A Mini Project Report on

BASIC ELECTRICAL ENGINEERING

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in

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Rotating Magnetic Field[1]

A rotating magnetic field is a magnetic field that has moving polarities in which its opposite poles rotate about a central point or axis. Ideally, the rotation changes direction at a constant angular rate. This is a key principle in the operation of the alternating-current motor.

Rotating magnetic fields are often utilized for electromechanical applications such as induction motors and electric generators. However, they are also used in purely electrical applications such as induction regulators.

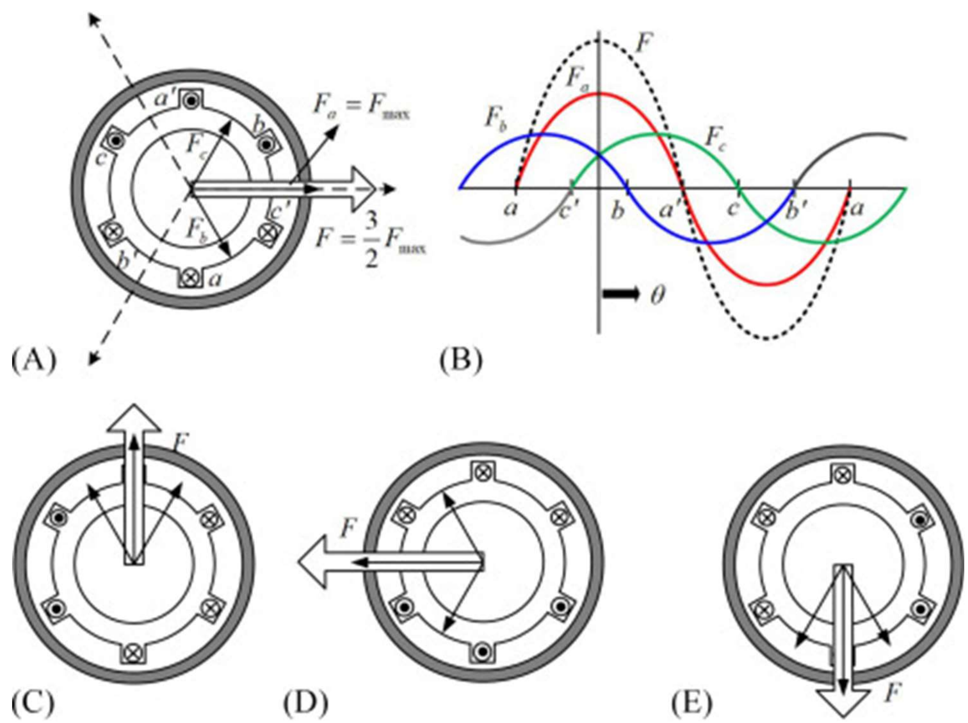


Fig. No. 1(a): Rotating Magnetic Field

- **Condition for Generation of Rotating Magnetic Field[2]:**
  When a balanced poly phase current flows in the balanced poly phase winding, a rotating magnetic field is produced. The necessary condition for generation of rotating magnetic field is that "the time angle displacement between the currents and space angle displacement between the winding axes must be equal."

Let us consider an example for better understanding of the above mentioned condition. In the figure below, three coils a, b and c with their magnetic axis coincident are excited by three phases balanced current $I_m\sin\omega t$, $I_m\sin(\omega t-120°)$ and $I_m\sin(\omega t+120°)$.

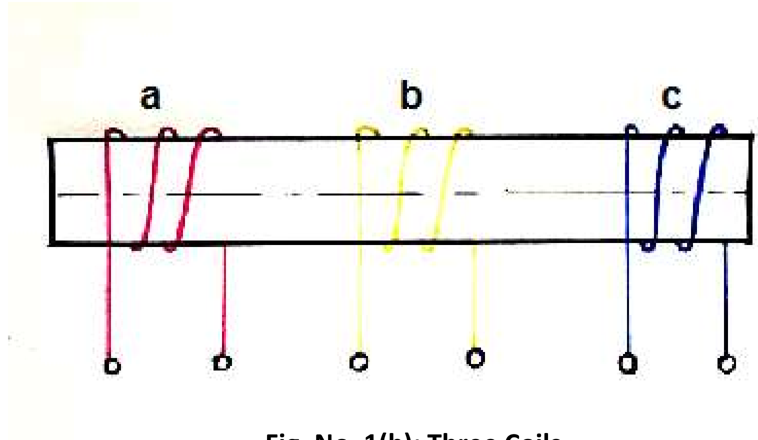


Fig. No. 1(b): Three Coils

In this case, the time angle displacement between the currents is 120 degree but the space angle displacement between the winding axes zero. Therefore, rotating magnetic field will not be produced.

- ## Working principle of rotating magnetic field in three phase induction motor[3]:

An electrical motor is an electromechanical device which converts electrical energy into mechanical energy. In the case of three phase AC (Alternating Current) operation, the most widely used motor is a 3 phase induction motor, as this type of motor does not require an additional starting device. These types of motors are known as self-starting induction motors.

To get a good understanding of the working principle of a three phase induction motor, it's essential to understand the construction of a 3 phase induction motor. A 3 phase induction motor consists of two major parts:

- A stator
- A rotor

Stator of 3 Phase Induction Motor:

The stator of three phase induction motor is made up if number of slots to construct a 3 phase winding circuit which we connect with 3 phase AC source. We arrange the three-phase winding in such a manner in the slots that they produce one rotating magnetic field when we switch on the three-phase AC supply source.

Fig. No. 1(c): Stator

Rotor of 3 Phase Induction Motor:

The rotor of three phase induction motor consists of a cylindrical laminated core with parallel slots that can carry conductors. The conductors are heavy copper or aluminum bars fitted in each slot and short-circuited by the end rings. The slots are not exactly made parallel to the axis of the shaft but are slotted a little skewed because this arrangement reduces magnetic humming noise and can avoid stalling of the motor.

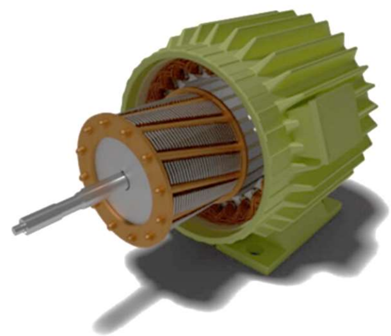


Fig. No. 1(d): Rotor

- **Working of Three-Phase Induction Motor- Production of Rotating Magnetic Field[4]:**

The stator of the motor consists of overlapping winding offset by an electrical angle of 120°. When we connect the primary winding, or the stator to a 3 phase AC source, it establishes rotating magnetic field which rotates at the synchronous speed.

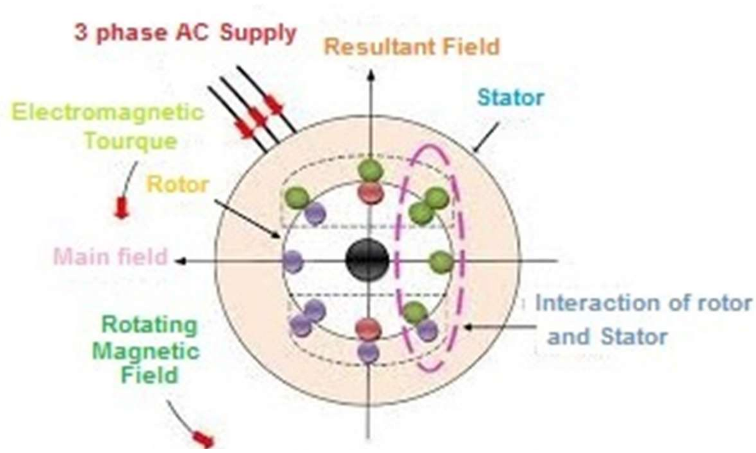


Fig. No. 1(e): Three Phase Induction Motor

According to Faraday's law an emf induced in any circuit is due to the rate of change of magnetic flux linkage through the circuit. As the rotor winding in an induction motor are either closed through an external resistance or directly shorted by end ring, and cut the stator rotating magnetic field, an emf is induced in the rotor copper bar and due to this emf a current flows through the rotor conductor.

Here the relative speed between the rotating flux and static rotor conductor is the cause of current generation; hence as per Lenz's law, the rotor will rotate in the same direction to reduce the cause, i.e., the relative velocity.

Thus from the working principle of three phase induction motor, it may be observed that the rotor speed should not reach the synchronous speed produced by the stator. If the speeds become equal, there would be no such relative speed, so no emf induced in the rotor, and no current would be flowing, and therefore no torque would be generated. Consequently, the rotor cannot reach the synchronous speed. The difference between the stator (synchronous speed) and rotor speeds is called the slip. The rotation of the magnetic field in an induction motor has the advantage that no electrical connections need to be made to the rotor.

Thus the three phase induction motor is:

- Self-starting.
- Robust in construction.
- Economical.
- Easier to maintain.
- Less armature reaction and brush sparking because of the absence of commutators and brushes that may cause sparks.

Resonance in Parallel RLC Circuit[5]

The frequency at which parallel RLC circuit resonates is called resonance frequency i.e. there occurs a frequency at which inductive reactance becomes equal to capacitive reactance (X_L=X_C). Parallel resonance occurs when the supply frequency creates zero phase difference between the supply voltage and current producing a resistive circuit.

- **Parallel RLC Circuit[6]:**

  Consider an RLC circuit in which resistor, inductor and capacitor are connected in parallel to each other. This parallel combination is supplied by voltage supply, V_S.

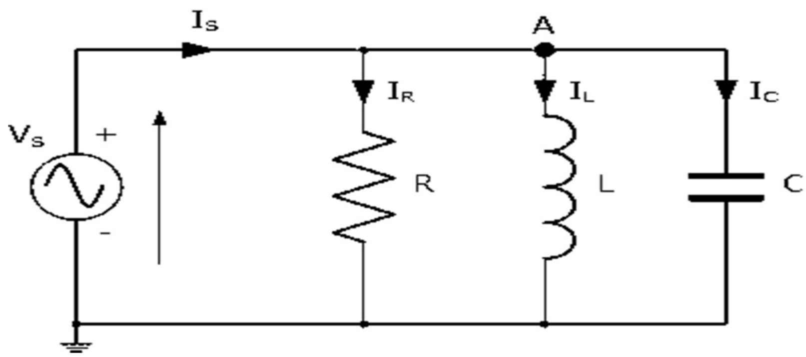


Fig. No. 2(a): Parallel RLC Circuit

Parallel circuit are the circuit in which the voltage across each element remains the same and the current gets divided in each component depending upon the impedance of each component.

The total current, I_S drawn from the supply is equal to the vector sum of the resistive, inductive and capacitive current, not the mathematic sum of the three individual branch currents, as the current flowing in resistor, inductor and capacitor are not in same phase with each other; so they cannot be added arithmetically.

Apply KCL, which states that the sum of currents entering a junction or node, is equal to the sum of current leaving that node we get,

$$I_S^2 = I_R^2 + (I_L - I_C)^2$$

where, I_S is the total source current.
I_R is the current flowing through the resistor.
I_C is the current flowing through the capacitor.
IL is the current flowing through the inductor.

- **Phasor Diagram of Parallel RLC Circuit[7]:**

For drawing the phasor diagram of parallel RLC circuit, voltage is taken as reference because voltage across each element remains the same and all the other currents i.e I_R, I_C, I_L are drawn relative to this voltage vector. We know that in case of resistor, voltage and current are in same phase, so draw current vector I_R in same phase and direction to voltage. In case of capacitor, current leads the voltage by 90° so, draw I_C vector leading voltage vector, V by 90°. For inductor, current vector I_L lags voltage by 90° so draw I_L lagging voltage vector, V by 90°. Now draw the resultant of I_R, I_C, I_L i.e current I_S at a phase angle difference of θ with respect to voltage vector, V.

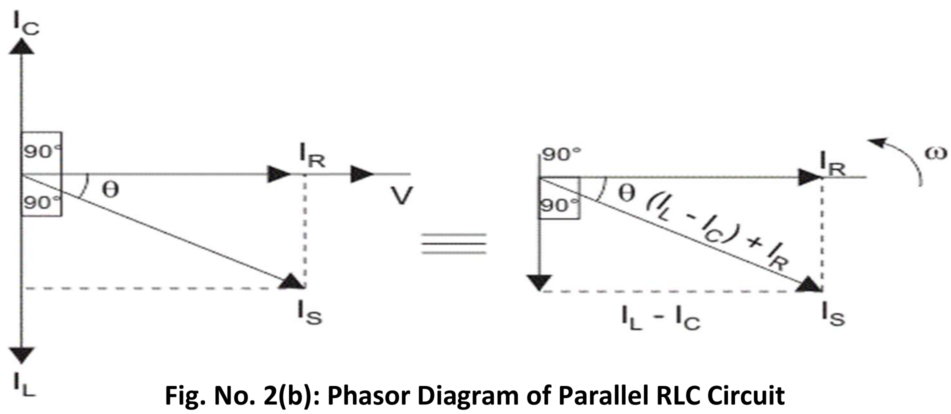


Fig. No. 2(b): Phasor Diagram of Parallel RLC Circuit

Let, V is the supply voltage,

θ is the phase angle difference between supply voltage and current.

Simplifying the phasor diagram, we get a simplified phasor diagram on right hand side. On this phasor diagram, we can easily apply Pythagoras's theorem and we get,

$$I_S^2 = I_R^2 + (I_L - I_C)^2$$

- **Impedance of Parallel RLC Circuit[8]:**

From the phasor diagram of parallel RLC circuit we get,

$$I_S^2 = I_R^2 + (I_L - I_C)^2$$

$$Now,\ I_R = \frac{V}{R},\ I_C = \frac{V}{X_C},\ and\ I_L = \frac{V}{X_L}$$

Substituting the value of I_R, I_C, I_L in above equation we get,

$$I_S = \sqrt{\left(\frac{V}{R}\right)^2 + \left(\frac{V}{X_L} - \frac{V}{X_C}\right)^2}$$

,

On solving, we get,

$$Addmittance\ \frac{1}{Z} = Y = \frac{I_S}{V}\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_L} - \frac{1}{X_C}\right)^2}$$

- **Admittance Triangle of Parallel RLC Circuit[9]:**

As shown above in the equation of impedance, Z of a parallel RLC circuit each element has reciprocal of impedance (1/Z) i.e., admittance, Y. The impedance Z has two components; resistance, R and reactance, X. Similarly, admittance also has two components such as conductance, G (reciprocal of resistance, R) and suspceptance, B (reciprocal of reactance, X).

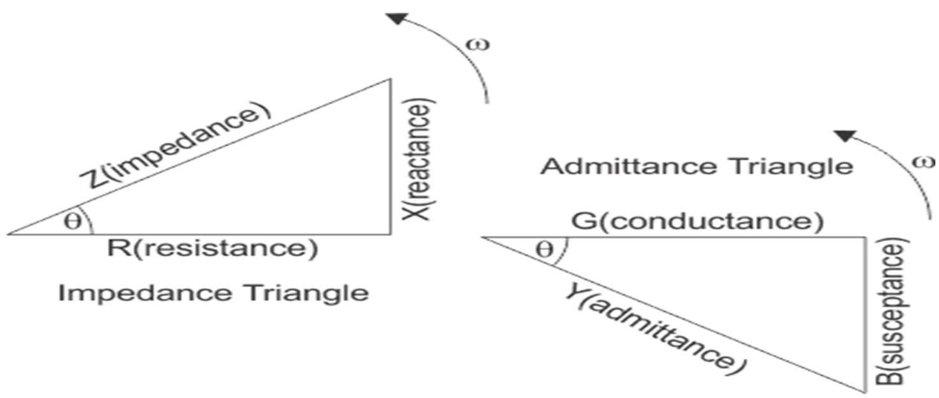


Fig. No. 2(c): Admittance Triangle of Parallel RLC Circuit

- **Resonance in Parallel RLC Circuit[10]:**

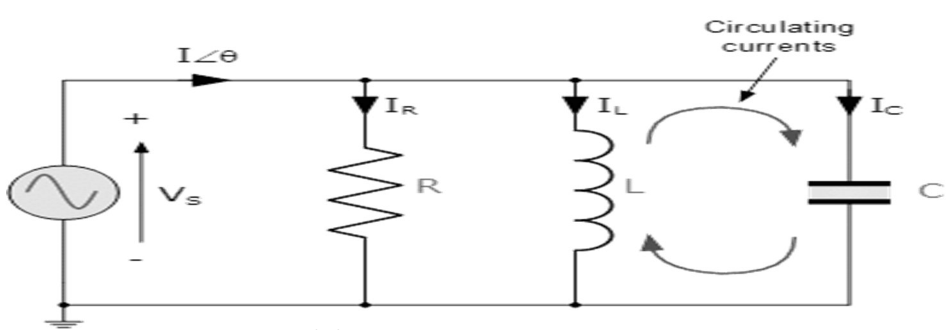


Fig. No. 2(d): Resonance in Parallel RLC Circuit

Let us define what we already know about parallel RLC circuits.

$$\text{Admittance, } Y = \frac{1}{Z} = \sqrt{G^2 + B^2}$$

$$\text{Conductance, } G = \frac{1}{R}$$

$$\text{Inductive Susceptance, } B_L = \frac{1}{2\pi f L}$$

$$\text{Capacitive Susceptance, } B_C = 2\pi f C$$

A parallel circuit containing a resistance, R, an inductance, L and a capacitance, C will produce a parallel resonance (also called anti-resonance) circuit when the resultant current through the parallel combination is in phase with the supply voltage. At resonance there will be a large circulating current between the inductor and the capacitor due to the energy of the oscillations, then parallel circuits produce current resonance.

A parallel resonant circuit stores the circuit energy in the magnetic field of the inductor and the electric field of the capacitor. This energy is constantly being transferred back and forth between the inductor and the capacitor which results in zero current and energy being drawn from the supply.

This is because the corresponding instantaneous values of I_L and I_C will always be equal and opposite and therefore the current drawn from the supply is the vector addition of these two currents and the current flowing in I_R.

- **Conditions for Resonance (Expression)[11]:**

We know that resonance takes place when $V_L = -V_C$ and this situation occurs when the two reactances are equal, $X_L = X_C$. The admittance of a parallel circuit is given as:

$$Y = G + B_L + B_C$$

$$Y = \frac{1}{R} + \frac{1}{j\omega L} + j\omega C$$

or

$$Y = \frac{1}{R} + \frac{1}{2\pi f L} + 2\pi f C$$

Resonance occurs when $X_L = X_C$ and the imaginary parts of Y become zero. Then:

$$X_L = X_C \quad \Rightarrow \quad 2\pi f L = \frac{1}{2\pi f C}$$

$$f^2 = \frac{1}{2\pi L \times 2\pi C} = \frac{1}{4\pi^2 LC}$$

$$f = \sqrt{\frac{1}{4\pi^2 \, LC}}$$

$$\therefore \; f_r = \frac{1}{2\pi\sqrt{LC}} \text{(Hz)} \quad \text{or} \quad \omega_r = \frac{1}{\sqrt{LC}} \text{(rads)}$$

- **What happens during Resonance?[12]**

At resonance the parallel LC tank circuit acts like an open circuit with the circuit current being determined by the resistor, R only. So the total impedance of a parallel resonance circuit at resonance becomes just the value of the resistance in the circuit and Z = R as shown,

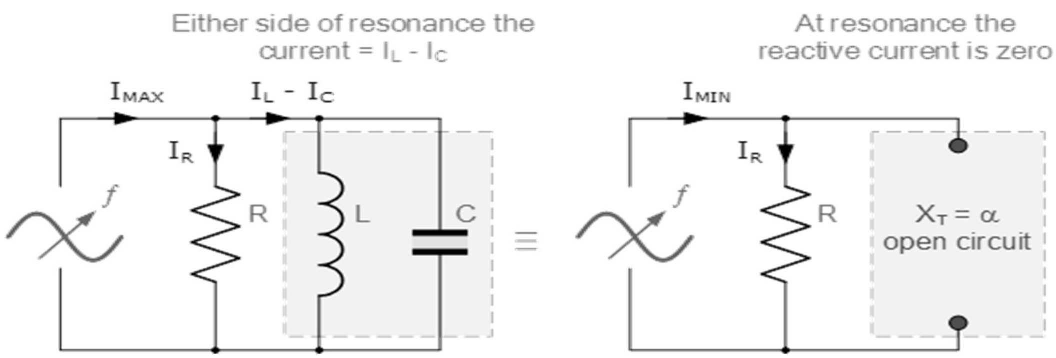


Fig. No. 2(e): Current at Resonance

Thus at resonance, the impedance of the parallel circuit is at its maximum value and equal to the resistance of the circuit creating a circuit condition of high resistance and low current. Also at resonance, as the impedance of the circuit is now that of resistance only, the total circuit current, I will be "in-phase" with the supply voltage, V_S.

We can change the circuit's frequency response by changing the value of this resistance. Changing the value of R affects the amount of current that flows through the circuit at resonance, if both L and C remain constant. Then the impedance of the circuit at resonance Z = R_{MAX} is called the "dynamic impedance" of the circuit.

- **Impedance in a Parallel Resonance Circuit[13]:**

If the parallel circuits impedance is at its maximum at resonance then consequently, the circuits admittance must be at its minimum.

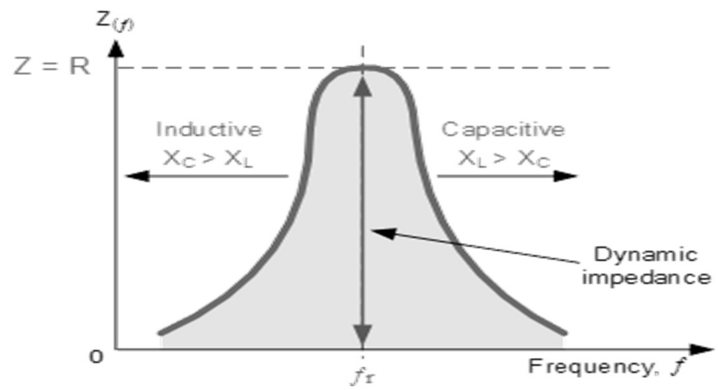


Fig. No. 2(f): Impedance in Parallel Resonance Circuit

- **Susceptance at Resonance[14]:**

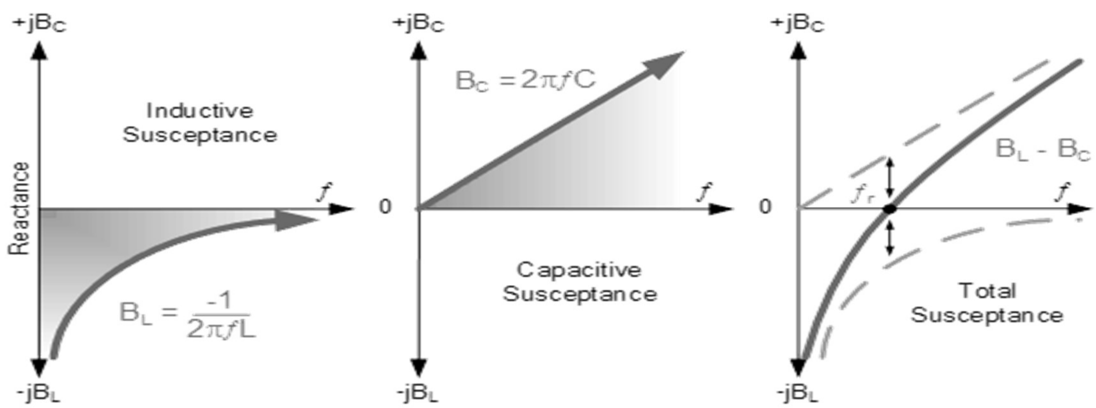


Fig. No. 2(g): Susceptance at Resonance

So at the resonant frequency, f_r the current drawn from the supply must be "in-phase" with the applied voltage as effectively there is only the resistance present in the parallel circuit, so the power factor becomes one or unity, ($\theta = 0^o$).

Also as the impedance of a parallel circuit changes with frequency, this makes the circuit impedance "dynamic" with the current at resonance being in-phase with the voltage since the impedance of the circuit acts as a resistance. Then we have seen that the impedance of a parallel circuit at resonance is equivalent to the value of the resistance and this value must, therefore represent the maximum dynamic impedance (Z_d) of the circuit as shown,

$$Z_d = \frac{L}{RC}$$

- **Current in a Parallel Resonance Circuit[15]:**

As the total susceptance is zero at the resonant frequency, the admittance is at its minimum and is equal to the conductance, G. Therefore at resonance the current flowing through the circuit must also be at its minimum as the inductive and capacitive branch currents are equal ($I_L = I_C$) and are 180^o out of phase.

We remember that the total current flowing in a parallel RLC circuit is equal to the vector sum of the individual branch currents and for a given frequency is calculated as:

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

$$I_L = \frac{V}{X_L} = \frac{V}{2\pi f L}$$

$$I_C = \frac{V}{X_C} = V.2\pi f C$$

$$\text{Therefore,}\quad I_T = \text{vector sum of } (I_R + I_L + I_C)$$

$$I_T = \sqrt{I_R^2 + (I_L + I_C)^2}$$

At resonance, currents I_L and I_C are equal and cancelling giving a net reactive current equal to zero. Then at resonance the above equation becomes,

$$I_T = \sqrt{I_R^2 + 0^2} = I_R$$

- **Parallel Circuit Current at Resonance[16]:**

Since the current flowing through a parallel resonance circuit is the product of voltage divided by impedance, at resonance the impedance, Z is at its maximum value, (=R). Therefore, the circuit current at this frequency will be at its minimum value of V/R and the graph of current against frequency for a parallel resonance circuit is given as shown in the figure.

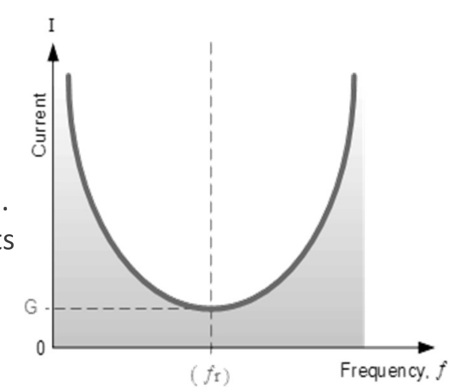


Fig. No. 2(h): Parallel Circuit Current at Resonance

- **Cut-off Frequencies[17]:**

The resonance effect can be used for filtering the rapid change in impedance near resonance and can be used to pass or block signals close to the resonance frequency. Both band-pass and band-stop filters can be constructed and some filter circuits. A key parameter in filter design is bandwidth. The bandwidth is measured between the cutoff frequencies. Cutoff frequencies is defined as the frequencies at which the power passed through the circuit has fallen to half the value passed at resonance. There are two of these half-power frequencies, one above, and one below the resonance frequency

$$\Delta\omega = \omega 2 - \omega 1;$$

where, $\Delta\omega$ is the bandwidth
$\omega 1$ is the lower half-power frequency
$\omega 2$ is the upper half-power frequency.

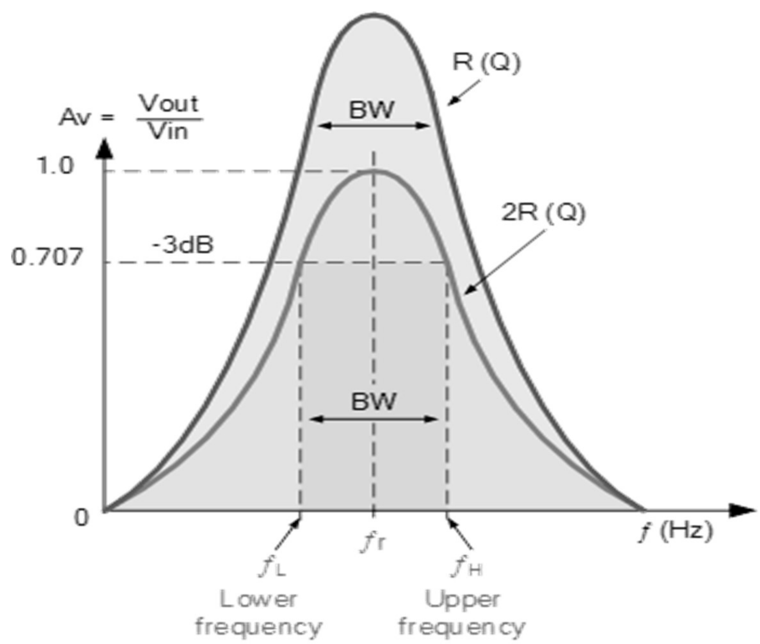


Fig. No. 2(i): Bandwidth of Parallel RLC Circuit

Grounding[18]

Grounding can be defined as the control of accidental currents to protect power system from damage and malfunctioning. It's a safety measure devised to prevent people from getting shocked if the insulation inside electrical devices fails. Grounding is the control of abnormal voltages or currents through the proper application of Ohm's Law:

$$V = IR + jIX_C + jIX_L$$

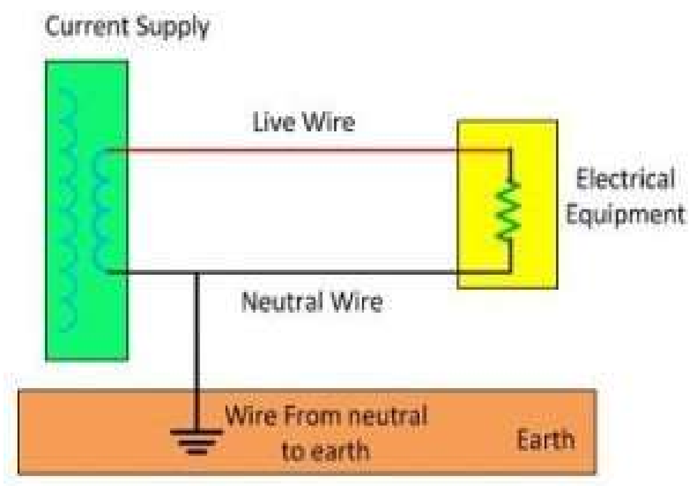


Fig. No. 3(a): Grounding

A short circuit is when electricity deviates from the path it is supposed to flow through, and it takes a shorter path to ground. To prevent this from causing any accidents electrical systems are grounded. Electrical grounding provides an alternate path for this surplus current to flow back into the ground when there is a fault in the wiring system and thus preventing any mishap. Grounding also limits the build-up of static electricity in devices.

Fig. No. 3(b): Symbol for Grounding

- **What does 'Ground' mean?[19]**

'Ground' is the reference point from which the voltage is measured. In grounding the circuit, the circuit of an electrical system is connected to a common point of reference. In typical cases, that common point of reference is the earth.

- **Purpose of Grounding[20]:**

Grounding is necessary for an equipment which has no insulation and is susceptible to a human contact - something like the Computers, Immersion rods, Steam Irons etc. When all metallic parts in an electrical equipment is grounded then even if the insulation inside the equipment were to fail there would be no dangerous voltages present in the equipment case. Grounding is a fault return path with a desired amount of impedance. It is a shield from external deviating and curling electric and magnetic field. It is three-dimensional energy dilution system when source of disturbance is outside the circuit. It provides equipotential surface to avoid sparks and circulating currents.

Some of the various importance of grounding are as follows:

1. Safety to personnel and equipment:
    a. Grounding saves human life from danger of electrocution death by blowing a fuse i.e. To provide an alternative path for the fault current to flow so that it will not endanger the user. If, for example, a live wire comes loose inside an electrical appliance and touches the metal case, it will raise the electric potential of the case. If someone were to touch the bare metal part of the appliance there is a possibility that the person might get "electrocuted".

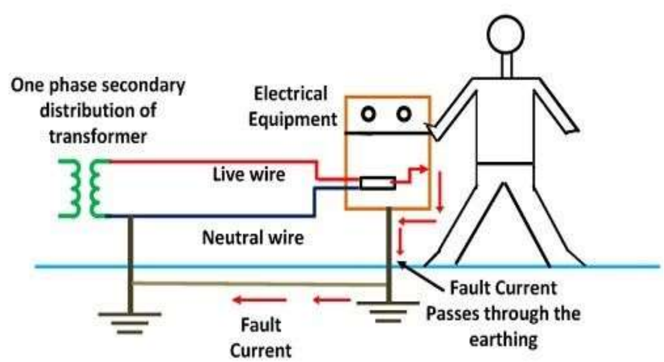


Fig. No. 3(c): Safety to personnel

    b. Coming to the second need, it is to protect the equipment itself, specially the electronic equipment which are sensitive to external noise - Electromagnetic noises, static charges. Grounding protect buildings, machinery and electrical appliances under fault conditions. It provides a stable platform for operation of sensitive electronic equipment by maintaining the voltage at any part of an electrical system at a known value to prevent over current or excessive voltage on the appliances or equipment.

2. To serve as a return conductor in electric traction system and communication.

3. Protection against electrical overloads in electric system. Some events such as power surges or lightning may produce dangerously high electricity which can completely damage electrical appliance. If the electrical systems were grounded properly then all the excess electricity would be directed into the ground instead of frying the appliances connected to the system. The appliances will be safe and protected from large electrical surges.

4. To stabilize the voltage level throughout an electrical system. When an electrical system is grounded, it makes it easier to distribute the right amount of power at the right places. This ensures that the circuits are not overloaded at any point and get fried because of the load. The earth behaves as a common reference point for the voltage sources in any electrical system. This helps in providing stabilized voltage levels throughout the electric system.

5. Grounding provides a reference voltage level against which all other voltages in an electrical system are established and measured.

- **Types of Grounding, Advantages and Disadvantages[21]:**

1. Underground System:

An ungrounded system is a system which is connected to ground through the capacitance between the lines and the earth. It's called ungrounded because of convention, and because there isn't any physical connection between the conductors in the system and the ground.

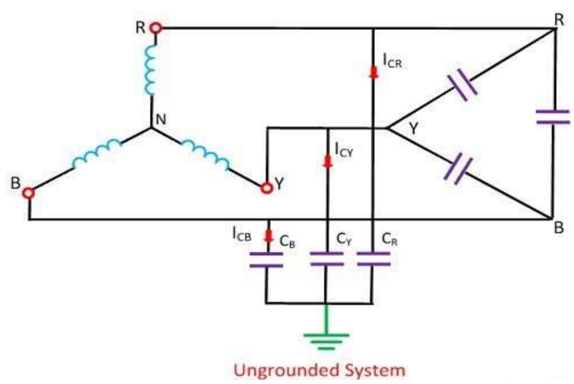


Fig. No. 3(d): Underground System

Underground System with fault on one phase:

Consider the ungrounded system below with a phase to earth fault in line Y. The potential of the fault line is equal to the earth potential, and the potential of the remaining two lines arise from the phase potential to the line value. The fault current I_F flows through the faulty line into the earth and return through the capacitance C_R and C_B. I_F two components namely I_{CR} and I_{CB}, which flow through capacitance C_R and C_B under the potential difference of V_{RY} and V_{BY} respectively. The current I_{CR} and I_{CB} lead their respective voltages by an angle of 90^o.

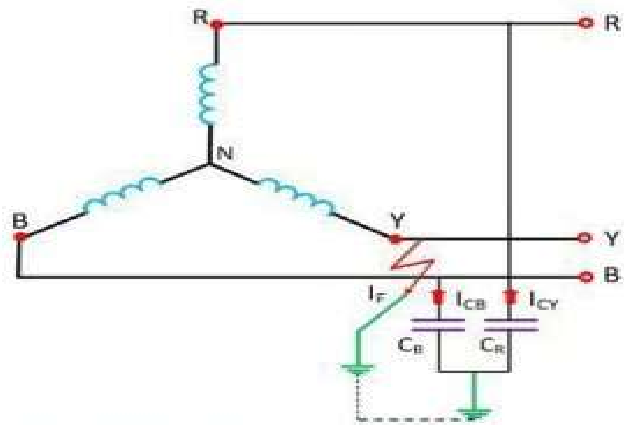


Fig. No. 3(e): Underground Neural System with Fault on one Phase

Therefore, $I_{CR} = \frac{V_{CY}}{X_{CR}} = \frac{\sqrt{3}V_P}{X_C}$

and, $I_{CB} = \frac{V_{BY}}{X_{CB}} = \frac{\sqrt{3}V_P}{X_C}$

where, V_P is the phase voltage of the line

and, X_C is the capacitance of the line.

The fault current is equal to the phasor sum of I_{CR} and I_{CB} as shown in the below.

$$I_F = \sqrt{3}I_{CR} = \frac{3V_P}{X_C}$$

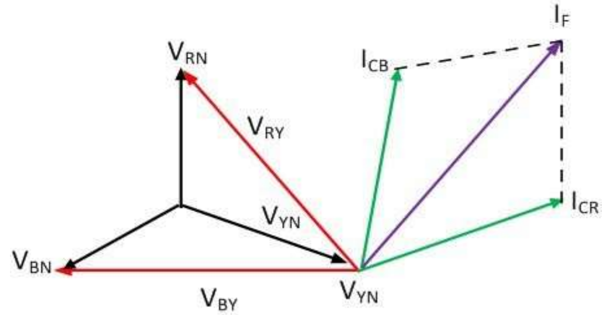


Fig. No. 3(f): Phasor Diagram for Fault on Phase

In case of the fault in one phase the remaining two healthy phases of the line raise from their phase value to the full line value. This cause the stress on the equipment connected to three-phase ungrounded systems. The capacitance currents in the two healthy phases increase from √3 times to their normal values.

Advantages and Disadvantages:

a. The main advantage of an ungrounded system is that since the system is not physically connected to the ground there is negligible ground fault current. Since there are negligible ground fault current special ungrounded systems can be used to minimize risk to people.

b. The main disadvantage is that if there is a fault, the total current that was allotted for three wires are now being carried through three wires. This will increase heat output and thus damage the electrical system.

2. Resistance Grounding:

In resistance grounding neutral line and the ground is connected through resistor. This resistor is used to limit the fault current through the neutral line. The value of resistance is chosen such that the ground-fault current is limited, but still enough ground current flows permit the operation of ground faults protections.

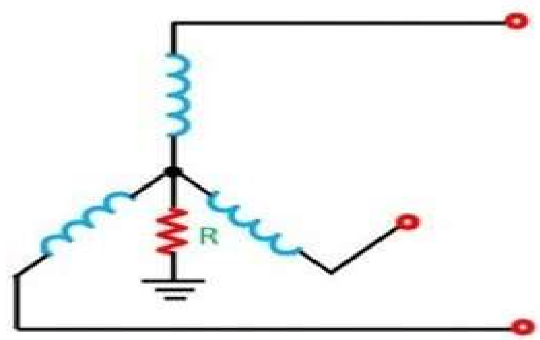


Fig. No. 3(g): Resistance Grounding

Types:

a. High Resistance Grounding:

High resistance grounding is used when low fault current is desired (< 10A). Due to low ground fault current the system can be operated on a single line-to-ground fault, just like an ungrounded system.

b. Low Resistance Grounding:

Low resistance grounding is used when ground fault current between 100A and 1000A is desired. Low resistance grounding is used in medium voltage systems (<= 15kV) because they reduce overvoltage.

Advantages and Disadvantages:

a. Resistance grounding decreases the arcing grounding risk and permits ground-fault protection. In resistance grounding the earth fault current is small so there is less interference with communication systems.
b. The main disadvantage is that the system neutral gets displaced during earth faults and so the equipment must be insulated for higher voltages. It also costs more than solidly grounded system.

3. **Solid Grounding:**

In solid grounding the system is connected directly to the ground, without any resistance in-between. The power system is then said to be effectively grounded or solidly grounded. The ground is generally connected to the system at a neutral point.

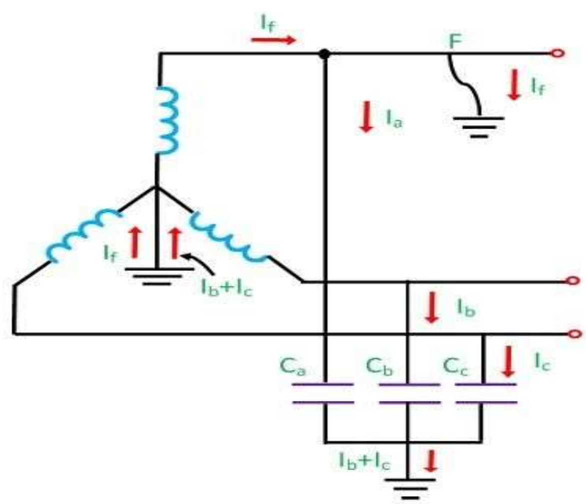


Fig. No. 3(h): Solidly Ground System

Consider the above system with three phases namely a, b, and c. If a single ground fault were to occur in phase 'a' the voltage of the phase will become zero, but the remaining two phases will still have the same voltages. In solidly grounded system not only the charging current but the power source also feed the fault current when a fault occurs.

Advantages and Disadvantages:

a. Solidly grounded systems have the advantage of greatly reducing overvoltage. It also allows users to easily locate faults and can supply line-neutral loads.
b. Solidly grounded system has the potential to have huge ground fault current and therefore they cannot operate with a ground fault.

- **Earthing[22]:**

  Electrical Earthing is the process through which electrical discharges in an electric system is directed to the earth through a low resistance wire. Earthing is achieved by connecting the neutral of supply system to the ground.

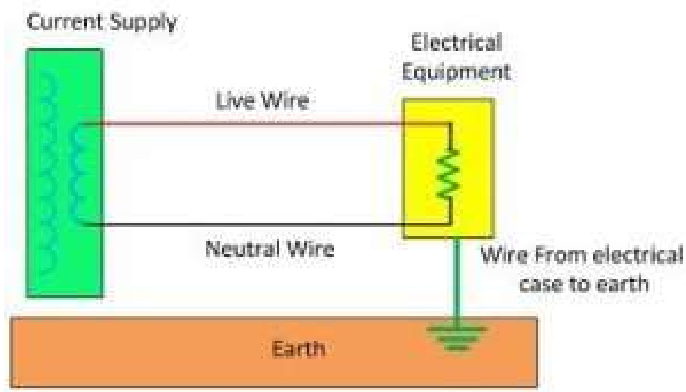


Fig. No. 3(i): Earthing

- **Grounding vs Earthing:**

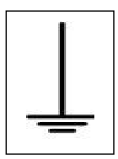
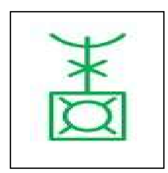
GROUNDING	EARTHING
1. Grounding provides a return path to the current.	1. Earthing is used to discharge electrical energy to the earth.
2. Symbol: 	2. Symbol: 
3. Primary purpose is to protect personnel from getting shock.	3. Primary purpose is to prevent power system from malfunctioning.
4. Grounding does not possess zero potential.	4. Earthing possesses zero potential
5. Black wire is used for grounding.	5. Green wire is used for earthing.
6. The current carrying part is connected to the ground.	6. The body of the system is connected to the ground.

Table (i): Grounding vs Earthing

Electricity and Magnetism[23]

Electricity and magnetism are essentially two aspects of the same thing, because a changing electric field creates a magnetic field, and a changing magnetic field creates an electric field. Electricity and magnetism, together form the basis of electromagnetism. In an electromagnetic wave (EMW), the electric field and magnetic field are perpendicular to one another.

- ## Understanding Electricity[24]:

Electricity is a stream of negatively charged particles, called electrons, flowing from negative to positive through a conductor. The flow of electricity is called current, and is measured in amps (A). The driving force, or pressure, of the current is measured in volts (V).

The electric force is created by electric charges. For all practical purposes, only two types of charged particles are considered- positive charge carrier called proton and negative charge carrier called electron. The total charge in the universe is conserved.

The electrostatic force between two point charges is given by Coulomb's Law.

$$F = \frac{kq_1q_2}{r^2}$$

where,

k is the electrostatic constant ($k = 8.98 \times 10^9 \frac{Nm^2}{C^2}$)

r is the distance between the two charges

q_1 and q_2 are the two charges, measured in coulombs.

- **Understanding Magnetism[25]:**

Magnetism is the force exerted by magnets when they attract or repel each other. Magnetism is caused by the motion of electric charges. All magnets have north and south poles. Opposite poles are attracted to each other, while the same poles repel each other. When a piece of iron is rub along a magnet, the north-seeking poles of the atoms in the iron line up in the same direction. The force generated by the aligned atoms creates a magnetic field. The magnetic field always loops from one pole to another.

There is no simple formula for magnetostatic force, however, there is a magnetic force constant represented by μ, which is equal to $4\pi \times 10^{-7} \frac{H}{m}$.

- **Electromagnetism[26]:**

The relation between electricity and magnetism can be properly understood by the fundamental knowledge of electromagnetism.

The direct relation between electricity and magnetism was firstly observed by a Danish physicist Hans Christian Oersted in the year 1820, while he was preparing a lecture and noticed a compass needle deflected away from the magnetic north when the electric current from the battery he was setting up was switched on and off. At the time of discovery, Oersted was unable to provide satisfactory explanations to his work, however, in the year 1873, James Clerk Maxwell's publication 'A Treatise on Electricity and Magnetism' shed some more light on this observation. Maxwell studied the phenomenon and unified and extended the previous observations of other scientists namely Andre-Marie Ampere and Michael Faraday to give some major formulas which has helped today's generation of scientists to understand the relation between electricity and magnetism to the major extent.

Electromagnetism is the study of the electromagnetic force that is carried by electromagnetic fields composed of electric fields and magnetic field. It is one of the four fundamental interactions in nature.

- ## Electromagnet and Electromagnetic Induction[27]:

An electromagnet is the easiest way to understand how the electric current can generate a magnetic field. In the experiment, a wire is wound into a coil and is connected to a cell. When the current is flowing through the circuit, the coil is brought close to iron-particles. It can be observed that the iron particles get attracted to the coil and stick to the coil. This observation proves that a magnetic field is created around the current-flowing coil. In the year 1825, an English physicist, Willian Sturgeon, built the first practical electromagnet.

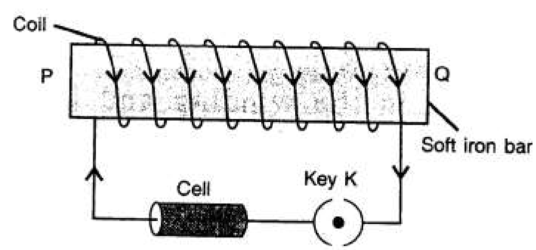


Fig. No. 4(a): An Electromagnet

In order to observe the generation of the current by the help of magnetic, another experiment can be performed. In this experiment, a coil is connected to the galvanometer. A galvanometer is an electromechanical instrument used for detecting and indicating an electric current. Then, a piece of bar magnetic is taken and is pushed in the coil. The galvanometer deflects in response to electric current flowing through the coil in a constant magnetic field. This observation proves that a magnetic field produces an electromotive force. In the year 1831, Michael Faraday discovered the induction of current in his famous induction ring experiment. The ‘induction ring’ experiment has a little different setup than the experiment mentioned above, but both the experiments have the same observation.

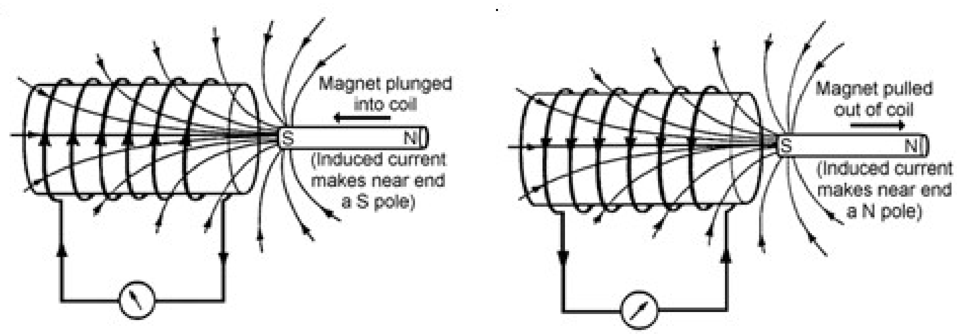


Fig. No.4(b): Electromagnetic Induction

- ## Maxwell's Equations[28]:

Maxwell's equations are a set of four equations that describe the world of electromagnetics. These equations describe how electric and magnetic fields propagate, interact, and how they are influenced by objects. These four basic laws of electricity and magnetism had been discovered experimentally through the work of physicists such as Coulomb, Gauss, Faraday and Ampere. Maxwell discovered logical inconsistences in these earlier results and identified incompleteness of Ampere's law as their cause. He basically combined the existing knowledge of the laws of electricity and of magnetism with insights of his own into a complete overarching electromagnetic theory.

a. **Gauss' law for electricity:** It states that, the total charge contained within a closed surface is proportional to the total electric flux across the surface.

$$\int E.da = \frac{1}{\epsilon_o}\int \rho.dV$$

b. **Gauss' law for magnetism:** Although magnetic diploes can produce an analogous magnetic flux, which carries a similar mathematical form, there exists no equivalent magnetic monopoles, and therefore the total magnetic charge over all space must sum to zero.

$$\int B.da = 0$$

c. **Faraday's law for induction:** The electric and magnetic fields become intertwined when the fields undergo time evolution, i.e., a change in magnetic flux produces an electric field over a closed loop.

$$\oint E.ds = -\frac{d}{dt}\int B.da$$

d. **Ampere's circuital law:** It states that, the steady current across a surface leads to a magnetic field. In addition, Maxwell determined that the rapid changes in the electric flux $\left(\frac{d}{dt}\right)E.da$ can also lead to changes in magnetic flux.

$$\oint B.ds = \mu_o\int J.da + \mu_o\epsilon_o\frac{d}{dt}\int E.da$$

- ## Applications of Electromagnetism[29]:

Since electricity is the known factor in everybody's day to day life, it has various roles in everyday objects, and since magnetism and electricity coexist, almost every electronic appliances we use have electromagnetic set-up. Some basic applications of electricity and magnetism in both household and industrial areas are mentioned below:

a. The most dominant use of power in homes as well as commercial buildings is lighting systems. These lighting systems used numerous fluorescent lighting fixtures. Ballasts used in the fluorescent lamps use electromagnetic principle so that the time of switching ON the light, it produces high voltage.

b. Electric fans, blowers and other cooling systems along with kitchen appliances like grinders use electric motors. These motors work on the principle of electromagnetic induction.

c. Entertainment systems like television, radio or stereo systems use loudspeaker. This device consists of electromagnet which is attached to the membrane or cone surrounded by the magnetic flux produced by the permanent magnet.

d. Generators and motors dominate in most of the industries which are the primary power source and driving systems respectively. Both of these industrial appliances work on the principle of electromagnetism.

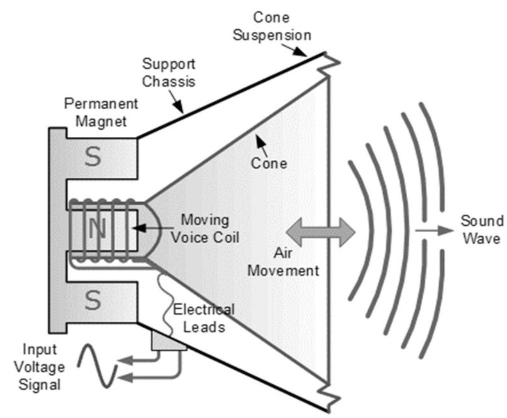


Fig. No. 4(c): Mechanism of Speaker

e. Various sensors and actuating devise like hall-effect sensors, magnetoresistive sensors, fluxgate sensors, solenoid valves, relays, motors etc. work based on electromagnetism.

f. The modern technology of transportation systems, namely the magnetic levitation trains, are entirely based on the concept of electromagnetism.

g. In communication system, the transmission of information from a source to a receiver over a long distance is carried out through electromagnetic waves at high frequencies.

h. Many of the medical stuffs like magnetic resonance imaging (MRI) scanner, hyperthermia treatment equipment etc., work based on the electromagnetism and can scan minute details of the human body.

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