power losses increase with the square of current. Therefore, keeping voltage high, current becomes low and the loss is minimized.

Q. 6. Oil transfers heat from transformer winding by the process of:

(A) convection. (B) conduction.
(C) radiation. (D) All of these

Ans. Option (A) is correct.

> ***Explanation:*** Transformers generate waste heat when they are in operation and oil is the coolant of choice. It transfers the heat through convection to the transformer housing.

Q. 7. Flush point of an oil is

(A) the temperature at which the oil flashes and continuously burns.
(B) the temperature at which the oil ignites spontaneously.
(C) the temperature at which the oil starts boiling.
(D) The temperature at which the oil forms fumes.

Ans. Option (B) is correct.

> ***Explanation:*** Flush point is a very important parameter of transformer oil. Flashpoint of an oil is the temperature at which the oil ignites spontaneously. This must be as high as possible (not less than 160° C from the point of safety).

III. Read the following text and answer the following questions on the basis of the same:

Losses of transformer

There are 4 types of losses in a transformer: Core loss, Ohmic loss, Stray load loss and dielectric loss.

(1) Core loss

Core loss has two components - hysteresis loss and eddy current loss. These together are called no-load losses of a transformer and are calculated by open circuit test.

(a) Hysteresis loss: This loss mainly depends on the core material used in the transformer. To reduce this loss, the high-grade core material can be used. CRGO- Cold rolled grain oriented Si steel is commonly used for this purpose.

(b) Eddy current loss: This loss can be reduced by designing the core using slight laminations.

These losses are present even when no load is connected. So, these are also known as no-load loss.

(2) Copper Loss

Copper losses occur because of the Ohmic resistance in the windings of the transformer. If the currents in primary and secondary windings of the transformer are I_1 and I_2, and if the resistances of these windings are R_1 & R_2 then the copper losses that occurred in the windings are $I_1^2R_1$ & $I_2^2R_2$ respectively. So, the entire copper loss will be $I_1^2R_1 + I_2^2R_2$.

This loss is also called variable or ohmic losses because this loss changes based on the load.

(3) Stray Loss

These types of losses in a transformer occur because of the occurrence of the leakage flux. As compared with copper and iron losses, the percentage of stray losses are less, so these losses can be neglected.

(4) Dielectric Loss

This loss mainly occurs within the oil of the transformer. Oil is an insulating material. Once the oil quality in the transformer deteriorates then the transformer's efficiency is affected.

Efficiency of Transformer

It is the ratio of output power and input power.

Efficiency = Output Power / Input Power.

The transformer is a highly efficient device which ranges between 95% – 98.5%.

Q.1. What is the relationship among core loss, hysteresis loss and eddy current loss?

(A) Eddy current loss = Core loss + Hysteresis loss
(B) Core loss = Hysteresis loss + eddy current loss
(C) Hysteresis loss = Core loss + eddy current loss
(D) Core loss = Hysteresis loss X eddy current loss

Ans. Option (B) is correct.

Q. 2. Which of the following losses in transformer is also known as no-load loss?

(A) Copper loss (B) Stray loss
(C) Dielectric loss (D) Core loss

Ans. Option (D) is correct.

> ***Explanation:*** Core loss is present even when no load is connected. So, these are also known as no-load loss.

Q.3. Which of the following losses in transformer is also known as variable loss?

(A) Copper loss (B) Stray loss
(C) Dielectric loss (D) Core loss

Ans. Option (A) is correct.

> ***Explanation:*** If the currents in primary and secondary windings of the transformer are I_1 and I_2 respectively and the resistances of these windings are R_1 and R_2 then the copper losses that occurred in the windings are $I_1^2R_1$ and $I_2^2R_2$ respectively. So, the entire copper loss will be $I_1^2R_1 + I_2^2R_2$.
> This loss is also called variable or ohmic losses because this loss changes based on the load.

Q. 4. How hysteresis loss can be reduced?

(A) Using core of Si Steel
(B) Using laminated core
(C) Using core of non-ferromagnetic material
(D) Using oil of higher dielectric constant

Ans. Option (A) is correct.

Q. 5. Specify the range of transformer efficiency.

(A) 10-15% (B) 95-98%
(C) 50-60% (d) 40-50%

Ans. Option (B) is correct.