



**G. PULLAIAH COLLEGE OF ENGINEERING AND TECHNOLOGY**  
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**Department of Electrical and Electronics Engineering**

*Bridge Course*

*On*

**Electrical Technology**

## Faraday's Laws of Electromagnetic Induction:

In 1831, Michael Faraday, an English physicist gave one of the most basic laws of electromagnetism called Faraday's law of electromagnetic induction. This law explains the working principle of most of the electrical motors, generators, electrical transformers and inductors. This law shows the relationship between electric circuit and magnetic field. Faraday performs an experiment with a magnet and coil. During this experiment, he found how emf is induced in the coil when flux linked with it changes. He has also done experiments in electro-chemistry and electrolysis.

### Faraday's First Law

Any change in the magnetic field of a coil of wire will cause an emf to be induced in the coil. This emf induced is called induced emf and if the conductor circuit is closed, the current will also circulate through the circuit and this current is called induced current.

Method to change magnetic field:

By moving a magnet towards or away from the coil

By moving the coil into or out of the magnetic field.

By changing the area of a coil placed in the magnetic field

By rotating the coil relative to the magnet.

### Faraday's Second Law

It states that the magnitude of emf induced in the coil is equal to the rate of change of flux that linkages with the coil. The flux linkage of the coil is the product of number of turns in the coil and flux associated with the coil.

## What is Lenz's Law?

To determine the direction of induced current, Lenz's rule is the most convenient method. Lenz's rule depends on the principle of conservation of energy and Newton's third law. Lenz's law states that induced electromotive force with different polarities induces a current whose magnetic field opposes the change in magnetic flux through the loop in order to ensure that original flux is maintained through the loop when current flows in it.

## Fleming Left Hand rule and Fleming Right Hand rule:

In late 19<sup>th</sup> century, John Ambrose Fleming introduced both these rules and as per his name, the rules are well known as **Fleming left hand and right hand rule.**

Whenever, a current carrying conductor comes under a magnetic field, there will be force acting on the conductor and on the other hand, if a conductor is forcefully brought under a magnetic field, there will be an induced current in that conductor. In both of the phenomenon's, there is a relation between magnetic field, current and force. This relation is directionally determined by **Fleming Left Hand rule** and **Fleming Right Hand rule** respectively. Directionally means these rules do not show the magnitude but show the direction of any of the three parameters (magnetic field, current, force) if the direction of other two are known. **Fleming Left Hand rule** is mainly applicable for electric motor and **Fleming Right Hand rule** is mainly applicable for electric generator.

### **Ohm's Law**

The law stating that the direct current flowing in a conductor is directly proportional to the potential difference between its ends. It is usually formulated as  $V = IR$ , where  $V$  is the potential difference, or voltage,  $I$  is the current, and  $R$  is the resistance of the conductor.

### **Electric power**

Electric power is the rate, per unit time, at which electrical energy is transferred by an electric circuit. The SI unit of power is the watt, one joule per second.

Electric power is usually produced by electric generators, but can also be supplied by sources such as electric batteries. It is usually supplied to businesses and homes by the electric power industry through an electric power grid. Electric power is usually sold by the kilowatt hour (3.6 MJ) which is the product of power in kilowatts multiplied by running time in hours. Electric utilities measure power using an electricity meter, which keeps a running total of the electric energy delivered to a customer.

### **Electromotive force (EMF)**

Electromotive force, also called emf (measured in volts), is the voltage developed by any source of electrical energy such as a battery or dynamo. It is generally defined as the electrical potential for a source in a circuit. A device that supplies electrical energy is called electromotive force or emf. Emfs convert chemical, mechanical, and other forms of energy into electrical energy. The product of such a device is also known as emf.

### **Voltage:**

Voltage, electric potential difference, electric pressure or electric tension (formally denoted  $\Delta V$  or  $\Delta U$ , but more often simply as  $V$  or  $U$ , for instance in the context of Ohm's or Kirchhoff's circuit laws) is the difference in electric potential energy between two points per unit electric charge. The voltage between two points is equal to the work done per unit of charge against a static electric field to move the test charge between two points. This is measured in units of volts (a joule per coulomb).

### **Electric current:**

An electric current is a flow of electric charge. In electric circuits this charge is often carried by moving electrons in a wire. It can also be carried by ions in an electrolyte, or by both ions and electrons. The SI unit for measuring an electric current is the ampere, which is the flow of electric

charge across a surface at the rate of one coulomb per second. Electric current is measured using a device called an ammeter.

### **Torque:**

Torque or moment of force is rotational force just as a linear force is a push or a pull, a torque can be thought of as a twist to an object. Mathematically, torque is defined as the cross product of the vector by which the force's application point is offset relative to the fixed suspension point (distance vector) and the force vector, which tends to produce rotational motion.

The magnitude of torque depends on three quantities: the force applied, the length of the lever arm connecting the axis to the point of force application, and the angle between the force vector and the lever arm.

### **Force:**

In physics, a force is any interaction that, when unopposed, will change the motion of an object. A force can cause an object with mass to change its velocity (which includes to begin moving from a state of rest), i.e., to accelerate. Force can also be described intuitively as a push or a pull. A force has both magnitude and direction, making it a vector quantity. It is measured in the SI unit of Newton's and represented by the symbol F.

### **Electric Field:**

The field or space around a charge particle where its force can be experienced by any other charged particle is called the electric field of former charge. Electric field is also known as electrostatic field intensity.

### **Magnetic Field:**

Magnetic fields can be defined in a number of ways, depending on the context. However, in general terms, it is an invisible field that exerts magnetic force on substances which are sensitive to magnetism. Magnets also exert forces and torques on each other through the magnetic fields they create.

### **Magnetic Flux:**

Magnetic flux is a measurement of the total magnetic field which passes through a given area. It is a useful tool for helping describe the effects of the magnetic force on something occupying a given area. The measurement of magnetic flux is tied to the particular area chosen. We can choose to make the area any size we want and orient it in any way relative to the magnetic field.

## **What is ELECTRIC MACHINE?**

In electrical engineering, **electric machine** is a general term for electric motors and electric generators and other electromagnetic machines. They are electromechanical energy converters:

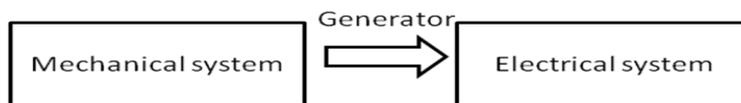
An electric motor converts electricity to mechanical power while an electric generator converts mechanical power to electricity. The moving parts in a machine can be rotating (rotating machines) or linear (linear machines) Besides motors and generators, a third category often included

is transformers, which although they do not have any moving parts are also energy converters, changing the voltage level of an alternating current.

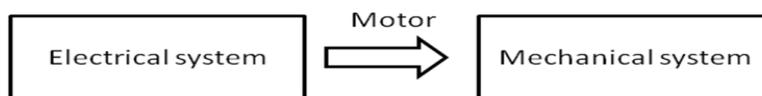
Electric machines, in the form of generators, produce virtually all electric power on Earth, and in the form of electric motors consume approximately 60% of all electric power produced. Electric machines were developed beginning in the mid 19th century and since that time have been a ubiquitous component of the infrastructure. Developing more efficient electric machine technology is crucial to any global conservation, green energy, or alternative energy strategy.

**Basic principle operation of Electric machine:**

The electromechanical energy conversion device is a link between electrical and mechanical systems. When the mechanical system delivers energy through the device to the electrical system, the device is called a generator.

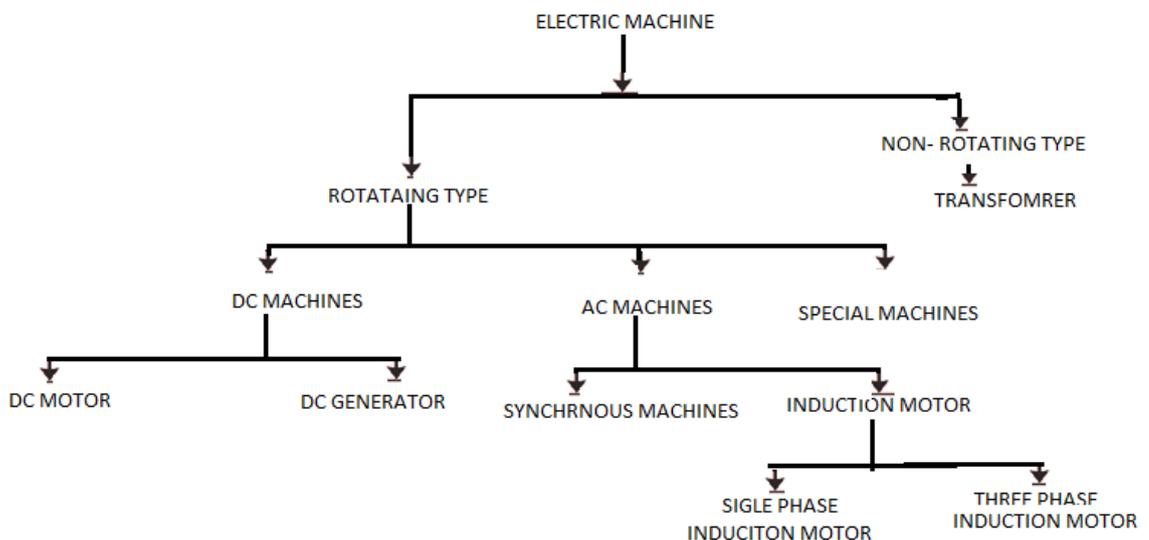


When an electrical system delivers energy through the device to the mechanical system, the device is called a motor.



The process is reversible; however, the part of energy converted to heat is lost and is irreversible. An electric machine can be made to work either as a generator or as a motor.

**Classification of Electric Machines:**



## DC Machine

A DC Machine is an electro-mechanical energy conversion device. There are two types of DC machines; one is DC generator, and another one is known as DC motor. A DC generator converts mechanical power ( $\omega T$ ) into DC electrical power ( $EI$ ), whereas, a DC motor converts DC electrical power into mechanical power. The AC motor is invariably applied in the industry for conversion of electrical power into mechanical power, but at the places where the wide range of speeds and good speed regulation is required, like in electric traction system, a DC motor is used.

The construction of dc motor and generator is nearly same. The generator is employed in a very protected way. Hence there is open construction type. But the motor is used in the location where they are exposed to dust and moisture, and hence it requires enclosures for example dirt proof, fire proof, etc. according to requirement.

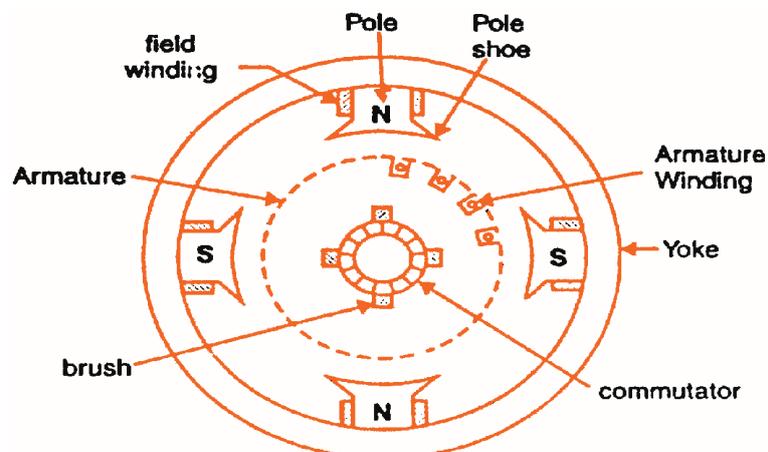
Although the battery is an important source of DC electric power, it can only supply limited power to any machines. There are some applications where large quantities of DC power are required, such as electroplating, electrolysis, etc. Hence, at such places, DC generators are used to deliver power.

## Basic Structure of Electrical Machine

The rotating electrical or DC machine has mainly two parts; one is **Stator**, and another one is **Rotor**. The stator and rotor are separated from each other by an air gap. The stator is the outer frame of the machine and is immovable. The rotor is free to move and is the inner part of the machine.

Both the stator and the rotor are made of ferromagnetic materials. Slots are cut on the inner periphery of the stator and the outer periphery of the rotor. Conductors are placed in the slots of the stator or rotor. They are interconnected to form windings.

The windings in which voltage is induced is called the **Armature windings**. The winding through which a current is passed to produce the main flux is called the **Field windings**. To provide main flux in some of the machine permanent magnets is also used.



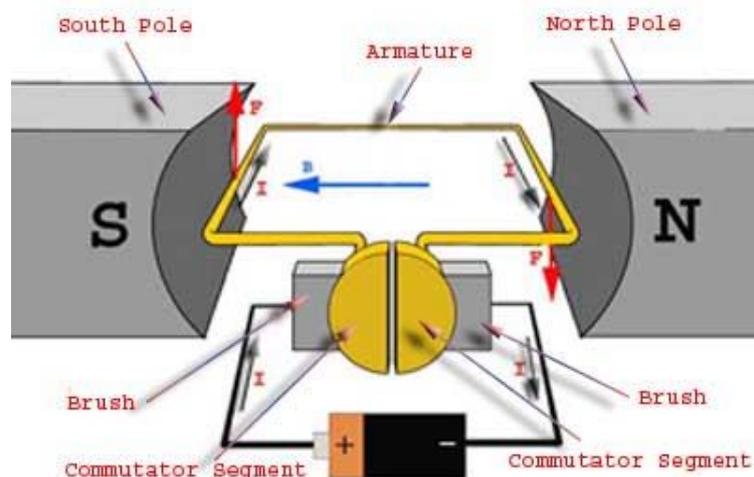
**Fig. 1 : Constructional parts of a DC machine**

## DC Generator

DC generator is an electrical generator is a machine which converts mechanical energy or power into electrical energy or power. It works based on the principle of production of dynamically or motionally induced e.m.f (Electromotive Force).

### Principle of DC Generator

Working principle of a DC generator: According to Faraday's laws of electromagnetic induction, whenever a conductor is placed in a varying magnetic field (OR a conductor is moved in a magnetic field), an emf (electromotive force) gets induced in the conductor.



**Fig. 2: Working principle of DC generator**

There are two types of generators, one is ac generator and other is DC generator. Whatever may be the types of generators, it always converts mechanical power to electrical power. An AC generator produces alternating power. A DC generator produces direct power. Both of these generators produce electrical power, based on same fundamental principle of Faraday's law of electromagnetic induction. According to this law, when a conductor moves in a magnetic field it cuts magnetic lines of force, due to which an emf is induced in the conductor. The magnitude of this induced emf depends upon the rate of change of flux (magnetic line force) linkage with the conductor. This emf will cause a current to flow if the conductor circuit is closed.

The direction of induced emf is given by **Fleming's Right hand rule** which states that "Hold out the right hand with the fore finger, middle finger and thumb at right angle to each other. If forefinger represents the direction of the magnetic field or magnetic lines of force, the thumb points in the direction of motion of conductor or applied force, then middle finger points in the direction of the induced current.

Hence the most basic essential parts of a generator are :

1. Magnetic Field
2. conductors which move inside that magnetic field.

### DC Motor

A DC motor is any of a class of rotary electrical machines that converts direct current electrical energy into mechanical energy. The most common types rely on the forces produced by magnetic fields. Nearly all types of DC motors have some internal mechanism, either electromechanical or electronic, to periodically change the direction of current flow in part of the motor.

DC motors were the first type widely used, since they could be powered from existing direct-current lighting power distribution systems. A DC motor's speed can be controlled over a wide range, using either a variable supply voltage or by changing the strength of current in its field windings. Small DC motors are used in tools, toys, and appliances. The universal motor can operate on direct current but is a lightweight motor used for portable power tools and appliances. Larger DC motors are used in propulsion of electric vehicles, elevator and hoists, or in drives for steel rolling mills. The advent of power electronics has made replacement of DC motors with AC motors possible in many applications.

### Principle of DC Motor

This DC or **direct current motor** works on the principle, when a current carrying conductor is placed in a magnetic field, it experiences a torque and has a tendency to move. This is known as motoring action. If the direction of current in the wire is reversed, the direction of rotation also reverses. When magnetic field and electric field interact they produce a mechanical force, and based on that the working principle of **DC motor** is established.

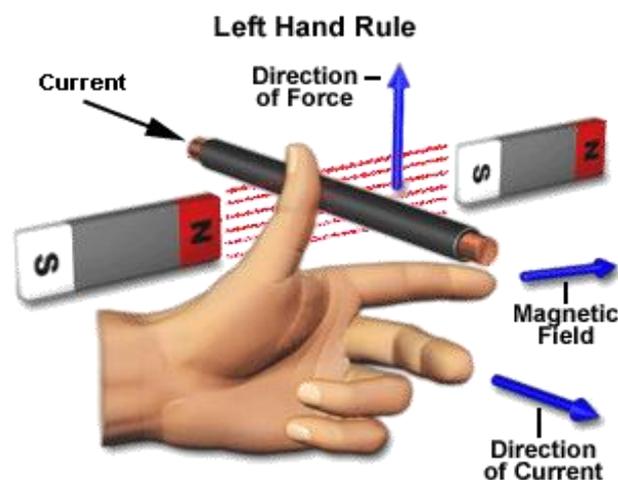


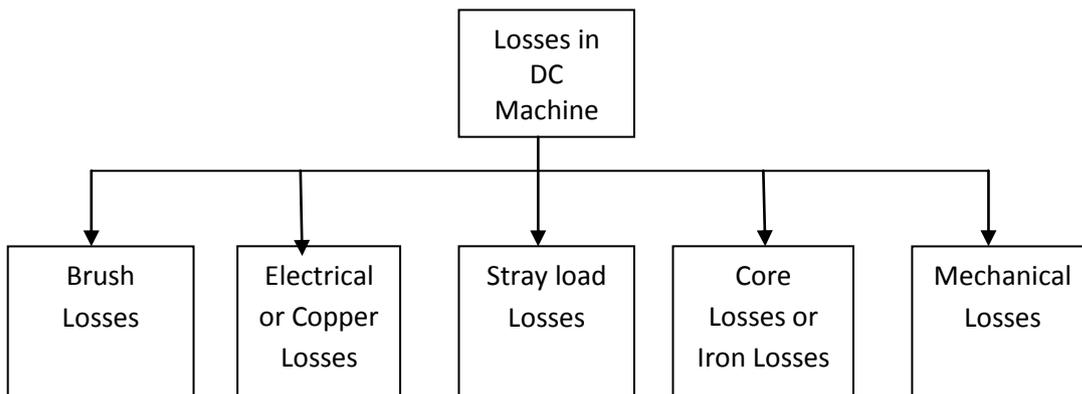
Fig. 3: Working Principle of DC motor

The direction of rotation of this motor is given by **Fleming's left hand rule**, which states that if the index finger, middle finger and thumb of your left hand are extended mutually perpendicular to each other and if the index finger represents the direction of magnetic field, middle finger indicates the direction of current, then the thumb represents the direction in which force is experienced by the shaft of the DC motor.

Structurally and construction wise a direct current motor is exactly similar to a DC generator, but electrically it is just the opposite. Here we unlike a generator we supply electrical energy to the input port and derive mechanical energy from the output port.

### Losses in DC Machine

The losses that occur in a DC Machine is divided into five basic categories. The various losses are Electrical or Copper losses ( $I^2R$  losses), Core losses or Iron losses, Brush losses, Mechanical losses, Stray load losses.



**Fig. 4: Losses in DC machine**

### Types of DC Generators

**DC Generators** are named according to the connection of the field winding with the armature. They are:

1. Separately Excited DC Motor
2. Self Excited DC Motor –
  - (i) Shunt wound DC Generator
  - (ii) Series wound DC Generator
  - (iii) Compound wound DC Generator

### Types of DC Motors

**DC motors** are named according to the connection of the field winding with the armature. They are:

1. Separately Excited DC Motor
2. Self Excited DC Motor - (i) Shunt wound DC Motor  
(ii) Series wound DC Motor  
(iii) Compound wound DC Motor

## Transformer

Another electric machine is a Transformer. It is static device which does not contain any rotating part. It is based on the principle of mutual induction, converts from one level voltage to another level voltage.

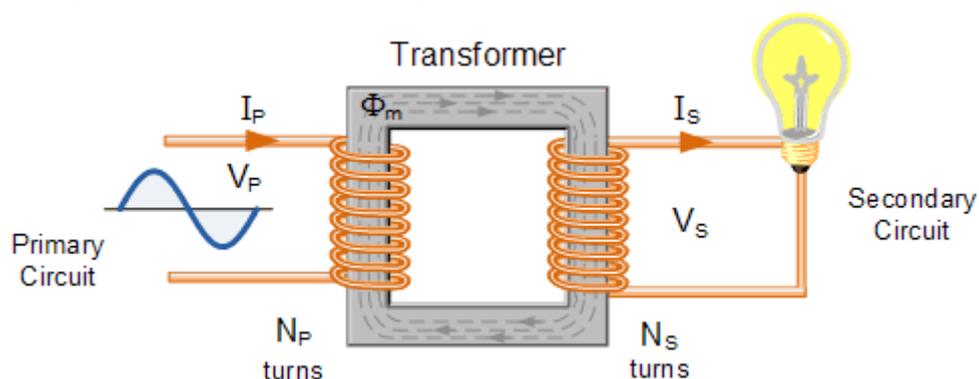
A transformer is an electrical device that transfers electrical energy between two or more circuits through electromagnetic induction. A varying current in one coil of the transformer produces a varying magnetic field, which in turn induces a voltage in a second coil. Power can be transferred between the two coils through the magnetic field, without a metallic connection between the two circuits. Faraday's law of induction discovered in 1831 described this effect. Transformers are used to increase or decrease the alternating voltages in electric power applications

Transformers are capable of either increasing or decreasing the voltage and current levels of their supply, without modifying its frequency, or the amount of electrical power being transferred from one winding to another via the magnetic circuit.

A single phase voltage transformer basically consists of two electrical coils of wire, one called the “Primary Winding” and can other called the “Secondary Winding”. For this tutorial we will define the “primary” side of the transformer as the side that usually takes power, and the “secondary” as the side that usually delivers power. In a single-phase voltage transformer the primary is usually the side with the higher voltage.

These two coils are not in electrical contact with each other but are instead wrapped together around a common closed magnetic iron circuit called the “core”. This soft iron core is not solid but made up of individual laminations connected together to help reduce the core’s losses.

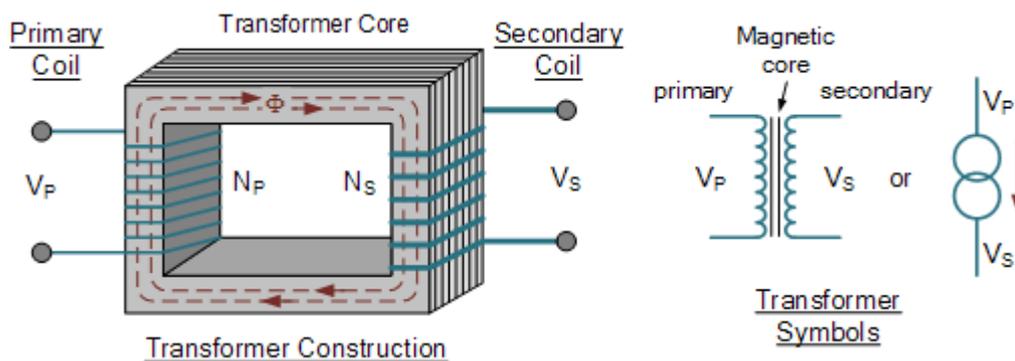
The two coil windings are electrically isolated from each other but are magnetically linked through the common core allowing electrical power to be transferred from one coil to the other. When an electric current passed through the primary winding, a magnetic field is developed which induces a voltage into the secondary winding as shown below.



**Fig. 5: Principle of operation - Single Phase Voltage Transformer**

In other words, for a transformer there is no direct electrical connection between the two coil windings, thereby giving it the name also of an Isolation Transformer. Generally, the primary winding of a transformer is connected to the input voltage supply and converts or transforms the electrical power into a magnetic field. While the job of the secondary winding is to convert this alternating magnetic field into electrical power producing the required output voltage as shown.

$$\text{Transformation ratio } K = \frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$$



**Fig 6:Construction and Symbols of Transformer**

Where:

- $V_p$  - is the Primary Voltage
- $V_s$  - is the Secondary Voltage
- $N_p$  - is the Number of Primary Windings
- $N_s$  - is the Number of Secondary Windings
- $\Phi$  (phi) - is the Flux Linkage

Notice that the two coil windings are not electrically connected but are only linked magnetically. A single-phase transformer can operate to either increase or decrease the voltage applied to the primary winding. When a transformer is used to “increase” the voltage on its secondary winding with respect to the primary, it is called a Step-up transformer. When it is used to “decrease” the voltage on the secondary winding with respect to the primary it is called a Step-down transformer.

The difference in voltage between the primary and the secondary windings is achieved by changing the number of coil turns in the primary winding ( $N_p$ ) compared to the number of coil turns on the secondary winding ( $N_s$ ).

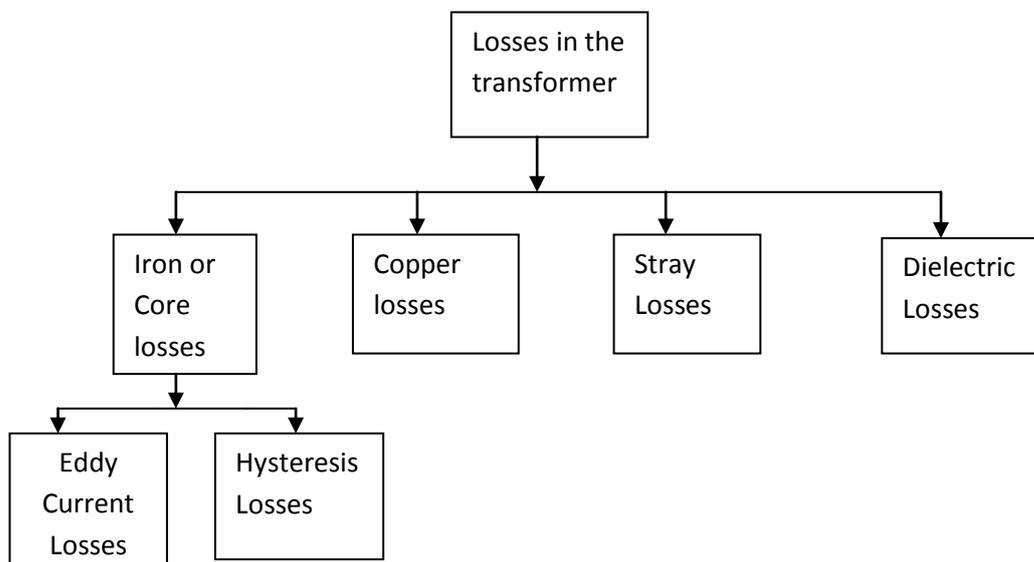
As the transformer is basically a linear device, a ratio now exists between the number of turns of the primary coil divided by the number of turns of the secondary coil. This ratio, called the ratio of transformation, more commonly known as a transformers “turns ratio”, ( $TR$ ). This turns ratio value dictates the operation of the transformer and the corresponding voltage available on the secondary winding.

### Types of Transformers:

There are various types of transformers that are used in electrical systems. They are

1. Instrument Transformer-
  - (i) Current Transformer
  - (ii) Potential Transformer
2. Power Transformer
3. Single-Phase Transformer (or) Three-Phase Transformer
4. Step-up (or) Step-down Transformer
5. Distribution Transformer

### Losses in Transformers:



**Fig. 7: Types of losses in a Transformer**

### What is Voltage Regulation?

The voltage regulation is the percentage of voltage difference between no load and full load voltages of a transformer with respect to its full load voltage.

#### Explanation of Voltage Regulation of Transformer:

Say an electrical power transformer is open circuited, means load is not connected with secondary terminals. In this situation, the secondary terminal voltage of the transformer will be its secondary induced emf  $E_2$ . Whenever full load is connected to the secondary terminals of the transformer, rated current  $I_2$  flows through the secondary circuit and voltage drop comes into

picture. At this situation, primary winding will also draw equivalent full load current from source. The voltage drop in the secondary is  $I_2 Z_2$  where  $Z_2$  is the secondary impedance of transformer.

Now if at this loading condition, any one measures the voltage between secondary terminals, he or she will get voltage  $V_2$  across load terminals which is obviously less than no load secondary voltage  $E_2$  and this is because of  $I_2 Z_2$  voltage drop in the transformer.

### Expression of Voltage Regulation of Transformer:

Expression of **Voltage Regulation of Transformer**, represented in percentage, is

$$\text{Voltage Regulation} = \frac{E_2 - V_2}{V_2} \times 100$$

(or)

$$\text{Voltage Regulation} = \frac{I_{SC}(R_{02} \cos \phi \pm X_{02} \sin \phi)}{V_{SC}} \times 100$$

The **Efficiency** of the transformer is defined as the ratio of useful power output to the input power, the two being measured in the same unit. Its unit is either in Watts (W) or KW. Transformer efficiency is denoted by  $\eta$ .

$$\eta = \frac{\text{output power}}{\text{input power}} = \frac{\text{output power}}{\text{output power} + \text{losses}}$$

$$\eta = \frac{\text{output power}}{\text{output power} + \text{iron losses} + \text{copper losses}}$$

$$\eta = \frac{V_2 I_2 \cos \phi}{V_2 I_2 \cos \phi + P_i + P_c}$$

(or)

$$\eta = \frac{X * KVA * \cos \phi}{X * KVA * \cos \phi + W_i + X^2 W_{cu}} \times 100$$

Where,  $x$  = fraction of load

$w_i$  = iron loss

$w_{cu}$  = copper loss

### INDUCTION MOTOR:

One of the most common electrical motor used in most applications which is known as **induction motor**. This motor is also called as asynchronous motor because it runs at a speed less than its synchronous speed. Here we need to define what synchronous speed is. Synchronous speed is the speed of rotation of the magnetic field in a rotary machine and it depends upon the frequency and number poles of the machine. An **induction motor** always runs at a speed less than synchronous speed because the rotating magnetic field which is produced in the stator will generate flux in the rotor which will make the rotor to rotate, but due to the lagging of flux current in the rotor with flux current in the stator, the rotor will never reach to its rotating magnetic field speed i.e. the synchronous speed.

There are basically two **types of induction motor** that depend upon the input supply

- Single phase induction motor
- Three phase induction motor.

Single phase induction motor is not a self starting motor where as three phase induction motor is a self-starting motor.

### **Types of 3-phase Induction Motor**

#### **Three Phase Induction Motor**

- Squirrel cage induction motor
- Slip ring induction motor

We had mentioned above that single phase induction motor is not a self starting and three phase induction motor is self starting. So what is self starting? When the machine starts running automatically without any external force to the machine, then it is called as self starting. For example we see that when we put on the switch the fan starts to rotate automatically, so it is self starting. Point to be noted that fan used in home appliances is single phase induction motor which is inherently not self starting. How? Question arises How it works? We will discuss it now.

#### **Why is Three Phase Induction Motor Self Starting?**

In three phase system, there are three single phase line with  $120^\circ$  phase difference. So the rotating magnetic field is having the same phase difference which will make the rotor to move. If we consider three phases a, b and c, when phase a is magnetized, the rotor will move towards the phase a winding a, in the next moment phase b will get magnetized and it will attract the rotor and then phase c. So the rotor will continue to rotate.

#### **Why Single Phase Induction Motor is not Self Starting?**

It will be having only one phase still it makes the rotor to rotate, so it is quite interesting. Before that we need to know why single phase induction motor is not a self starting motor and how the problem is overcome. We know that the AC supply is a sinusoidal wave and it produces pulsating magnetic field in uniformly distributed stator winding. Since pulsating magnetic field can be assumed as two oppositely rotating magnetic fields, there will be no resultant torque produced at the starting and due to this the motor does not run. After giving the supply, if the rotor is made to rotate in either direction by external force, then the motor will start to run. This problem has been solved by making the stator winding into two winding, one is main winding and another is auxiliary winding and a capacitor is fixed in series with the auxiliary winding. This will make a phase difference when current will flow through the both coils. When there will be phase difference, the rotor will generate a starting torque and it will start to rotate.

Practically we can see that the fan does not rotate when the capacitor is disconnected from the motor but if we rotate with hand it will start to rotate. So this is the reason of using capacitor in

the single phase induction motor. There are several advantages of induction motor which makes this motor to have wider application. It is having good efficiency up to 97%. But the speed of the motor varies with the load given to the motor which is an disadvantage of this motor. The direction of rotation of induction motor can easily be changed by changing the sequence of three phase supply, i.e. if RYB is in forward direction, the RBY will make the motor to rotate in reverse direction. This is in the case of three phase motor but in single phase motor, the direction can be reversed by reversing the capacitor terminals in the winding.

### Three-Phase Induction motor

This is another type of AC motor where rotating magnetic field cuts the rotor conductors, hence circulating current induced in these short circuited rotor conductors. Due to interaction of the magnetic field and these circulating currents the rotor starts rotates and continues its rotation. This is induction motor which is also known as asynchronous motor runs at a speed lesser than synchronous speed, and the rotating torque, and speed is governed by varying the slip which gives the difference between synchronous speed  $N_s$ , and rotor speed  $N_r$ , It runs governing the principal of EMF induction due to varying flux density, hence the name induction machine comes.

**Slip:** Slip, is defined as the difference between synchronous speed and operating or rotor speed, at the same frequency, expressed in rpm, or in percentage or ratio of synchronous speed. Thus

$$S = \frac{N_s - N_r}{N_s}$$

Single phase induction motor like a 3 phase, runs by the principal of emf induction due to flux, but the only difference is, it runs on single phase supply and its starting methods are governed by two well established theories, namely the Double Revolving field theory and the Cross field theory.

Apart from the four basic types of motor mentioned above, there are several types Of special electrical motors like Linear Induction motor(LIM), Stepper motor, Servo motor etc with special features that has been developed according to the needs of the industry or for a particular gadget like the use of hysteresis motor in hand watches because of its compactness.

### Synchronous machines:

AC system has a number of advantages over DC system. These days 3-phase AC system is being exclusively used for generation, transmission and distribution of power. The machine which provides 3-phase power from mechanical power is called an **Alternator or Synchronous generator**. Alternators are the primary source of all the electrical energy we consume. These machines are the largest energy converters found in the world. They convert mechanical energy into AC energy.

An alternator operates on the same fundamental **principle of electromagnetic induction** as a DC generator. But there is one important difference between the two. In a DC generator, the armature winding is placed on the rotor in order to provide a way of converting alternating voltage generated in the winding to a direct voltage at the terminals through the use of a rotating commutator. The field poles placed on the stationary part of the machine. Since no commutator is required in an alternator, it is usually more convenient and advantageous to place the field winding on the rotating part (rotor) and armature winding on the stationary part (stator).

Among the four basic **classifications** mentioned above the rest all are AC electrical motors, and are driven by alternating current, for e.g., the **synchronous motor**, which always runs at synchronous speed. Here the rotor is an electro - magnet which is magnetically locked with stator rotating magnetic field and rotates with it. The speed of these machines are varied by varying the frequency ( $f$ ) and number of poles ( $P$ ), as  $N_s = 120 f/P$ .