Eddy currents

Currents induced in the conductor due to changing magnetic flux are called eddy currents. They flow in closed loops in plane perpendicular to the magnetic field. The value of eddy currents can be found using faraday's law of electromagnetic induction.

Applications and disadvantages of eddy currents

Eddy currents are used to advantage in certain applications like:
(i) **Magnetic braking in trains**: Strong electromagnets are situated above the rails in some electrically powered trains. When the electromagnets are activated, the eddy currents induced in the rails oppose the motion of the train. As there are no mechanical linkages, the braking effect is smooth.
(ii) **Electromagnetic damping**: Certain galvanometers have a fixed core made of nonmagnetic metallic material. When the coil oscillates, the eddy currents generated in the core oppose the motion and bring the coil to rest quickly.
(iii) **Induction furnace**: Induction furnace can be used to produce high temperatures and can be utilised to prepare alloys, by melting the constituent metals. A high frequency alternating current is passed through a coil which surrounds the metals to be melted. The eddy currents generated in the metals produce high temperatures sufficient to melt it.
(iv) **Electric power meters**: The shiny metal disc in the electric power meter(analogue type) rotates due to the eddy currents. Electric currents are induced in the disc by magnetic fields produced by sinusoidally varying currents in a coil.
Disadvantages of eddy current include:
1. Heat is lost in the core of transformers due to eddy currents.
2. The value of eddy current is highly sensitive to the value of permeability. This causes difficulty in the functioning of detectors.

Inductance

Inductance is the property of an electrical conductor by which a change in current through it induces an electromotive force in both the conductor itself. It is the constant of proportionality that relates flux linkage with current.

Dependency of geometric parameters on inductance of a coil

NUMBER OF WIRE WRAPS, OR TURNS IN THE COIL: All other factors being equal, a greater number of turns of wire in the coil results in greater inductance; fewer turns of wire in the coil results in less inductance.
COIL AREA: All other factors being equal, greater coil area (as measured looking lengthwise through the coil, at the cross-section of the core) results in greater inductance; less coil area results in less inductance.
COIL LENGTH: All other factors being equal, the longer the coils length, the less inductance; the shorter the coils length, the greater the inductance.

Inductor

An inductor is also called a coil or a reactor, is a passive two-terminal electrical component that stores electrical energy in a magnetic field when electric current is flowing through it. An inductor typically consists of an electric conductor, such as a wire, that is wound into a coil.

Flux linkage

For a closely wound coil of N turns, the same magnetic flux is linked with all the turns. When the flux ϕ_B through the coil changes, each turn contributes to the induced emf. Therefore, a term called flux linkage is used which is equal to $N\phi_B$ for a closely wound coil and in such a case $N\phi_B \propto IN$

Mutual inductance

If two coils of wire are brought into close proximity with each other so the magnetic field from one links with the other, a voltage will be generated in the second coil as a result. This is called ***mutual inductance*** when voltage impressed upon one coil induces a voltage in another.

Self inductance

Self inductance is defined as the induction of a voltage in a current-carrying wire when the current in the wire itself is changing. In the case of self-inductance, the magnetic field created by a changing current in the circuit itself induces a voltage in the same circuit. Therefore, the voltage is self-induced.The self-inductance of the coil depends on its geometry and on the permeability of the medium.

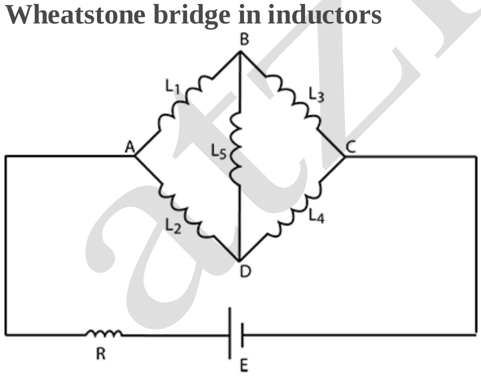
Back emf

The **back electromotive force**, is the voltage, or electromotive force, that pushes against the current which induces it. Back emf is the voltage drop in an alternating current (AC) circuit caused by magnetic induction.For example, the voltage drop across an inductor is due to the induced magnetic field inside the coil.The voltage's polarity is at every moment the reverse of the input voltage.

Back emf playing the role of inertia

The self-induced emf is also called the back emf as it opposes any change in the current in a circuit. Physically, the self-inductance plays the role of inertia. It is the electromagnetic analogue of mass in mechanics.So, work needs to be done against the back emf in establishing the current. This work done is stored as magnetic potential energy.

Wheatstone bridge in inductors

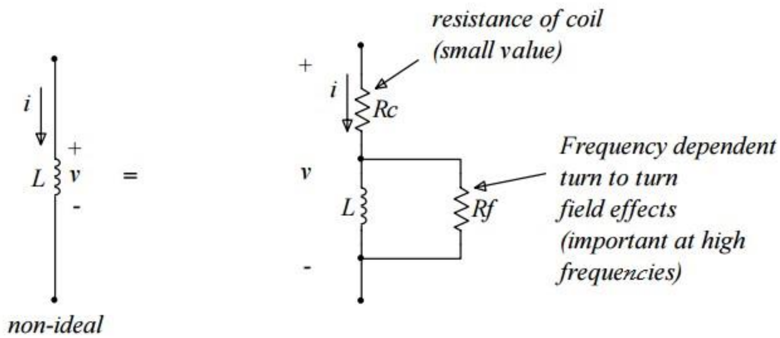


The attached figure shows the figure of a wheatstone bridge of inductors. In balance condition, $V_B=V_D$ and no current flows through L_5 and hence it acts as an open circuit.
The condition for achieving this balance is $L_1L_4=L_2L_3$

Inductor as an open circuit during switching

The stored energy in an inductor tries to maintain a constant current through its windings. Because of this, inductors oppose changes in current, and act precisely the opposite of capacitors, which oppose changes in voltage. A fully discharged inductor (no magnetic field), having zero current through it, will initially act as an open-circuit when attached to a source of voltage (as it tries to maintain zero current), dropping maximum voltage across its leads.

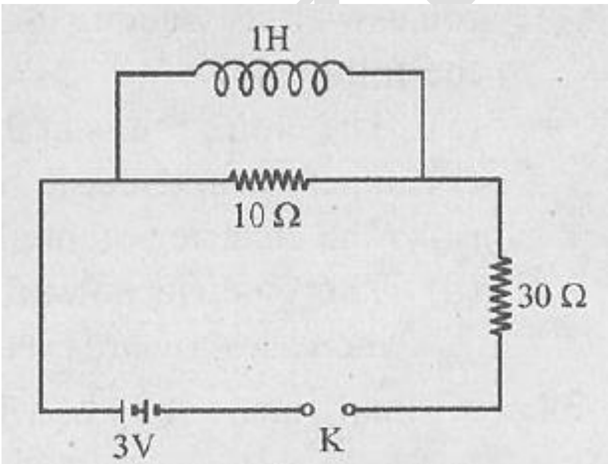
Non-ideal inductor



The two contributions to the non-ideal behaviour of inductors are as follows:

The finite resistance of the wire which is used to wind the coil.
The cross-turn effects which become important at high frequencies.

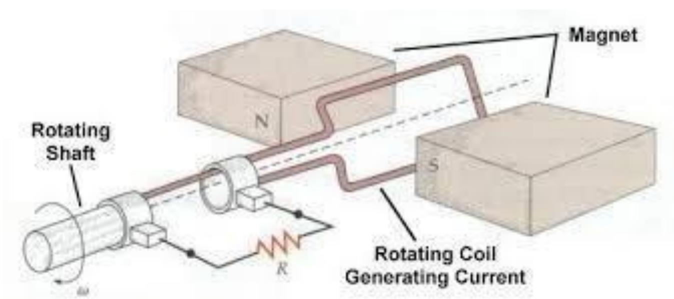
Final value of current in a circuit



Example: In the given figure resistance of 1 H coil is zero, find the final value of current in 10Ω resistor, when plug of key K is inserted.

Solution:
In steady state the inductor acts as a component with zero resistance. So the current will not pass through 10 ohm resistor.

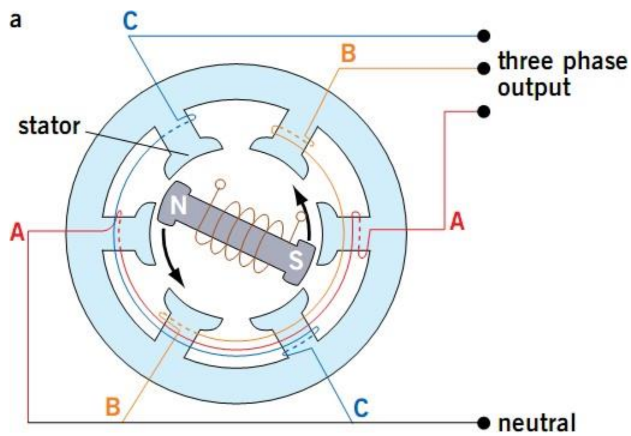
Electric generator



An electric generator is a mechanical rotating device which converts mechanical energy into electrical energy. It is based on the principle of electromagnetic induction.
Electric generator consists of two fixed permanent magnets with their opposite poles facing each other. A rectangular conductor coil is placed in between the magnets. The coil is connected to a rotating shaft and external load circuit via brushes. The rotation of coil leads to the generation of electric current in the coil in accordance with the faraday's law of electromagnetic induction.

When the coil is rotated by external forces in a magnetic field, then emf is induced in the coil and as a result current flows. The current produced is alternating in nature and reverses direction every cycle.

Basic Principle of 3-phase AC generator



Basic principle:

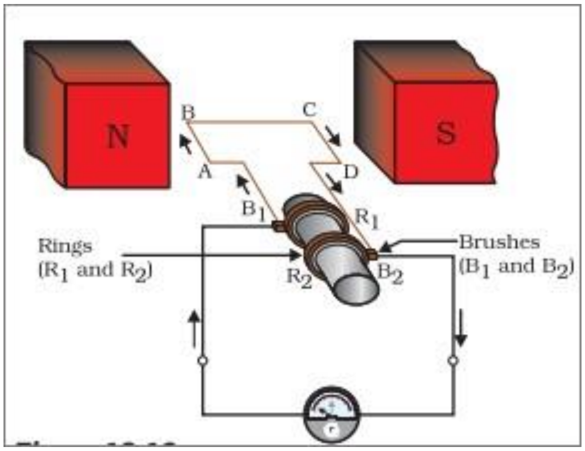
According to Faraday's law of electromagnetic induction, when a conductor moves in a magnetic field, EMF gets induced across the conductor. If the closed circuit is provided to the conductor, induced emf causes current to flow in the circuit.

In a symmetric three-phase power supply system, three conductors each carry an alternating current of the same frequency and voltage amplitude relative to a common reference but with a phase difference of one third the period. The common reference is usually connected to ground and often to a current-carrying conductor called the neutral. Due to the phase difference, the voltage on any conductor reaches its peak at one third of a cycle after one of the other conductors and one third of a cycle before the remaining conductor. This phase delay gives constant power transfer to a balanced linear load. It also makes it possible to produce a rotating magnetic field in an electric motor and generate other phase arrangements using transformers.

Stator: The stator is the stationary part of a rotary system, found in electric generators, electric motors, sirens, or biological rotors. The main use of a stator is to keep the field aligned in the power generator.

Rotar: The rotor is a moving component of an electromagnetic system in the electric motor, electric generator, or alternator. Its rotation is due to the interaction between the windings and magnetic fields which produces a torque around the rotor's axis.

AC Generator



Principle : AC generator works on the principle of electromagnetic induction in which electric current is induced in the coil placed in magnetic field.

Construction:

An electric generator, as shown in Fig., consists of a rotating rectangular coil ABCD placed between the two poles of a permanent magnet. The two ends of this coil are connected to the two rings R1 and R2. The inner side of these rings are made insulated. The two conducting stationary brushes B1 and B2 are kept pressed separately on the rings R1 and R2, respectively. The two rings R1 and R2 are internally attached to an axle. The axle may be mechanically rotated from outside to rotate the coil inside the magnetic field. Outer ends of the two brushes are connected to the galvanometer to show the flow of current in the given external circuit.

Working: When the axle attached to the two rings is rotated such that the arm AB moves up (and the arm CD moves down) in the magnetic field produced by the permanent magnet. Let us say the coil ABCD is rotated clockwise in the arrangement shown in Fig. By applying Flemings right-hand rule, the induced currents are set up in these arms along the directions AB and CD. Thus an induced current flows in the direction ABCD. If there are larger numbers of turns in the coil, the current generated in each turn adds up to give a large current through the coil. This means that the current in the external circuit flows from B2 to B1. After half a rotation, arm CD starts moving up and AB moving down. As a result, the directions of the induced currents in both the arms change, giving rise to the net induced current in the direction DCBA. The current in the external circuit now flows from B1 to B2. Thus after every half rotation the polarity of the current in the respective arms changes. Such a current, which changes direction after equal intervals of time, is called an alternating current (abbreviated as AC). This device is called an AC generator.

Dynamo

A dynamo is an electrical generator that produces direct current with the use of a commutator. It consists of two permanent magnets and a rotating coil in between as shown in the attached figure. Commutator converts the alternating current into direct current by reversing the direction of current every alternate cycles. They are used for low power applications like domestic purposes and charging batteries of motor vehicles.

Different power generators

In commercial generators, the mechanical energy required for rotation of the armature is provided by water falling from a height, for example,from dams. These are called **hydro-electric** generators. Alternatively, water is heated to produce steam using coal or other sources. The steam at high pressure produces the rotation of the armature. These are called **thermal**generators. Instead of coal, if a nuclear fuel is used, we get **nuclear power** generators.

Electromagnetic Induction

The property due to which a changing magnetic field within a closed conducting coil induces electric current in the coil is called electromagnetic induction.

Generation of electric current due to relative motion

When a bar magnet is moved inside a coil connected to a galvanometer, then the motion induces a deflection in the galvanometer signalling the presence of electric current.Further, the deflection (and hence current)is found to be larger when the magnet is pushed towards or pulled away from the coil faster. Instead,when the bar magnet is held fixed and the coil is moved towards or away from the magnet, the same effects are observed. It shows that it is the relative motion between the magnet and the coil that is responsible for generation (induction) of electric current in the coil.

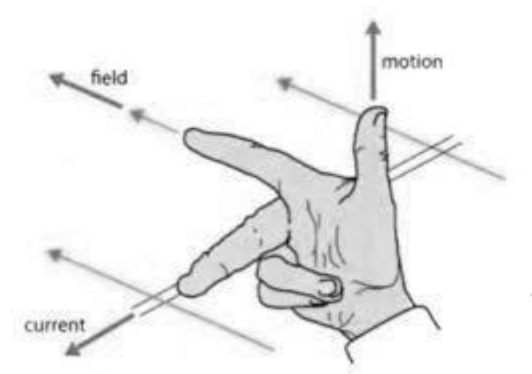
Factors affecting induced emf

So, emf is dependent on number of turns of coil,shape of the coil, strength of magnet and speed with which magnet is moved. Emf is independent of resistivity of wire of the coil.

Lenz's Law

According to Lenz's Law, if an induced current flows in a coil due to electromagnetic induction, its direction is always such that it will oppose the change which produced it. Hence, the magnetic field produced by the current in the coil is opposite to the direction of external magnetic field. It is shown by a negative sign in the Faraday's law.
$\varepsilon = -\Delta\phi/\Delta t$

Fleming's right hand rule



Fleming's right hand rule is used to determine the direction of induced current in a coil. If the thumb (direction of motion), index finger (along magnetic field) and middle finger are held mutually perpendicular as shown in the figure, then middle finger gives the direction of induced emf in the wire.

Factors affecting induced current

Induced current in the coil can be increased by increasing the number of turns in the coil, rapidly moving the coil and increasing the applied magnetic field.

Direction of electric current in loops using Lenz's law

When the North-pole of a bar magnet is moved towards a closed loop like a coil connected to a galvanometer, the magnetic flux through the coil increases. Hence according to Lenz's law, current is induced in the coil in such a direction that it opposes the increase in flux.This is possible only if the current in the coil is in a counter-clockwise direction with respect to an observer situated on the side of the magnet.Note that magnetic moment associated with this current has North polarity towards the North-pole of the approaching magnet. Similarly, if the North pole of the magnet is being withdrawn from the coil, the magnetic flux through the coil will decrease. To counter this decrease in magnetic flux,the induced current in the coil flows in clockwise direction and its South pole faces the receding North-pole of the bar magnet. This would result in an attractive force which opposes the motion of the magnet and the corresponding decrease in flux.