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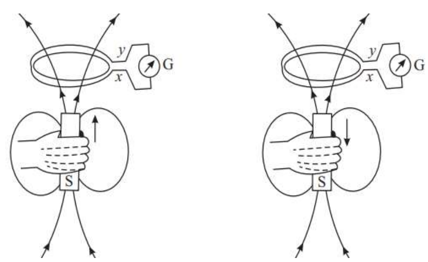
ELECTROMAGNETIC INDUCTION AND ALTERNATING CURRENT

ELECTROMAGNETIC INDUCTION



Current is induced only when the magnetic field due to the current in the circuit on the left changes.

This phenomenon in which a magnetic field induces an emf is termed as electromagnetic induction.

Faraday's Law of Electromagnetic Induction

The relationship between the changing magnetic field and the induced emf is expressed in terms of magnetic flux φB linked with the surface of the coil.

the magnetic flux dφB for the area element ds as dφB = B.ds

The SI unit of magnetic flux is weber (Wb), where 1 Wb = 1 Tm^2 .

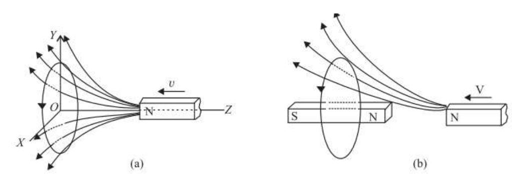
Faraday's law states that an emf is induced across a loop of wire when the magnetic flux linked with the surface bound by the loop changes with time. The magnitude of induced emf is proportional to the rate of change of magnetic flux.

$$|\varepsilon| = \frac{d\varphi_B}{dt}$$

Lenz's Law

When a current is induced in a conductor, the direction of the current will be such that its magnetic effect opposes the change that induced it.

$$\varepsilon = -\frac{d\varphi}{dt}$$



Eddy currents

Induced closed loops of currents are set up in the body of the conductor due to the change of flux linked with it. These currents flow in closed paths and in a direction perpendicular to the magnetic flux. These currents are called eddy currents as they look like eddies or whirlpools and also sometimes called Foucault currents as they were first discovered by Foucault.

INDUCTANCE

When current in a circuit changes, a changing magnetic field is produced around it. If a part of this field passes through the circuit itself, current is induced in it.

By changing current in a coil, the magnetic flux linked with each turn of the coil changes and hence an induced emf appears across that coil. This property is called self-induction. for a pair of coils situated close to each other such that the flux associated with one coil is linked through the other, a changing current in one coil induces an emf in the other.

Mutual induction of the pair of coils.

$\varphi \propto I$ or $\varphi = LI$

where L is called self-inductance of the coil. The circuit elements which oppose change in current are called inductors

Faraday's Law in terms of Self-Inductance

if current in a loop changes, the magnetic flux linked through it also changes and gives rise to self–induced emf between the ends

$\varepsilon = -\, d\varphi\ dt = -L\ dI\ dt$

ohm-second is called a henry

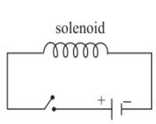
current through an inductor cannot change instantaneously

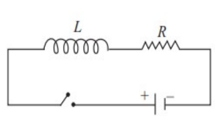
Self-inductance of a solenoid

$$L = \frac{\varphi}{I} = \frac{\mu_0 N^2 A}{l}$$

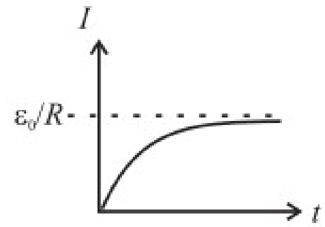
LR Circuits

A solenoid has inductance (L) and resistance (R), and each of these influence the current in the circuit

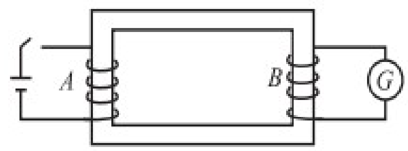




The time taken by the current to reach about two-third of its steady state value is equal to by L/R, which is called the inductive time constant of the circuit.



Mutual Inductance



When current changes in a coil, a changing magnetic flux develops around it, which may induce emf across an adjoining coil.

$$\varphi_2 = MI_1$$

A solenoid has inductance (L) and resistance (R), and each of these influence the current in the circuit

$$e_2 = -M\frac{dI}{dt}$$

The SI unit of mutual inductance is also henry (H), the same as the unit of self-inductance

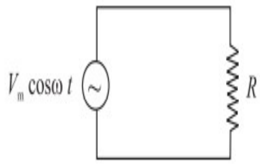
ALTERNATING CURRENTS AND VOLTAGES

$V = V_m \cos \omega t$ (19.12a) and $I = I_m \cos \omega t$

Vm and I m are known as the peak values of the alternating voltage and current respectively.

AC Source Connected to a Resistor

$I = \frac{V}{R}$



I = I m cos ωt

Average power

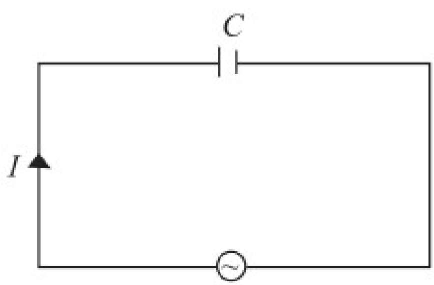
$$P_{av} = R\left(\frac{{I_{rms}}^2}{2}\right)$$

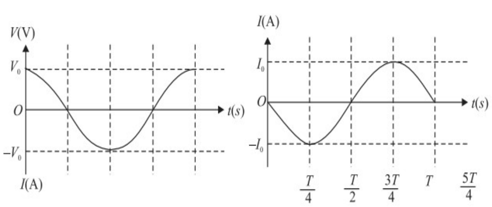
AC Source Connected to a Capacitor

q = CVm cos ωt

Since I = dq/dt, we can write

I = – ωCVm sin ωt



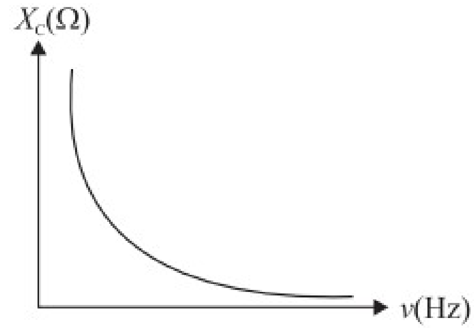


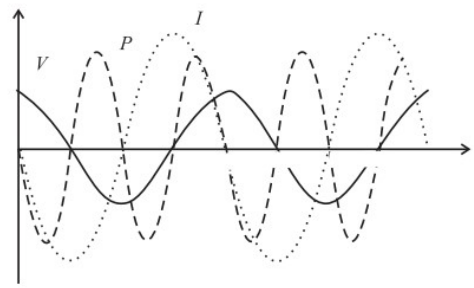
$$I = \frac{V_m}{1/_{\omega c}}\sin wt$$

$$X_c = \frac{1}{\omega C} = \frac{1}{2\pi\nu C}$$

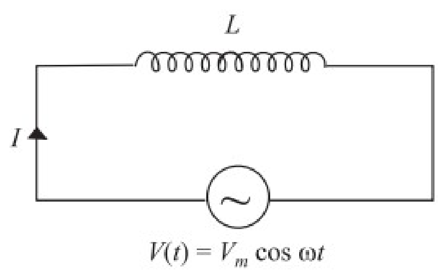
$$I_{rms} = \frac{V_{rms}}{X_c}$$

$$P = -\frac{1}{2}\omega C V^2 \sin 2\omega t$$



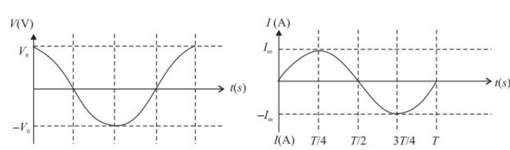


AC Source Connected to an Inductor

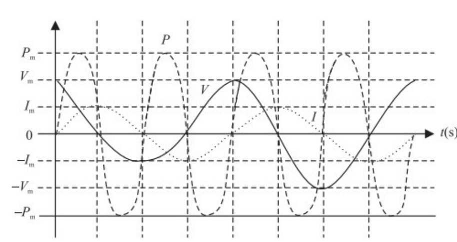


$V(t) = V_m \cos \omega t$

$I(t) = \frac{V_m}{\omega L}\sin \omega t + \text{constant}$

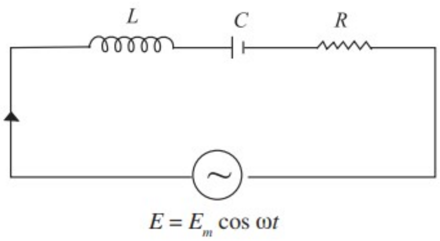


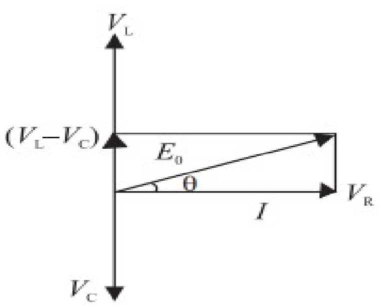
$X_L = \omega L = 2\,\pi\nu L$



Inductive reactance is a measure of the extent to which the inductor limits ac current in the circuit. It depends on the inductance and the frequency of the generator

Series LCR Circuit





$$\frac{E_0}{I_0} = \sqrt{(X_L - X_c)^2 + R^2}$$

$$V_f = \frac{1}{2\pi\sqrt{LC}}$$

This frequency is called resonance frequency and at this frequency impedance is minimum.

Power in a LCR Circuit

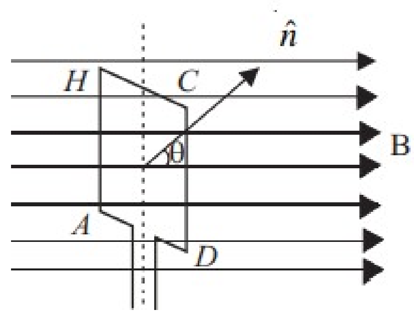
$$\boldsymbol{Average\ power} = \frac{\boldsymbol{V_m}}{\sqrt{\boldsymbol{2}}}\frac{\boldsymbol{V_m}}{\sqrt{\boldsymbol{2}}\boldsymbol{Z}}\,\mathbf{cos}\,\boldsymbol{\varphi}$$

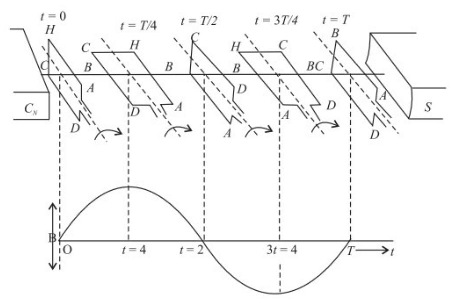
POWER GENERATOR

A generator is a device that converts mechanical energy into electrical energy with the help of magnetic field. A conductor or a set of conductors is rotated in a magnetic field and voltage is developed across the rotating conductor due to electromagnetic induction. The energy for the rotation of the conductors can be supplied by water, coal, diesel or gas or even nuclear fuel. Accordingly, we have hydro-generators, thermal generators, and nuclear reactors, respectively.

A.C. Generator or Alternator

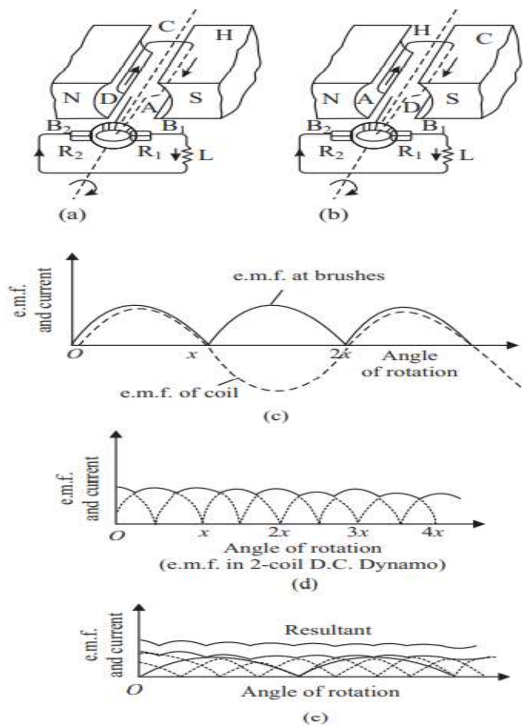
A generator basically consists of a loop of wire rotating in a magnetic field.





Dynamo (DC Generator)

A dynamo is a machine in which mechanical energy is changed into electrical energy in the form of direct current



TRANSFORMER

Basically, a transformer is a device which transfers electric energy (or power) from primary windings to secondary win

the resistance of the primary and secondary coils is zero; z there is no flux leakage so that the same magnetic flux is linked with each turn of the primary and secondary coils; and z there is no energy loss in the core.

Types of transformers

A step-up transformer increases the voltage (decreases the current) in secondary windings

A step-down transformer decreases the voltage (increases the current) in the secondary windings.

Efficiency of Transformers

$$\eta = \frac{\text{Energy output}}{\text{Energy input}} \times \mathbf{100}$$

Check Yourself

1. In a transformer the energy losses result from
   A. Resistive heating in copper coils - cooper loss,
   B. Eddy current losses in form of heating of iron core - Eddy current loss.
   C. Magnetization heating of the core during repeated reversal of magnetization - hysteresis loss.
   D. Flux leakage from the core.

2. If L and R represents inductance and resistance respectively,then dimension of L/R will be
   A. T^{-1}
   B. LT
   C. L
   D. None of the above
3. When a capacitor is being charged the charged current
   A. Increase
   B. Decrease
   C. Constant
   D. Incomplete data
4. In an a.c. circuit the current
   A. Is in phase with the voltage
   B. Leads the voltage
   C. Lags the voltage
   D. Any of the one depending upon circumstances
5. An LCR circuit the capacitance is made one forth when in resonance.Than what should be the change in inductance sothat the circuit emain in resonance
   A. 4 times
   B. ¼ times
   C. 8 times

2 times

Stretch Yourself

1. Calculate the frequency at which the inductive reactance of 0.7 H inductor is 220 ohm
2. What are the advantages of A.C. over D.C.
3. What is a phasor and what is a phasor diagram
4. What is electromagnetic induction?
5. What are eddy current? what are their harmful effects

Hint to Check Yourself

1 2C 3B 4 D 5 A