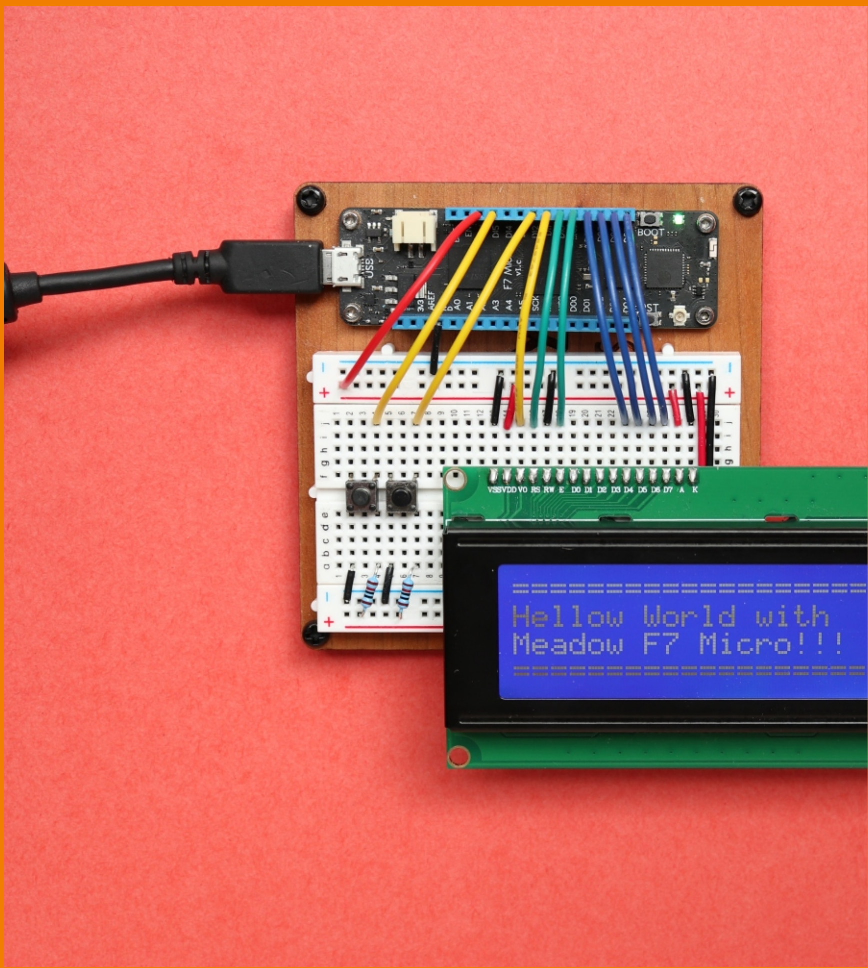
MAGNETIC CIRCUITS



Harsh Shrivastava, Dr. S Riyaz Ahammed

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CHAPTER 1

INTRODUCTION OF MAGNETIC CIRCUITS

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William Gilbert was known as the father of magnets. According to Greek legend magnetism was first discovered by a shepherd named Magnes, who lived in Magnesia, Greece. Magnetite was the first natural magnet because it was discovered at a place called Magnesia.Magnetism plays a vital role in every electrical industry today, in research as well as for home appliances. A magnet is a piece of iron that produces a magnetic field and due to this magnet attracts unlike poles and repels like poles.

Magnets have various properties that make them distinct when the magnet is dipped in iron filings, iron fillings are attracted to the end of the magnet as the attraction is maximum at the ends of the magnet which are known as poles of magnets. Magnetic poles always exist in pairs. The Pole towards the geographic north is known as the North Pole and the pole pointing towards the geographic south is known as the South Pole. Magnets repel likes poles while attracting unlike poles. The force acting between the two magnets is known as a magnetic force of attraction. The magnetic force of attraction is greater when the distance between these magnets is lesser. Magnetic force is inversely proportional to the distance between two magnets. Now illustrating the types of magnet given below Figure 1.1[1]–[3].

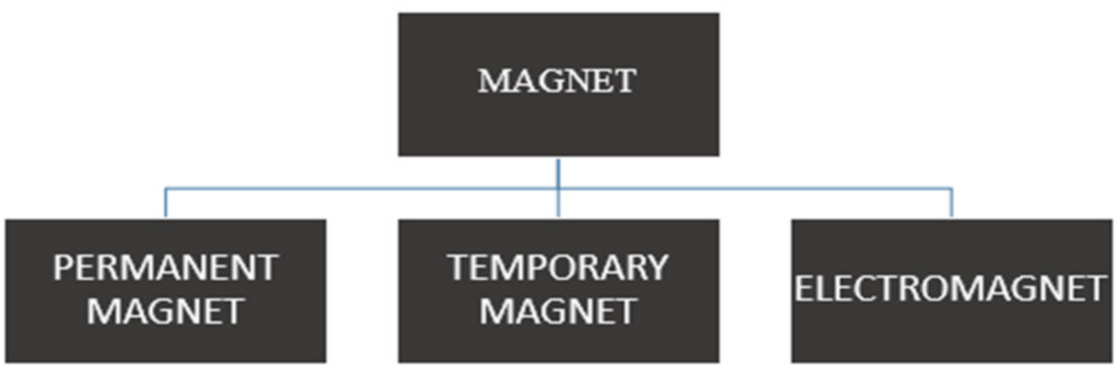

Figure 1.1: Illustrating the different types of magnets.

Types of magnets:

There are basically three types of magnets and they are as follows:

I. Permanent magnet
II. Temporary magnet
III. Electromagnets

Permanent magnets

Permanent magnets are the most commonly used magnets. Those magnets are known as permanent magnets because after magnetizing once they do not lose their magnetic property.Those are the following methods that are used for demagnetizing the permanent magnets such as heating the magnet at a higher temperature**,** also we can reduce the magnetic attraction between the magnet's atoms gets loosened with the help of a hammer, and stroking one magnet with another will reduce the thickness and magnetic strength of permanent magnet can't be changed.

There are four types of permanent magnets:

1) Samarium Cobalt
2) Neodymium Iron Boron (NIB)
3) Ceramic or ferrite
4) Alnico

Temporary magnets

Temporary magnets are those magnets that can be magnetized in the presence of a magnetic field. Those magnets are known as temporary magnets because after magnetizing once they lose their magnetic property. Examples of the temporary magnet are Iron nails and paper clips. Soft metals are used to make out a temporary magnet. They return their magnetized only if temporary magnets are present in near-permanent magnets. Temporary magnets are obtained in a variety of different forms.Now we have to see the comparison between permanents and temporary magnets, as shown in the given Table1.1

Table 1.1: Comparison between Permanent magnets and Temporary magnets

Permanent magnets	**Temporary magnets**
It has an ability to regain a magnetic field	Do not regain the magnetic field
Do not need another magnet for magnetized	Need other magnet for magnetization after demagnetized
Hard materials are used for permanent magnets	Generally we use soft materials for those magnets.
It always created with another strong magnetic force.	It always able to function through magnetic force or electric current

Electromagnets

When the flow of the electric current is produced in the magnet with the help of a magnetic field, those type of magnet are known as Electromagnets. Electromagnets consist of a coil of wire packed around the metal core made from iron. When this material is placed to an electric current than a magnetic field is generated and making the material behave like a magnet. The strength of the magnetic field can be controlled by controlling the electric current.The magnetic core around the coil of wire is made of either ferromagnetic or ferromagnetic material. For example, iron. The magnetic flux is strengthened by the magnetic core and makes the magnet more powerful as compared to other magnets.When charges like protons and electrons are fixed at a constant position, electric forces are created like an attractive or repulsive force between the charged particle. When those charges are move then moving charges produce magnetic forces either a repulsive or attractive force between the charged particles due to the motion. Within a magnet there a lot of moving particles and generate the magnetic field for the magnet, as shown in the Figure 1.2.

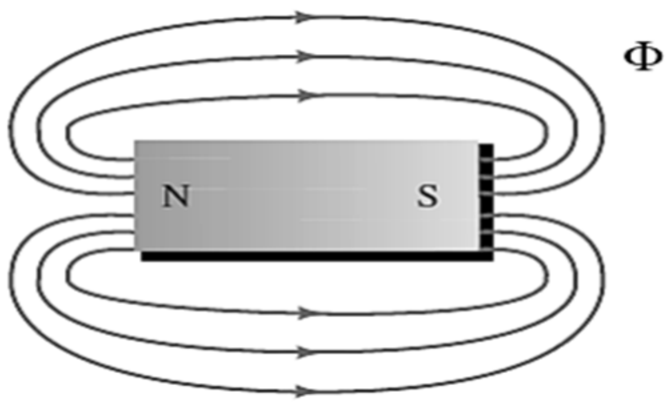

Figure 1.2: Bar magnet

There are lots of properties that we can see in a magnet and are follows:

Attractive Property – Iron, nickel, and cobalt are examples of ferromagnetic materials that are attracted to magnets by their attractive properties, as shown in the Figure 1.3[4]–[6].

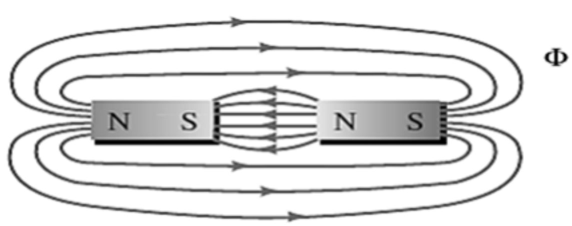

Figure 1.3: Attraction property

Repulsive Property – The repulsive property explained that unlike poles attract one another while like poles repel one another, as shown in the Figure 1.4.

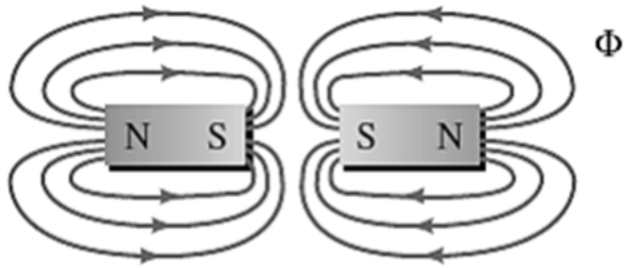

Figure 1.4: Repulsion

Directive Property – It is useful property that makes a magnet different from other and helpful in electrical devices. It provides help to find out the direction and gives correct direction to north-south poles.

Magnetic field definitions:

Magnetic field lines: The region surrounds the magnet in which the magnet experiences the force of attraction is called magnetic field. The total number of lines that align the magnet in a proper region of magnetic field and also shows the direction in which a magnetic material will be placed at the particular location, as shown in the Figure 1.4.

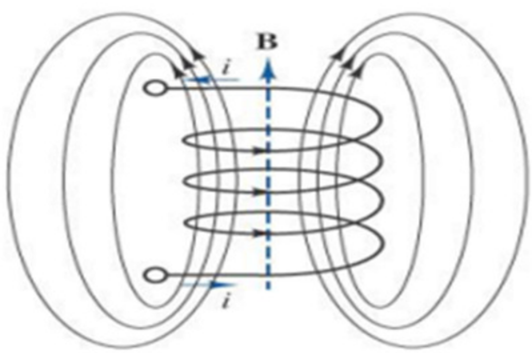

Figure 1.4: Magnetic field lines

Magnetic flux and magnetic flux density: Magnetic flux lines do not have starting or ending points as do electric flux lines but they exist in continuous loops. The symbolic representation of magnetic flux is Φ. In the SI system, the unit of flux is the weber (Wb).

Flux density is defined as the ratio of the total flux passing through an area to the size of the area. We can see that the symbolic representation of magnetic flux density is B.The SI unit of B is Tesla (T).
The mathematical formula of B is defined as:

$$B = \Phi / A \quad \text{Tesla(T)}$$

Here,

B = Tesla (T)
Φ = weber (Wb)
A = square meter (m^2)

The direction of the magnetic flux lines can be simply determined by using the thumb of the right hand in the direction of the flowing current flow and find out the direction of the fingers. This method is commonly known as the right-hand rule. The number of flux lines per unit area is called the flux density and it is denoted by the capital letter B.

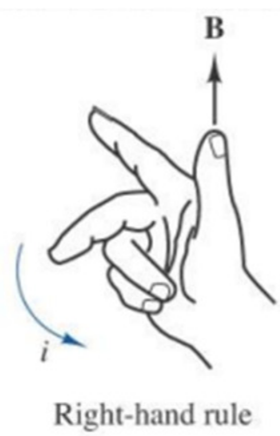

Figure 1.5: Diagram of Right- hand thumb rule

In the given figure above, we can clearly see how with the help of Right- hand-thumb rule we can find out the direction of magnetic field. In this rule, the thumb rule says that "the direction of the current flow and the rolling fingers show the direction of the magnetic field", as shown in the above Figure 1.5.

Permeability: The variation in strength is due to the higher or lesser no. of flux lines passing through the core. Those materials in which flux lines are easy to set up are said to be magnetic and they have high permeability. With the help of permeability value we can calculate how many magnetic field lines are established in the electric circuits. The symbolic representation of permeability(μ).

The permeability of all non-magnetic materials, such as copper, aluminum, wood, glass, air, etc. is the same for free space. If the permeability of material is slightly less than free space, this type of materials are said to be diamagnetic. If the permeability is lightly greater than that of free space are known as paramagnetic and those materials have very high permeability are referred to as ferromagnetic.The ratio of the permeability of a material to the free space is called its relative permeability[7]–[10].

MMF(magnetomotive force): When current is passing through a coil then it creates a magnetic flux. Either the value of the current is greater or the number of turns is greater, the flux will be automatically greater. The ability of a coil to produce a flux is called its MMF. MMF represents by a symbol and it is defined as Fm.

$Fm = MMF = NI$ (Amp- turn)

Reluctance: The magnetic flux is proportional to the MMF and inversely proportional to a quantity called reluctance R, which is inverse to electrical resistance. Reluctance is the quantity which opposes the measure of the magnetic circuit offers to the flux.

$R = L/ \mu A$

Here, R = is the reluctance, L = is the length of the magnetic path
A = is the cross-sectional area.
The units At/Wb is the number of turns of the applied winding.

Magnetizing force: magnetizing force can be defined as the ratio of mmf to the per unit length. It is represented by a stmbol H. Mathematical expression of H is shown below:

$H = Fm/L$ (At/m)
The SI unit of H is At/m.

Relation between H and B is: $B = \mu H$

Ohm's Law for Magnetic Circuits:
Ohm's law states that "generated flux is directly proportional to the MMF and it is inversely proportional to the reluctance", as shown in the given Figure 1.6.
A mathematical expression can be write as:
$\Phi = Fm / R$

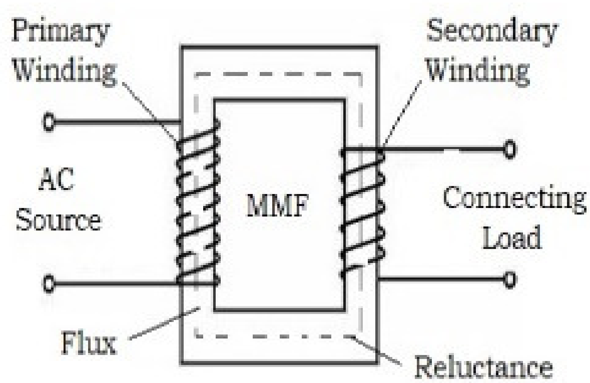

Figure 1.6: Diagram of Ohm's Law for Magnetic Circuits

Ampere's circuital Law:
Ampere law was discovered by Andre-Marie Ampere in 1826. Ampere law states that "the integrated magnetic field around a closed loop to the electric current passing through the loop".

$$\int H.dl = I$$

Where

H is the magnetic field intensity. The unit of the magnetic field is At/m, as shown in the given below Figure 1.7.

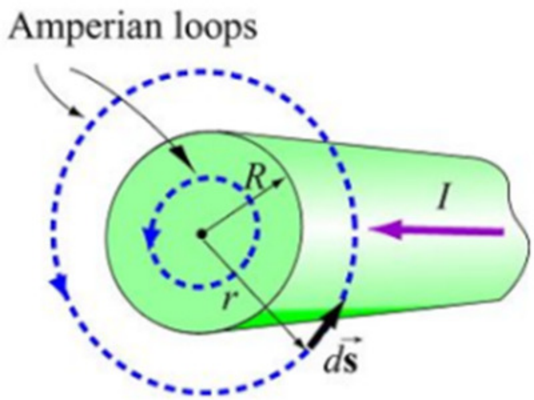

Figure 1.7: Diagram of ampere's circuital law

In other words, law states that "the algebraic sum of the entering and exiting value of the MMF around a closed loop of a magnetic circuit is equal to zero, or the sum of the entering MMF equals the sum of the exiting MMF around a closed loop". This equation is referred to as Ampere's circuital law. When it is applied to magnetic circuits, sources of MMF are expressed as:

$$Fm = Hl \quad (At)$$

Series Magnetic Circuits:

Now we have to understand how to solve the problem when all the quantity is given, solve the problem step by step as according to procedure that given below:

1. Solve a circuit in which Φ is known
2. Firstly find the value of B using Φ/A
3. Calculate the value of H for each magnetic section from B-H curve
4. Calculate NI with the help of Ampere's circuital law
5. And at last use all the calculated value to determine the coil current and turns as required.

Now see the analogy between electric and magnetic circuits in the given Table 1.2and compare with the help of the followingFigure 1.7 and Figure 1.8.

Table 1.2: Illustrates the Analogy between electric and magnetic circuits

Electrical	**Magnetic**	**Magnetic units**
Voltage v	Magnetomotive force Fm	Amp- turns

Current i	Magnetic flux Φ	Webers Wb
Resistance R	Reluctance R	Amp-turns / Wb
Conductivity σ	Permeability μ	Wb/A-t-m
Current density J	Magnetic flux density B	Wb/m^2=teslas T
Electric field E	Magnetic field intensity H	Amp-turn/m

Figure 1.7: Show the circuit diagram of electrical and magnetic circuit

(a) Electrical circuit (b) Magnetic circuit

Figure 1.8: equivalent circuit diagram of electrical circuit (a) and mechanical circuit (b)

B-H Curves:

The B-H curve is not fixed for ferromagnetic materials but it is continuously varied with flux density and there is no easy way to calculate it. What is really want to know about the given value of B and also the value of H and vice-versa,a set of curves called B-H or magnetization curves, provides this information.

The curve is obtained between B and H and also the curve represents the relation. The curves for cast iron, cast steel, and sheet steel shown in the below given Figure 1.9.

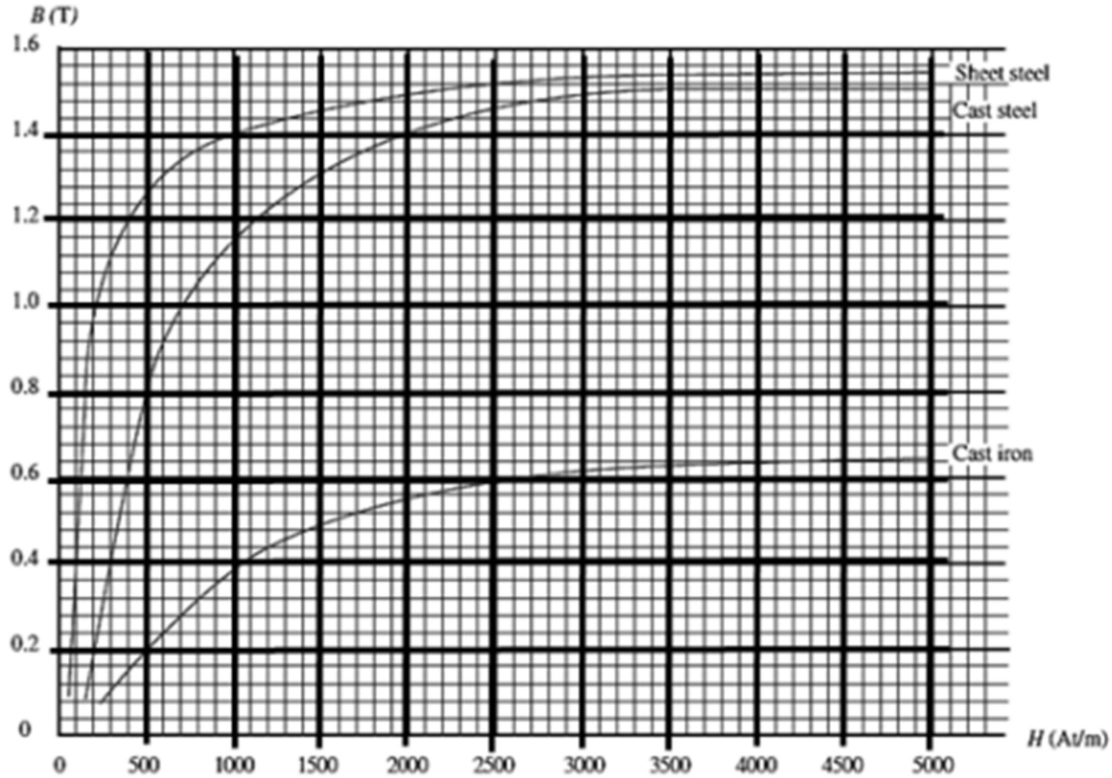

Figure 1.9: B-H curve

Hysteresis Loop:

With the help of the hysteresis loop we can determine the relationship between the magnetic flux density and the magnetizing field strength. When the imposed magnetizing field is removed, a ferromagnetic material that has been magnetized in one direction will not relax back to zero magnetization. A field moving in the opposite direction must force it back to zero. The material's magnetization will create a loop known as a hysteresis loop when an alternating magnetic field is applied to it.

The property known as hysteresis is connected to the material's presence of magnetic domains and the magnetization curve's inability to be traced back. It takes some energy to turn the magnetic domains back around after they have been reoriented. As a magnetic "memory," this property of ferrromagnetic materials is useful.

"Permanent magnets" are useful compositions of ferromagnetic materials that are able to maintain an imposed magnetization indefinitely. Iron and chromium oxides are useful for recording audio to tape and magnetically storing data on computer disks due to their magnetic memory properties. This loop is used for measuring the magnetic flux for especially that flux from the ferromagnetic substance, while those substances changing their magnetizing field, as shown in graph belowFigure 1.10.

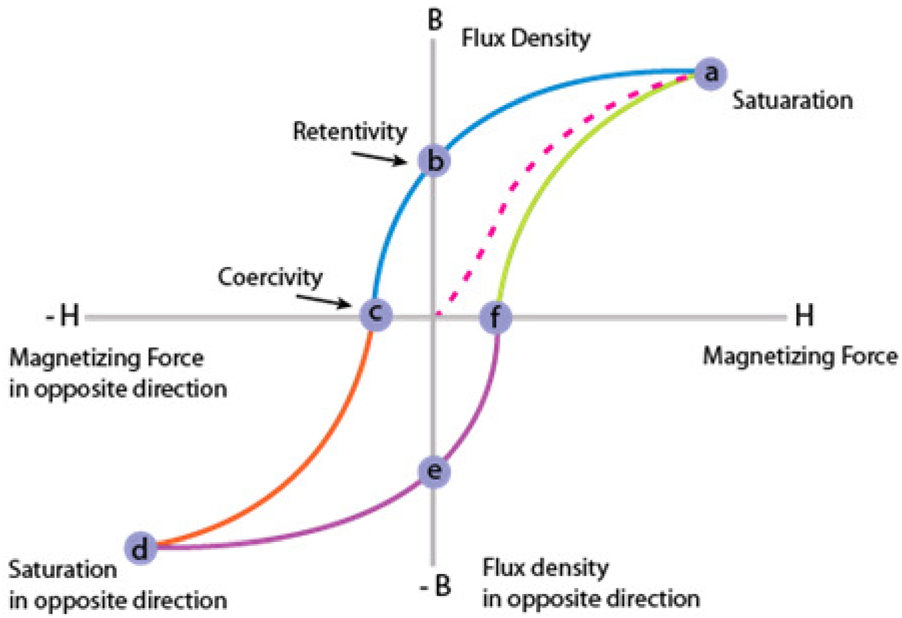

Figure 1.10: Graph show the hysteresis curve

i. **Retentivity** – Retentivity is an ability of materials to regain a certain amount of some residue value of magnetic field when magnetizing force is removed after a particular value of saturation range. In the above figure, retentivity is represent by b, in the above Figure 1.10.

ii. **Residual Magnetism** or **Residual Flux** - The value of magnetic flux density that remains in a material when it attain a zero magnetizing force. Let's us understand that residual magnetism and retentivity have equal value when the material has been magnetized to the saturation point. However, the level of value is higher than the level of residual magnetism when the magnetizing force did not proceed to the saturation level.

iii. **Coercive Force** - The amount of reverse magnetic field which must be applied to a magnetic material to make the magnetic flux return to zero.

iv. **Reluctance** - The magnetic flux is inversely proportional to the MMF and the reluctance R, which isopposite of electrical resistance. The quantity that stands in opposition to the ratio of the magnetic circuit's output to the flux is called reluctance. In an electrical circuit, resistance is inversely proportional to reluctance.

In this chapter, we discussed magnetsm and how it is discovered and how it is used nowadays in our daily life. Magnetism plays a vital role in electrical equipment such as in research as well as for home appliances. We have learn about the types of magnet and how one magnet is different from others and the uses of magnet. Types of materials on the basis of magnetizing property that have. In this, we learn about the different aspects of magnetic circuits and ohm's law and ampere's circuital law for magnetic circuits. Also tell about the different analogy between electrical and magnetic circuits. At last we learn about the hysteresis curve.

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CHAPTER 2

BASIC PRINCIPLES AND CONSERVATION OF ENERGY

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Energy is something the ability to do work. The word conservation refers to something which doesn't change means something that is constant or fixed. As we know Energy plays a vital role in our daily life as well as the use of energy is increasing day by day. Energy can be used in distinct forms as like somewhere it is used as potential energy and somewhere as kinetic energy. There are different aspects as energy is used in many ways. We can generate energy by various methods such as nuclear power plants, hydropower plants, diesel power plants, steam power plant, wind mill, geothermal energy, etc. Energy generation is the most important and profitable factor for a developing country like India. "The total installed power capacity in India is around 255.012 GW as of the end of November 2014, and India became the world's largest producer of electricity in the year 2013 outdriving the countries like Japan and Russia with a global share of 4.8% in power generation". As we heard a lot of times about the law of conservation, the law of conservation of energy is based on the principle that energy can neither be created nor destroyed, it can only be transferred from one form to another form and change from place to another place. Here are some of the examples by which we can understand the changeable process of energy from one form to other and how it is transferred from source to destination. An electric bulb in our homes and we see a bulb every day but never think about how it will glow and how electricity is converted into light energy, an electrical bulb is a device that converts electrical energy into light and heat energy as we can see the things around us.

Similarly in a microphone that we use in our daily for listening to songs, we thought ever how a microphone convert sound energy into electrical energy, while in a loudspeaker is a device that is used for the conversion of electrical energy into sound energy. In a hydroelectric power plant, we can see that water falls from a height onto a turbine causing it to turn and then those turns are running at high speed and producing an electricity. The turbine turns a coil in a magnetic field and magnetic field generating an electric current. Therefore, potential energy of the water is converted into kinetic energy of the turbine, which converts into electrical energy. Let's take the simplest examples of how it is possible and how it is happened, energy from the sun is come in the form of heat and nowadays we can utilized this heat energy as for many purpose, as by converting the heat energy into electricity with the help of photoelectric cell, we use that energy for running home appliances as well as for industrial purpose. Similarly we can see that nuclear power plant is a plant that converts the nuclear energy into light and heat energy. There are very heavy materials such as uranium, thorium, etc. are used in nuclear power plants for generation of electricity[1]–[3].

The molecules' kinetic energy is transformed into heat when any substance is heated. During expansion, some of the energy is used for the work. Heat energy is produced when a device is subjected to current. As a result, appliances like toasters, home irons, and geysers use electrical energy to generate heat. Mechanical energy is converted into heat energy in bicycle pumps, like the ones we use every day. The pump is then getting hot. We are aware that molecules have less room to move when gas is compressed, and the mechanical work done gets converted into heat energy. On the other hand, if a gas is allowed to expand because there is more room in the vessel, it works, and the temperature of its molecules goes down as its energy is used for different things. It should be noted that heat is also produced by friction and attraction whenever we rub our hands together. Mechanical energy is converted from electrical energy in an electric motor. We can observe the conversion of mechanical energy into electrical energy in a generator. Alternator efficiency is limited by fan cooling loss, bearing loss, iron loss, coper loss, and voltage drop in diode bridges in automobile alternators.

There are some places where there is a strong wind running the whole day, then with the help of high winds the blades of a windmill run the turns, then the shaft of which turns a coil in a magnetic field, electric current is generating in the system. Thus the motion energy of the wind is changed into the mechanical energy of the windmill, then this mechanical energy is converted into electrical with the help of a generator. It should be noted that "the principle of energy conversion that mass can be converted into energy which is given by the great scientist Einstein is known by Einstein's mass-energy relation".

$$E = mc^2$$

Here, E = energy produced

m = mass converted to energy called mass defect

c = Velocity of light.

Thus it will be more useful to have a mass-energy principle which states about mass-energy is always converted in the universe.

Energy: Energy is defined as the capability of doing work.The SI unit of energy used to measure energy is the joule(J). 1 joule is defined as the energy transferred when a force of 1 Newton is taken as it through a distance of 1 meter.

Even though we frequently hear people talk about how they use energy, energy never really gets used up. It simply changes from one form to another and is used for a variety of purposes. Different forms of energy have different uses. For instance, energy from low-level heat. It's better to talk about how energy resources are used or unsheathed. For instance, coal, oil, wind, and so on, are all highly utilized in comparison to other forms of energy. Kinetic energy refers to the amount of energy that is moving as a result of a bullet traveling at a predetermined speed. The charge that was applied to the bullet by gunpowder, which loses some chemical potential energy in the process, gave the bullet the energy.

Mechanical Energy: Mechanical energy is simply defined as the summation of the potential energy and kinetic energy in a system.

$$E\text{M} = E\text{P}+E\text{K}$$

Here, EM = mechanical energy

EP = potential energy

EK = kinetic energy

Energy conservation law:

The law of conservation of energy is based on "the principle that energy can neither be created nor destroyed, it can only be transferred from one form to another form and change from place to another place". If we considered all kinds of energy, the total energy of an isolated system is always same.

The law of conservation of energy is applicable for all types of energy. In a nutshell, the law of energy conservation asserts that-: The total energy of a closed system, that is, one that is separated from its surroundings, is preserved as shown in Figure 2.1.

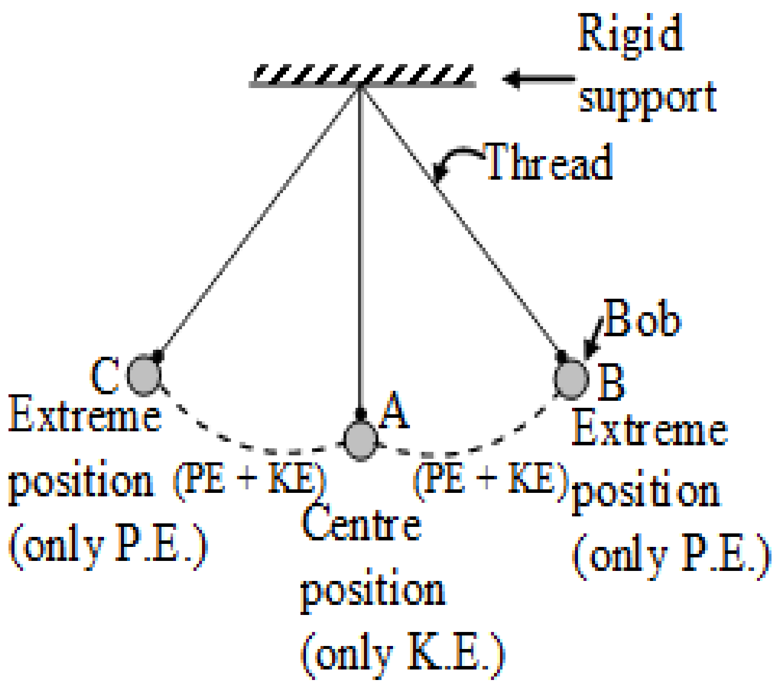

Figure 2.1: Energy conservation law in pendulum

A swing pendulum is an illustration of the law of energy conservation because it consists of a body whose energy can be either kinetic energy or potential energy and whose total energy never changes. Let's us understand the law with the help of the following expression:

UT = U + W + Q

UT **=** It is the total energy of a system

U = It is the initial energy of a system

Q = It is the generated heat from the system is denoted by Q

W = the total amount of work done is denoted by W.

The equation is used to determine the change in the internal energy in the system.

$\Delta U = W + Q$

Conservation of Energy:

Energy conservation is not the same as conservation because there are so many restrictions on how to use limited resources that will eventually run out. The moderate way to save would be to reduce demand on a limited supply, allowing the supply to begin self-repair. Similar to how a microphone, which we use to listen to songs on a daily basis, converts sound energy into electrical energy, a loudspeaker is a device that converts electrical energy into sound energy. We can observe that water falls from a height onto a turbine in a hydroelectric power plant, causing it to turn. These turns then run at high speed and generate electricity. An electric current is produced when a coil in a magnetic field is turned by the turbine. As a result, the turbine's kinetic energy transforms the water's potential energy into electrical energy. The molecules' kinetic energy is transformed into heat when any substance is heated. During expansion, some of the energy is used for the work. Heat energy is produced when a device is subjected to current. As a result, appliances like toasters, home irons, and geysers use electrical energy to generate heat. Mechanical energy is converted into heat energy in bicycle pumps, like the ones we use every day as shown given below Figure 2.2.

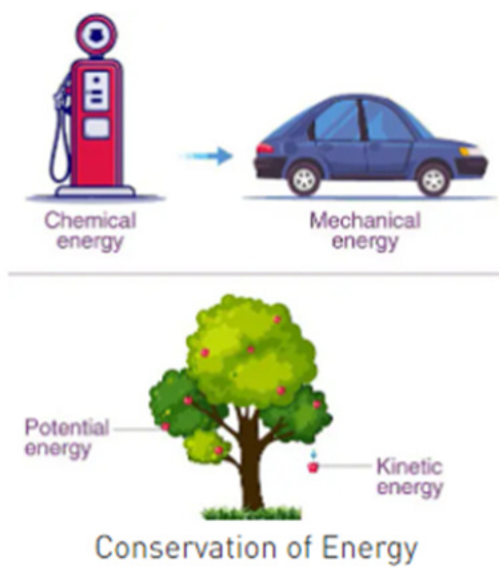

Figure 2.2: showing the conservation of energy

On the other hand, if a gas is allowed to expand because there is more room in the vessel, it works, and the temperature of its molecules goes down as its energy is used for different things. It should be noted that heat is also produced by friction and attraction whenever we rub our hands together. Mechanical energy is converted from electrical energy in an electric motor. We can observe the conversion of mechanical energy into electrical energy in a generator. Alternator efficiency is limited by fan cooling loss, bearing loss, iron loss, copper loss, and voltage drop in diode bridges in automobile alternators[4]–[6].

Types of power plants for energy conversion:

There are different types of the power plant as mentioned below:

i. hydro-electric power plant
ii. steam power plant
iii. nuclear power plant
iv. geo-thermal power plant
v. solar power plant
vi. wind power plant
vii. tidal power plant

Hydroelectric power plant:

The plants that use water to generate electricity are known as hydro-power plants. The turbine converts the kinetic energy of the water into mechanical power and is attached to the alternator, which rotates the turbine and the alternator rotates the produced electricity when the water flows through the smallest area at a faster speed. For many years, this plant has been recognized and utilized. Hydropower plants can immediately supply power to the grid, making them flexible and dependable backup power sources in the event of major power outages or disruptions. In addition, hydropower plants are a form of energy that is both environmentally friendly and cost-effective. In addition to producing electricity, hydropower provides flood control, irrigation support, and water supply. The initial costs of a large hydropower plant's installation primarily consisted of civil construction works and electrical equipment costs. Due to the fact that hydropower is a site-specific technology, these costs can be reduced during the planning stage by selecting the right location and design.

Let's talk about some of the advantages of hydroelectricity energy, like the fact that it is renewable and can be used again and again, that it does not produce any harmful gases, that it does not use fossil fuels, that it reduces CO_2 emissions, that it prevents climate change, and that it protects the environment from both pollution and the greenhouse effect.

However, even if something has advantages, it also has disadvantages, such as the need for a large quantity of water in a hydroelectric plant. As can be seen in the figure below, hydroelectric power is something that is harmful to the environment, as shown in the given Figure 2.3.

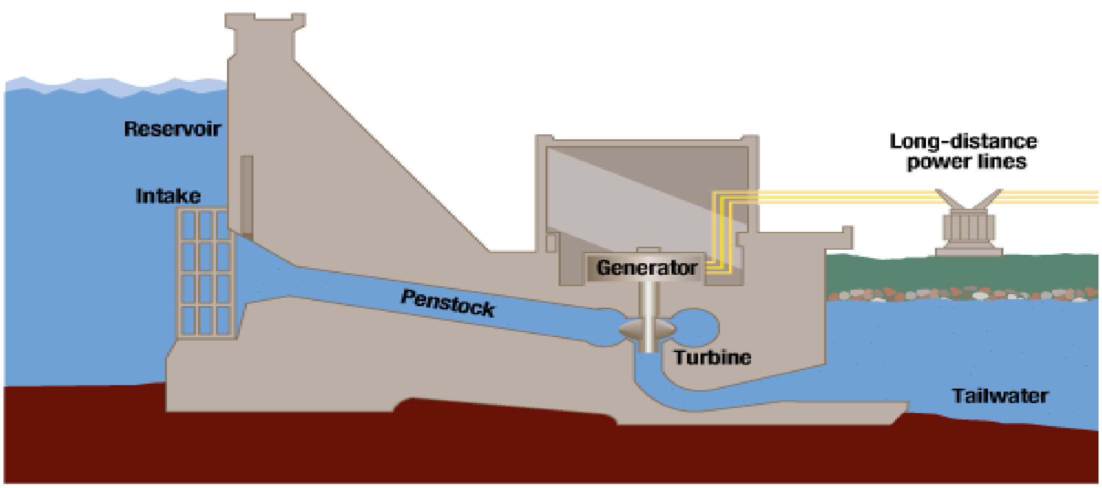

Figure 2.3: Hydro-electric power plant

Nuclear power plant:

The term "nuclear power plant" refers to a facility in which heavy materials like uranium, thorium, and other elements are used to convert nuclear energy into electricity. Through a chain reaction, the nuclear reaction can go through either nuclear fission or nuclear fusion. Nuclear fission occurs when a heavy atom is split into two smaller atoms. Nuclear fusion is the process by which two small atoms fuse to form a large atom. The power produced by nuclear power plants appears to be more reliable than that produced by other renewable energy sources like solar and wind. Additionally, nuclear energy sources generate a lot of energy and have a higher density than fossil fuels. Because of this, nuclear power plants use less fuel but produce a lot of power, making them more efficient once they are operational. However, nuclear power is expensive due to the high costs of the materials required. Nuclear power plant as depicted in the following Figure 2.4.

Figure 2.4: Nuclear power plant

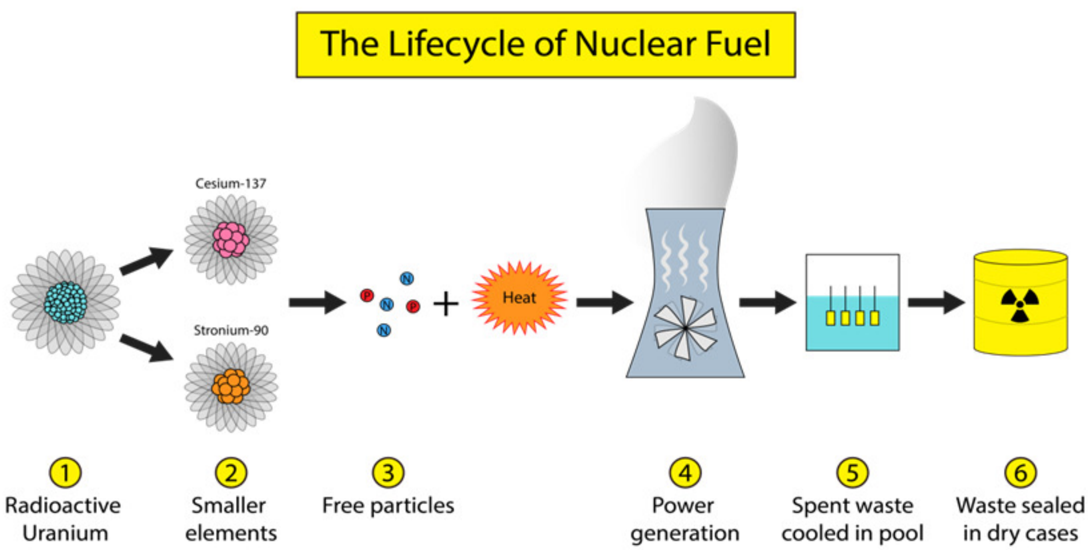

Figure 2.5: Shows the lifecycle of nuclear fuel

The lifecycle of nuclear fuel as discussed above and when a bigger atom is split into two smaller atoms, this process is known as nuclear fission and then those free particles are heated and that how power is generated, as shown in the above Figure 2.5.

Steam power plant:

The steam power plant is a type of power plant that generates electricity by spinning an alternator attached to a turbine, rotating the turbine, and burning waste materials and coal to produce heat and heat billing the fluid. Once the fluid is heated, steam will be produced, and the stem fire will be ignited. Electricity will be generated in the steam power plant as a result of the spinning of the alternator attached to the turbine. A large amount of fuel is required annually by a steam power plant that uses oil or coal as its fuel. To ensure that fuel costs are kept to a minimum across the board, the steam power plant should be located adjacent to coal mines. Because this kind of plant is going to be built in a place where coal isn't available, you need to make sure that a fuel station is close by. The water is available in this area; they were located there and away from the population, which caused a lot of pollution and a lot of gas that will be produced by the stem power plant. All of these facilities are available in the power system, and maintenance can be easily provided through the transport facility. The area can be easily transported, and the equipment can be easily transferred to the station. The location of the power plant should be near the center of the load to cut down on transmission costs. The land must be able to support a lot of heavy machinery and be affordable enough to buy. The steam power plant ought to be situated in an area where the land is inexpensive and further expansion, if necessary, is feasible. Additionally, the area's carriage capacity ought to be sufficient for the installation of heavy machinery. The steam power plant's block diagram is depicted in the Figure 2.6.

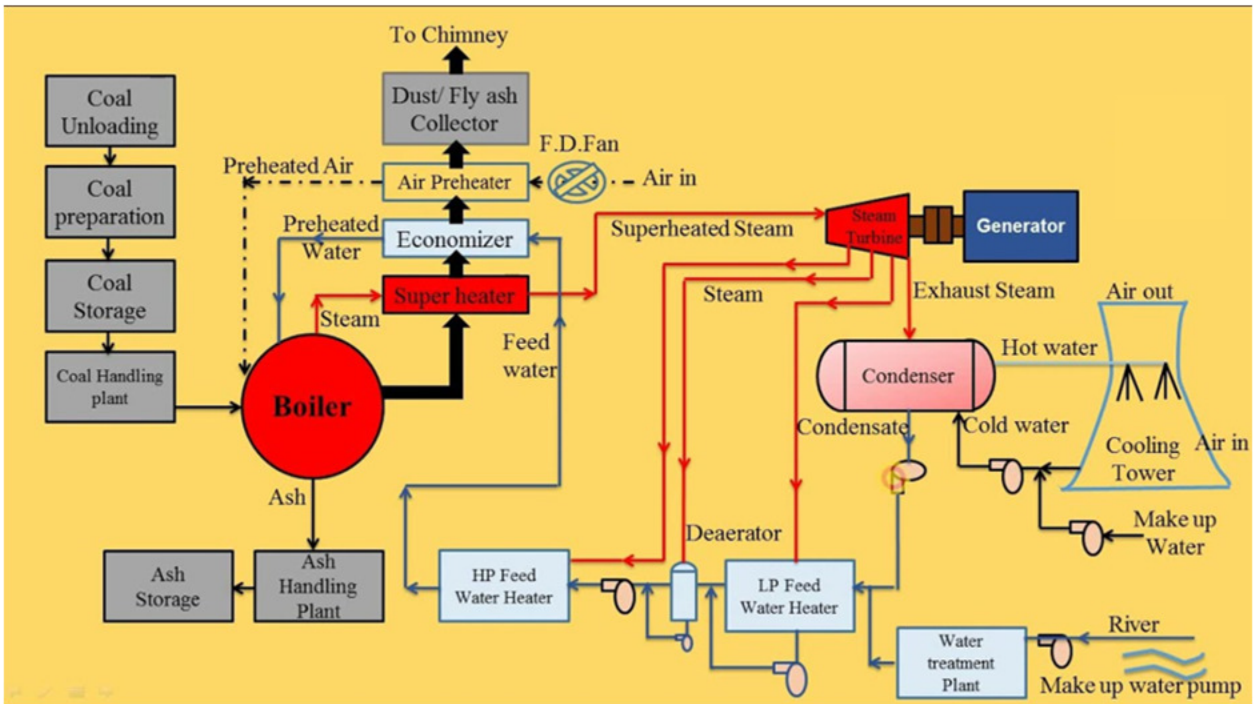

Figure 2.6: Block diagram of steam power plant

Solar power plant:

Solar energy is the energy that comes from the sun. Utilizing photovoltaic cells, solar energy is converted into electrical energy. In most places, solar panels can be found on the roof of any building because they are responsible for producing electricity. As a result, the real story begins when solar energy is converted into electricity through these solar panels. Additionally, these solar panels are recognized by the modules, which are typically southern-faced to maximize power and potential. Each of these solar panels consists of a metal frame, a glass casing, and a silicon cell layer that is further protected by a special film and wiping. The solar panels are arranged into "arrays" to maximize electricity production. This is accomplished by these solar cells, which are also known as photovoltaic cells because they absorb sunlight during daylight hours. Direct current (DC) electricity is the term used to describe the electrical energy produced by photovoltaic cells in response to solar energy. However, since direct current electricity cannot be used to power buildings and machinery, it must be converted into alternating current (AC) electricity in order to be utilized. Special solar inverters must be installed in order to confirm the conversion of direct current to alternating current. These inverters can be set up as one of the inverters for the entire system in contemporary solar systems, or micromini inverters must be attached to the panels. The participant converts DC electricity to 120 volts AC, which can then be immediately utilized for home appliances. The power generated by solar panels first travels through your home's electrical panel and then the electric grid. Your utility meter will go backward if your solar plant is producing more electricity than you use right now[7]–[10].

Solar energy is one of the cleanest and most abundant renewable energy sources, and it meets all of the needs of users without causing harm to the environment or causing pollution. It is also very effective and good for high energy use. They produce electricity that typically doesn't require a lot of upkeep and lasts about 20 to 25years, as shown in the given Figure 2.7.

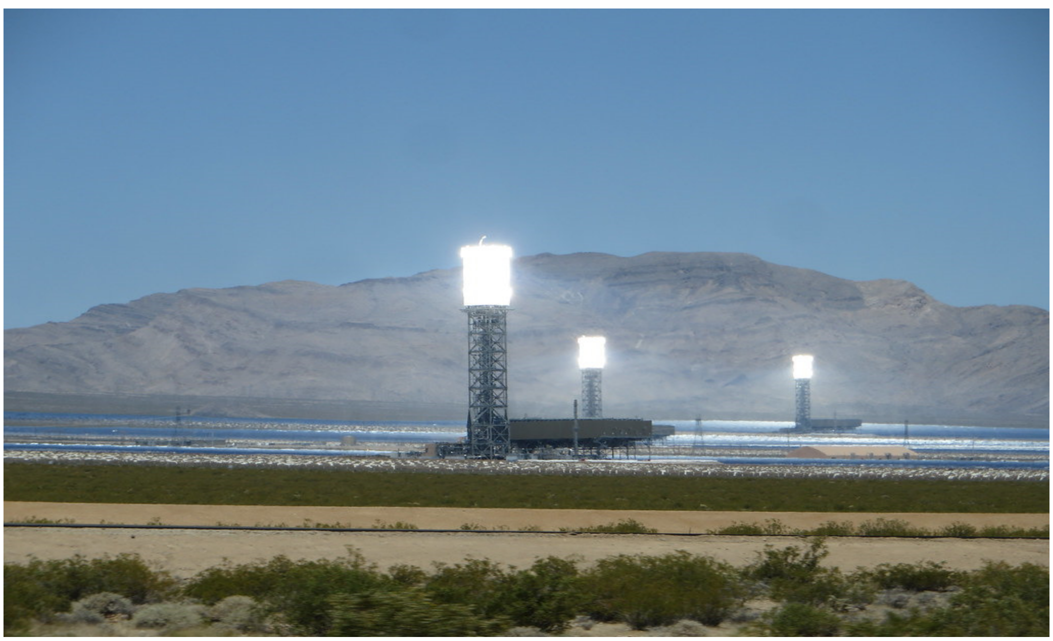

Figure 2.7: Solar power plant

Geothermal power plant:

Through a series of wells, hot water or steam is extracted from the Earth and fed into the power plant. The majority of geothermal plants return the water that was pumped up from the ground to the surface. As a result of the fact that the rate of water used is frequently higher than the rate at which it is returned, it is necessary to build up water supplies. Dry steam power stations, flash steam power stations, and binary cycle power stations are the three main geothermal plant types that use steam turbines to generate electricity. Geothermal power plants are thought to be better for the environment because they don't produce harmful gases and are less harmful than coal-fired power plants, as we can see in the Figure 2.8.

The three main technologies utilized in geothermal energy production plants are: flash, dry steam, and a binary cycle.

i. **Dry vapor**: This is the most common technology, and it involves moving a turbine and an electrical energy generator using steam at high temperatures (over 235°C) and pressure.
ii. **Flash:** Systems are powered by dominant-water tanks at temperatures between 150 and 170 °C in single or double flash. Because of the rapid change in pressure between the tank and the atmosphere, the water that comes to the surface through wells is separated into steam that is sent to the plant and liquid that is injected into the tank. The geothermal fluid can undergo the process twice if it reaches the surface at extremely high temperatures.
iii. **Cycle of binary:** The geothermal fluid is used to vaporize a second liquid with a lower boiling point than water through a heat exchanger in tanks that produce water at moderate temperatures (between 120 and 180 °C). The secondary fluid expands inside the turbine, condenses, and is then returned to the exchanger in a closed circuit without interacting with the outside world.

Figure 2.8: Geothermal power plant

Wind power plant:

The power plants that use a turbine to convert wind energy into electrical energy are known as wind power plants.

Getting electricity from wind power involves converting wind energy into blade rotational energy and then converting that rotational energy into electrical energy by the generator. Since wind energy rises proportionally to wind speed, technologies derived from hydroelectric and thermal power plant design and manufacturing should be implemented in the higher wind seed area, even though we operate our own wind energy business. As depicted in the figure below, we offer solutions to meet the requirements of customers in a variety of contexts thanks to our strength of standing on both the manufacturer and the customer as shown in the below Figure 2.9.

Figure 2.9: Wind power plant

Tidal power plant:

The surge of ocean waters during the ebb and flow of the tides results in the production of ideal energy. A renewable energy source is tidal energy. In areas with a significant tidal range—the difference in area between high tide and low tide in the 20th century, engineers developed methods for utilizing tidal movement to generate electricity. A plant that converts tide energy into electricity is known as a tide energy power plant, and its output is considered to be more predictable than that of wind and solar power. Despite the fact that the world's first large-scale plant of its kind became operational in 1966, tidal power is still not widely used. We can use the potential energy of water contained in the daily movement of the rising and falling sea levels to generate electricity because the position of the earth and the moon in relation to the sun changes throughout the year. In many ways, the hydroelectric generation that we examined in the hydro energy tutorials is comparable to the generation of electricity by tides. This time, the water flows in and out of the turbines in both directions as opposed to just one forward direction, which is the difference.

Energy from the Ocean, Tidal, and Waves: Tidal energy, like hydro energy, converts moving water into clean energy. Power from the Sea $30.60$8.02 Shop at Amazon Strong tidal currents known as tidal streams contain a significant amount of kinetic energy in the motion of the tidal water, which is driven by the pull of gravity. Similar to how water flows down a river or stream, the daily ebb and flow of the ocean's tides along a coastline and into and out of small inlets, bays, or coastal basins is similar. Similar to how waterwheels and turbines are utilized to generate hydroelectricity, seawater movement is harnessed.

However, in a tidal energy system, the sea water can generate power both when it enters the system and when it leaves, as it can flow in either direction. As a result, the rotor blades of tidal generators are designed to generate power in either direction. Reversible electrical generators, on the other hand, are more expensive than single-direction generators. The Figure shows a tide power plant as follows given below Figure 2.10.

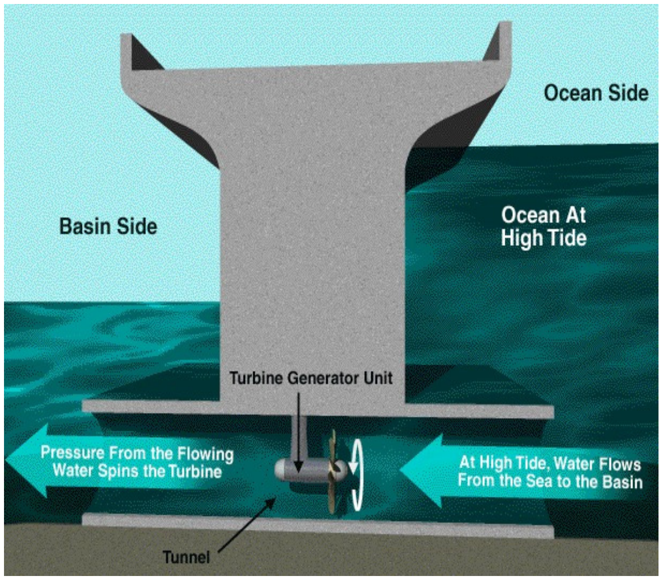

Figure 2.10: Tidal power plant

Oceanographers and meteorologists are able to accurately predict the ebb and flow of the tides around the oceans many years in advance due to the fact that a tidal cycle, also known as the "diurnal cycle," takes approximately 12 hours and 24 minutes between two high tides that are in close proximity to one another. We now know that when the tides come in and out, a lot of water moves around the earth because of the constant rotation of the earth and the moon in relation to each other. The ocean level constantly fluctuates between a high tide and a low tide before returning to a high tide due to these predictable and regular tides, which result in two high tides and two low tides per day.

Millions of gallons of water flow around the Earth's oceans as the Earth, Moon, and Sun rotate around each other in space. This causes periodic shifts in these moving bodies of water due to the gravitational pull of the moon and sun on the earth. We refer to these water shifts in the vertical direction as "tides." Alignment of the Sun and Moon on Tidal Energy Tidal effects are caused by the sun and moon aligning their gravitational pulls, which causes millions of gallons of water to move or flow toward the shore, resulting in a "high tide" condition, as shown in the below Figure 2.11.

The water flows away from the shore as the mass of water moves to another location on the earth, resulting in a "low tide" condition when the earth's gravity and the moon's gravity are at 90 degrees to one another. During each phase of the earth's rotation, the ebb and flow of the tides occur twice, with stronger weekly and annual lunar cycles overlaying these tides. The gravitational pull of the moon and sun together becomes much stronger than usual when the moon is in perfect alignment with the earth and the sun. This causes the high tides to be very high and the low tides to be very low during each tidal cycle. Spring tides are the name given to such tides. These spring tides occur when the moon is full or new. The other tidal situation occurs during minimum neap tides, when the moon's and sun's gravitational pulls are in opposition to one another, canceling each other out. The end result is much weaker tides as a result of a smaller pulling action on the sea water, which results in much smaller differences between high tide and low tide. During the quarter moon phase, there are nap tides. Then, because their effects differ from the usual high and low sea levels, spring tides and neap tides produce different amounts of potential energy in the movement of the sea water. We can use these tidal changes to produce renewable energy. Therefore, we can assert that alternative energy is gaining momentum.

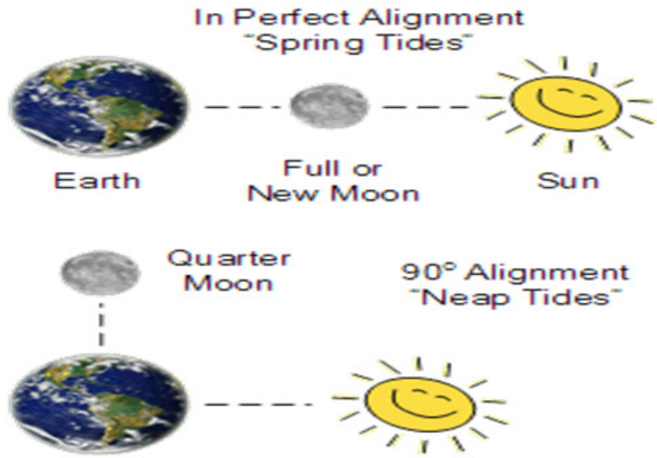

Figure 2.11: Alignment of the moon and sun on tidal energy

The most significant advantage of this is that, in contrast to solar or wind energy, the tides are perfectly predictable and consistent. This makes it possible to exploit miles of coastline for tidal energy, and the greater the tidal influence, the greater the movement of the tidal water and, consequently, the greater the potential energy that can be harvested for power generation. Because the ocean's energy is replenished by the sun as well as by the tidal effects of the moon and the sun's gravitational forces, tide energy can be considered a renewable energy source.

In this chapter, we learn about the basic principles of the law of conservation of energy and how energy is converted from one form to another form. Talk about the basic introduction of conservation of energy and simplified definitions of energy and mechanical energy and how energy can be converted and how we utilized the energy and types of power plants that are used for converting the energy from one form to another form and can be used for many purposes as for home appliances as well as for industrial purposes.

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CHAPTER 3

POLYPHASE TRANSFORMER

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An electrical device known as a transformer is used to move energy from one circuit to another. The voltage is transported upward or downward using transformers. The mutual induction between two circuits connected by a shared magnetic flux or inductively attached coils, however, governs the transformer concept. Electricity is generated and distributed over great distances for use by businesses and industry using a three-phase electrical system. Through the use of 3-phase transformers, three-phase voltages can be raised or lowered since the 3-phase transformer's windings can be connected in a variety of ways. So far, we have looked at the design and functioning of a single-phase, two-winding voltage transformer that can change the secondary voltage's relationship to the primary supply voltage. But voltage transformers can also be created for a connection to not only 1 single phase, but for 2-phases, 3-phases, 6-phases, and even explain combinations of up to 24-phases for some DC rectification transformers.In 1884, three physicists from Austria-Hungary - Otto Blathy, Miksa Deri, Karol Zipernowski, founded the transformer designs that are still using for all electrical purposes. In 1885 Karol Zipernowsky and Miksa Deri constructed the first ring-shaped transformer.

We can employ 3-phase transformers on a 3-phase supply by securing their main windings to one another and their secondary windings to one another in an immovable arrangement. Faraday received the first invention for generating electricity from magnets on August 29, 1831. He had demonstrated several experiments to illustrate electromagnetic induction. For the production, transmission, and distribution of electrical power as well as for all industrial applications, three-phase, also known as three-phase and three-phase provide, is employed. We must deal with three alternating voltages and currents that differ in phase-time by 120 degrees while thinking about three-phase transformers, as shown below. Three-phase supplies have various electrical advantages over single-phase power. One of the most significant discoveries of the industrial era, which also gave rise to the harnessing of electricity, steam power, running water, and gas illumination, is the electrical transformer. In actuality, the transformer is necessary for the latter to happen. The law of electromagnetic induction, which Michael Faraday, an English scientist, and inventor, discovered, is the ancestor of electrical transformers. The idea, also referred to as Faraday's Law, explains the phenomenon of electrical voltage produced when a coil of wire was wound around an iron core. A wire with more or fewer turns might be used to produce current with a varied voltage since the current would travel through the iron to the other side[1]–[3].

In the latter half of the 19th century, transformers were 100 percent efficient roughly 97.5 percent for a 10 KW transformer. Lightning is another application of transformers. When the secondary circuit length was long about 100-104V, the preferred voltage for the lighting system was 50-52V, and a transformer was used to step down the voltage for economic reasons. There are various types of transformer that is we using nowadays and numerous ways of using electrical device for many purpose and for distinct uses. Basically transformer is used for high range transfer of power and as well as in industrial purposes.

Polyphase transformer:

The primary and secondary of the transformer can be connected in a variety of ways, such as having the primary connected in a delta pattern and the secondary in a star-delta, delta, or star-star pattern. The transformer use determines the type of connection employed. Transformers are referred to as polyphase transformers when they are utilized to supply three or more than three phases. Power is typically generated in three phases between 11 and 33 kV. Higher voltages between 132kV and 400kV are used to transmit generated power to the load centers (or 700kV). A step-up 3-phase transformer is necessary for transferring the generated 3-phase electricity at such higher voltages. The construction is becoming more and more widespread, which is see in the Figure.

Classification of polyphase transformer in accordance to construction of core and shows construction of transformers how primary and secondary are placed around it.

1) Core type transformer
2) Shell type transformer

Core Type Transformer:

The Construction of transformers both the primary and secondary windings of a transformer are arranged around each limb in its construction. Two windings will be tightly coupled as a result of this. As a result, leakage flux is significantly reduced. There is insulation between windings and between the core and inner windings. Typically, low voltage windings are positioned closer to the core to reduce insulation. The LV winding is positioned over the core limb, and the HV winding is positioned on the LV winding, respectively, for each phase's primary and secondary on each limb. The fact that the amount of insulation required to isolate the LV winding from the core is minimal is the primary reason for positioning the LV winding next to or near the core, as you can see the diagram of transformer given below Figure 3.2.

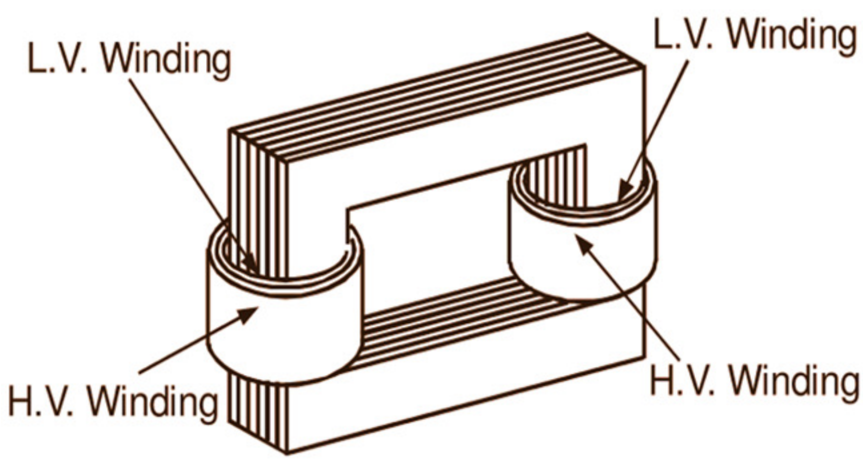

Figure 3.2: Diagram of Core Type Transformer

Laminations are changed is in the form of L shaped strips. Distinct layers are arranged differently and continuous joints are excluded to minimize reluctance of magnetic path as shown in below Figure 3.3.

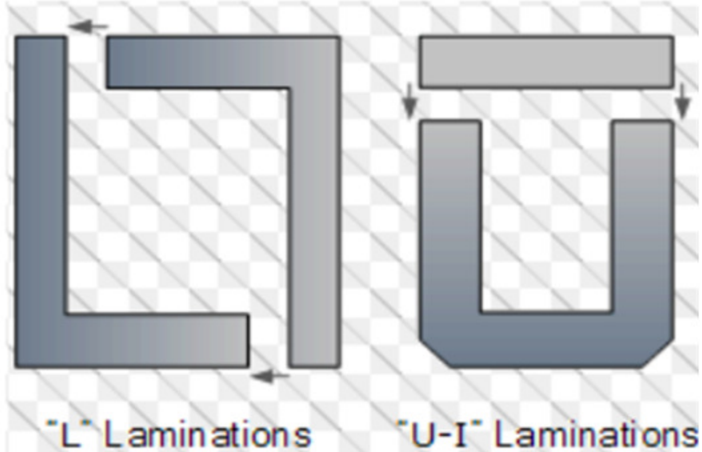

Figure 3.3: Core type L laminations and U-I laminations

Shell Type Transformer:

Around the central limb are the constructions of the primary and secondary windings. The entire flux is carried by the central limb, while half of it is carried by the side limbs. As a result, the central limb is twice as big as the other limbs. When three single-phase transformers are placed side by side, the entire structure is the same. As a result, shell-type construction gives three phases more independence. This type of transformer as shown below in the given Figure 3.4.

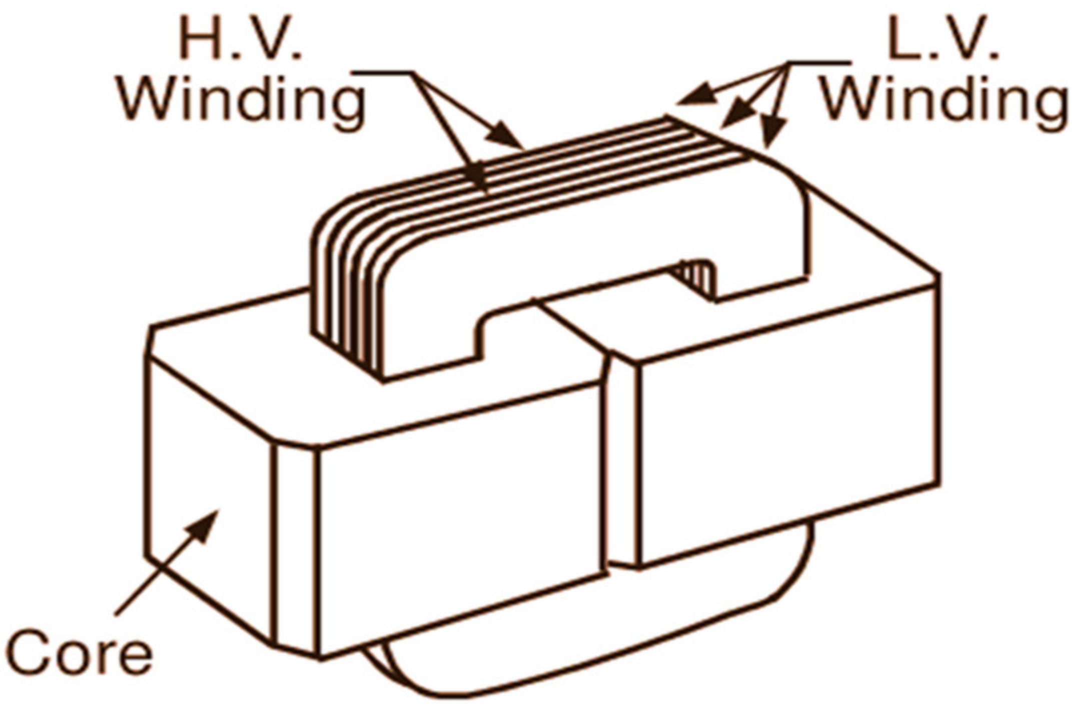

Figure 3.4: Diagram of shell Type Transformer

Laminations are cut in the form of E and I shaped strips. Alternate layers are stacked differently and continuous joints are eliminated to minimize reluctance of magnetic path as shown in below Figure 3.5.

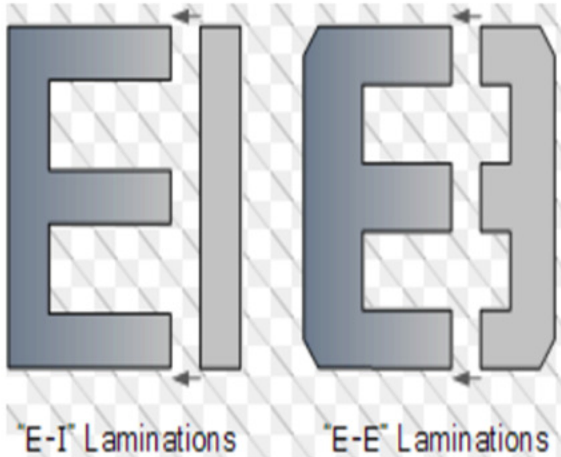

Figure 3.5: Shell type E-I laminations and E-E laminations

The generation of Heat in the transformer is produce in two ways and they are as follows:

i. Iron losses produce in core
ii. Copper losses produce in windings

To protect the electrical equipment from the losses or temperature rise due to these losses, heat is removed by only cooling which is explained in the given below Table 3.1.

Table 3.1: Illustrates the type of cooling on the basis of size of transformer

Transformer Size	**Type of Cooling**	**Description**
Small	Natural Air Cooling	The heat generate is carried away by surrounding air
Medium	Oil Cooling	Located in tanks filled with oil Heat produced is carried away by oil to surface of the tank. Oil give better insulation to windings.
Large	Oil Cooling	Oil moving in a direction through radiators where heat is released towards surrounding air

3-Phase Transformers Generation of electric power is three phase in nature. Transmission is carried out at high voltages. Before transmission, it is required to step up voltage. At distribution substation voltage must be stepped down. Hence three phase transformers are required to step up and step down voltages in various stages of a power system.

Working Principle of Polyphase Transformer:

The mutual induction principle is the same for a three-phase transformer as it is for a single-phase transformer. The secondary winding experiences an EMF when the alternating supply is applied to the primary windings. The amount of induced EMF depends upon the number of secondary turns. Primary and secondary windings are shown in the given below Figure 3.6[4]–[6].

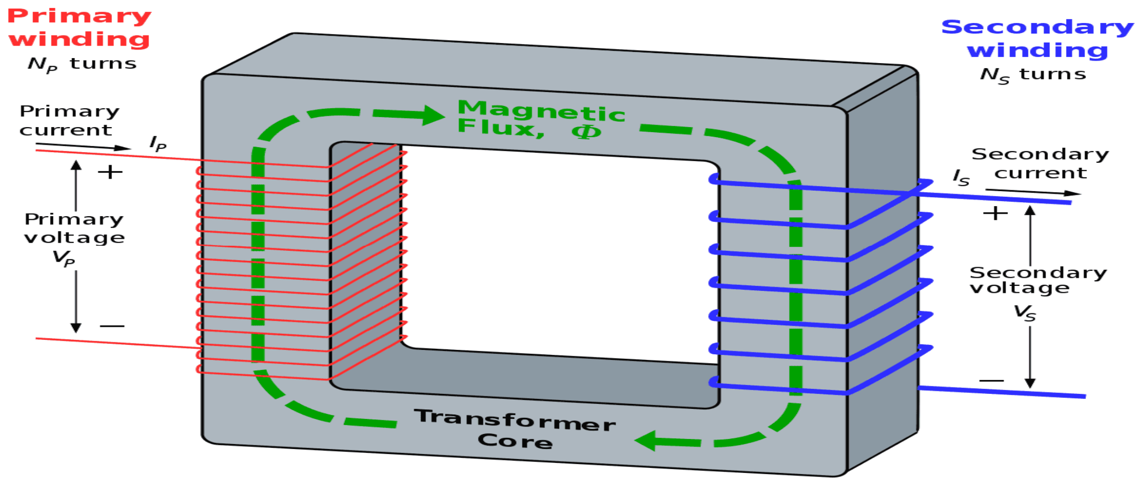

Figure 3.6: Basic diagram of transformer

Three-phase Connections

There are two methods to connect three-phase windings.

- Star connection
- Delta connection

Star Connection:

In star connection, all three windings are connected to one terminal, which results in a star point or neutral connection point.

From here, the neutral terminal is taken. All windings have their second terminal removed, and these terminals get power. This arrangement is referred to as a star connection, Y, or Wye-connection due to its shape. The figure that follows depicts the three-phase star connection in the below Figure 3.7.

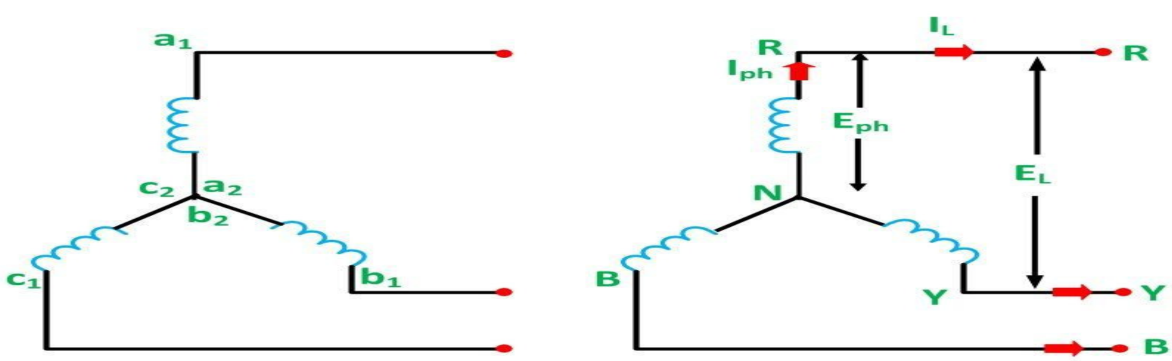

Figure 3.7: Star connection

Delta Connection:

In the three windings in a delta connection are connected in series to form a triangle. Three junction points receive the supply. This arrangement has a shape similar to Delta. Consequently, it is referred to as a delta connection or a -connection. This connection is sometimes also referred to as a mesh connection. The connection diagram of the delta connection is shown below in Figure 3.8.

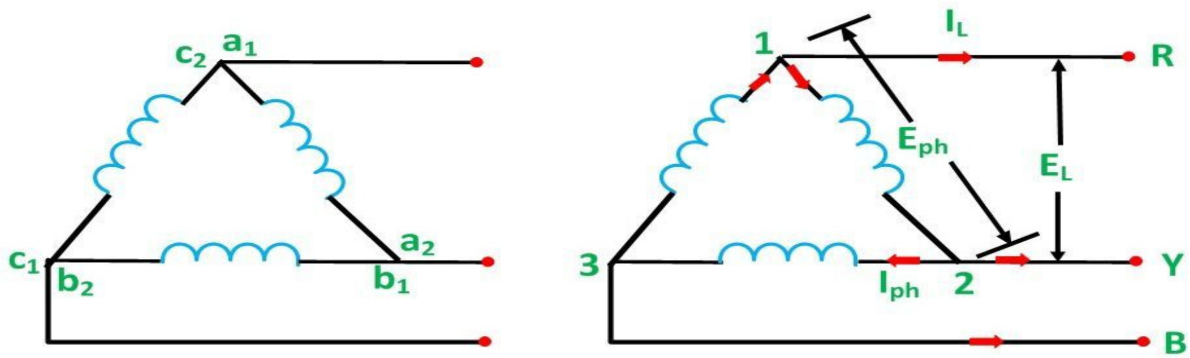

Figure 3.8: Delta connection

Three Phase Voltages and Currents in Star and Delta Connection: Line-to-neutral voltage-current and line-to-line voltage-current must be taken into account when drawing the connection diagram. Line voltage is referred to as line voltage, and phase voltage is referred to as line voltage. In star connection, a line-to-line current is the similar to line-to-neutral current.

ILL = ILN

We determine the three-phase, four-wire configuration as depicted in the above star connection diagram for the purpose of calculating the voltage in the connection. The line-to-line voltage is 3 times the line-to-neutral voltage, according to Kirchhoff's law.

VLL = √3VLN

In delta connection, line-to-line voltage is the same as line-to-neutral voltage.

VLL = VLN

Construction of polyphase Transformer:
The Connections of 3-phase transformer are described below and can be as follows. Primary and secondary of three-phase transformers can be self-sufficiently connected either in star or delta. There are four possible connections of transformer as given below as follows:

1) Delta – Delta Connection
2) Delta – Star Connection
3) Star – Star Connection
4) Star – Delta Connection

Delta-Delta (Δ-Δ) Connection

The fact that each delta-connected three-phase transformer must be wound for the full-line voltage and 57% line current is one drawback. A larger and more expensive coil is required for the winding, which has a greater number of turns and insulation between turns than the star connection. There is no "neutral" or common connection in delta-connected three-phase transformers as shown in the given below Figure.

The lagging power factor of phasor diagram is cos ϕ is shown in the below Figure 3.10.

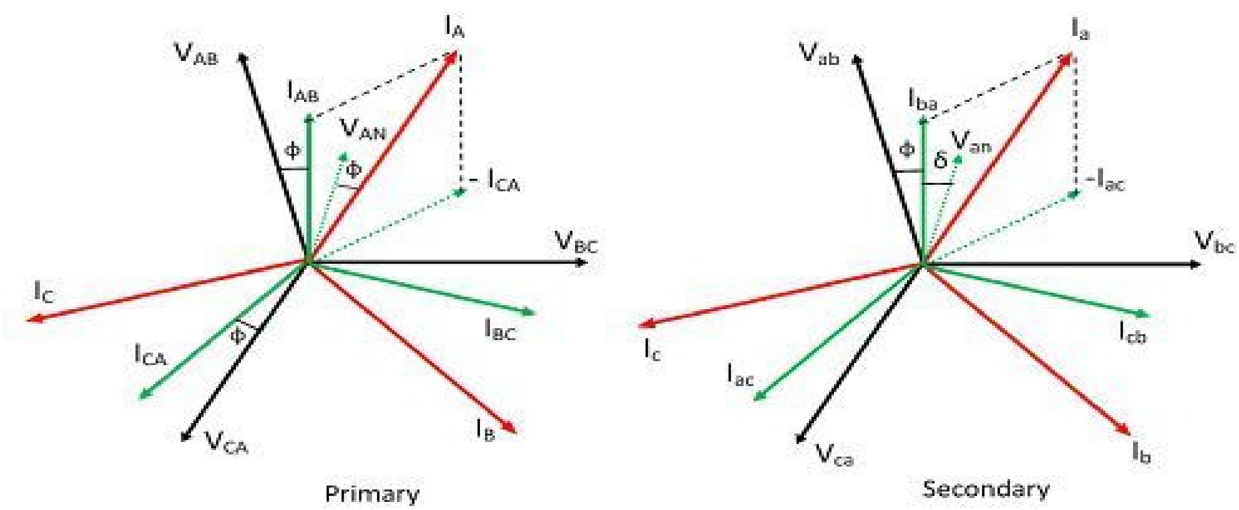

Figure 3.10: Phasor diagram of Delta-Delta (Δ-Δ) Connection of transformer

In delta-delta configuration, line voltage and phase voltage are same in magnitude on primary and secondary winding. The primary line-to-line voltage (V_{AB}, V_{BC}, V_{CA}) are in phase with the secondary voltage (Vab, Vbc, Vca) and the voltage ratio is equal to the turns ratio of transformer.

V_{AB} / Vab = V_{BC} / Vbc = V_{CA} / Vca = N

The line current is √3 times phase current under balance condition. When magnetizing current is neglected, the current ratios is given below

$$\frac{I_{AB}}{I_{ab}} = \frac{I_{BC}}{I_{bc}} = \frac{I_{CA}}{I_{ca}} = \frac{I_A}{I_a} = \frac{I_B}{I_b} = \frac{I_C}{I_c} = N$$

In this type of connection, the primary and secondary winding voltage is in phase. Therefore, this connection is also known known as 0° connection.

Star-Star (Y-Y) Connection

The voltage that exists between any lines in a three-phase transformer is referred to as the "line voltage," or VL, whereas the voltage that exists between any lines in a star-connected transformer and the neutral point is referred to as the "phase voltage," or VP. The phase voltage that exists between the neutral point and any line connection is 1/3 VL of the line voltage. Y-Y connection diagram show below in the given Figure.

The phase current is equal to the line current in the star-star connection, and both currents are in phase. The line voltage is √3 times phase voltage. The phasor diagram of this connection is similar to the delta-delta connection.

For ideal transformer, the voltage ratio is given below:

$$\frac{V_{AN}}{V_{an}} = \frac{V_{BN}}{V_{bn}} = \frac{V_{CN}}{V_{cn}} = N$$

The current ratio of transformer in case of Star-Star (Y-Y) Connection:

$$\frac{I_A}{I_a} = \frac{I_B}{I_b} = \frac{I_C}{I_c} = N$$

Phase voltage becomes severely unbalanced when the load is unbalanced. Since the star-to-star connection lacks a neutral, this system is useless with unbalanced loads. The magnetizing current has a significant impact on the star-to-star connection, which is its primary drawback. However, in the case of a connection between stars, the magnetizing current of three-phase windings is identical in magnitude and phase. As a result, it will add up, and the sum at the star point will not be zero. This voltage will add to the waveform of the fundamental voltage and generate twice as much peak voltage as the normal value. The following techniques are used to solve the star-to-star connection unbalanced and third harmonics problem.

Delta-Star (Δ-Y) Connection

The primary winding of a three-phase transformer is connected using a Delta connection, while the secondary winding is connected using a star connection in a Delta-star connection. A Delta connection connects the primary winding. As a result, the phase voltage and the line voltage are the same in the primary winding. Star connection is used to connect the secondary winding. As a result, the secondary winding's line voltage is √3 times the phase voltage. The connection diagram of a Delta-star configuration is as shown in below Figure 3.12.

Therefore, the voltage ratio of this configuration is;

$$\frac{V_{LP}}{V_{LS}} = \frac{V_{PP}}{\sqrt{3}V_{PS}}$$

$$\frac{V_{PP}}{V_{PS}} = N$$

$$\frac{V_{LP}}{V_{LS}} = \frac{a}{\sqrt{3}}$$

The figure below depicts the phasor diagram of the delta-star connection for the lagging power factor and balanced load conditions as shown below in the Figure 3.13.

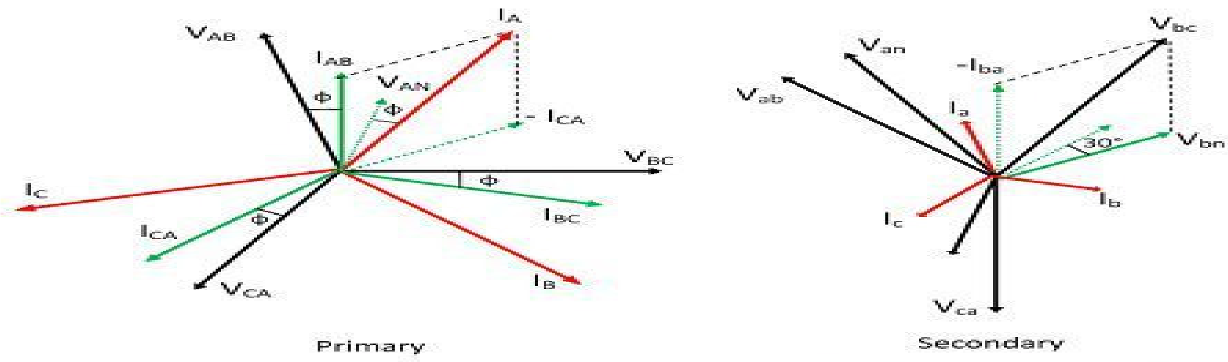

Figure 3.13: Phasor diagram of delta-star connection

Star-Delta (Y-Δ) Connection

A transformer's primary winding is connected in a star pattern, while the secondary winding is connected in a delta pattern in a star-delta connection. The primary line voltage is approximately three times the phase voltage because the primary winding is connected in a star. Additionally, the secondary winding has a delta connection. As a result, the phase voltage and the line voltage are the same in the secondary winding. The connection diagram of the star-delta configuration is shown below in the Figure.

The voltage ratio in this configuration is;

$$\frac{V_{LP}}{V_{LS}} = \frac{\sqrt{3}V_{PP}}{V_{PS}}$$

$$\frac{V_{PP}}{V_{PS}} = N$$

Open Delta (V-V) Connection:

When one of the transformers in the bank is disabled and the service must continue until the damaged transformer is fixed or replaced, an open delta connection can be used. Additionally, it can be utilized for small three-phase loads where the installation of a complete three-transformer bank is not required.

Open delta connections have a total load carrying capacity that is 57% higher than that of delta-delta connections. The open delta connection performs less effectively than the closed delta connection.

However, in the open delta or V-V connection, the transformer can be used less effectively. Let's talk about how power from three phases is delivered by the transformer in an open delta connection when one phase is missing. V-V Connection two transformers are used and primary and secondary connections are made as shown below in the Figure.

Scott (T-T) Connection

This kind of connection calls for the use of two transformers. On both the primary and secondary windings of one of the transformers, there are center taps. Teaser transformer is the name given to the other transformer. The teaser transformer operates at the p.f., while the main transformer operates at its rated voltage of 0.866, cos 30° = 0.866 which corresponds to the main transformer operating at 86.6 percent of its KVA rating. Additionally, the Scott connection can be used to convert from three phases to two phases. Although the teaser transformer may be designed to operate at a flux density that is lower than that of the main transformer, it is typically constructed in the same way as the main transformer. As a result, in the event that one of the transformers in a delta-delta bank fails, it is possible to use two identical single phase transformers in open delta (V-V) or T-T mode. The only requirement is that one of the transformers should tap at 50%. As can be seen in the image below, the connection is made. T-T connection is depicted below has been in the given Figure.

Advantages of T-T connection:

1) It is applied in the installation of an electric furnace.
2) Additionally, it is utilized to power single-phase loads like electric trains.
3) It connects a two-phase system with a three-phase system.

In this articles we learn about the basic concept of transformer and detailing about the polyphase transformer and how coneection of transformer is made and how it make distinct connections with different types of core such as core type of shell type and how the basic principles of polyphase transformner work and it divide its connections into different type. As we already known as basic utilization of transformer.

As can be seen also we find the diagram and image bywhich we can learn about the connections of winding.

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CHAPTER 4

DC CIRCUITS

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A circuit is made up of both active and passive components and can be either AC or DC. Those elements supplies power to the sources is knowns as active sources such as diode, transistors, SCR, integrated circuits and elements do not require any extra power sources are known as passive sources such as resistors, capacitors and inductors. Thus, by determining the voltages and currents in various circuit elements using a variety of methodologies, circuit theory or analysis aids in understanding the characteristics or behaviour of the circuit. So, let's go over some fundamental electrical principles before we discuss DC circuit theory in coming articles. We are aware that there are two types of electricity: direct current (DC) and alternating current (AC). A circuit that uses AC is known as an AC circuit, whereas a circuit that uses a DC source is known as a DC circuit. We are currently only talking about DC circuits and their theory. The DC source enables the flow of current or electricity with a constant polarity that doesn't alter over time. To help the reader understand DC circuit components and parameters, a straightforward DC circuit. Electron current flow is the flow of electrons from a negative terminal to a positive terminal, whereas conventional current flow is the movement of electrons from a positive terminal to a negative terminal. The terminal that is attached to the battery's negative terminal has always had a negative charge that repels electrons, while the positive charge at the positive terminal attracts them. As a result, electron current flow is the phrase used to describe the passage of electrons from negative to positive terminals. But conventional ways of assuming the flow of current is from positive to negative is called as conventional current flow. Conventional current is described and use in many circuit diagrams and the actual flow of electron current is pointing in the case of labelling the individual current flow[1]–[3].

The positive charge carriers are responsible for the typical current flow. Because electrons are negative charge carriers, conventional current is always measured in the opposite direction from the direction that electron current actually flows. Also, amps are used to measure it. It is crucial to understand that both conventions are in use and are essentially equivalent because all of the electrical effects of electron flow from negative to positive, or from a high potential to a lower potential, are the same as those that would be produced by the flow of positive charges in the opposite direction. The electron flow convention is applied throughout this guidebook.

The difference between a conventional electron flow and an actual electron flow has no bearing on computational outcomes or real-time behaviour. The majority of concepts for examining DC circuit results are not direction-dependent. The conventional current, however, is the norm and is generally followed. In addition to magnitude, all voltages and currents also have polarity. One current flow through the entirety of a series circuit with its polarity flowing from the negative battery terminal to the positive battery terminal. Polarities are also seen in voltage dips across loads. The simplest way to find this oppositeness is to use the direction of the electron current as a base also where the electron current enters the load, the voltage is negative. This holds true anyhow of the number or type of loads in the circuit. The drop across the loads is contrary to that of the source. The voltage drops oppose the source voltage and reduce it for the other loads. The energy utilized by the sources that generated is known as load and leaving and the lower energy for other loads. Polarity of voltage is shown in the given below Figure 4.1.

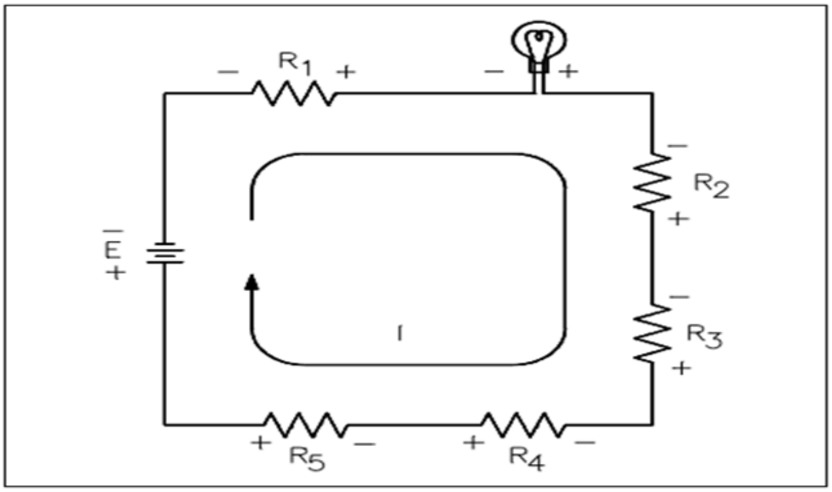


Figure 4.1: Diagram of voltage polarities

Those elements supplies power to the sources is known as active sources such as diode, transistors, SCR, integrated circuits and elements do not require any extra power sources are known as passive sources such as resistors, capacitors and inductors. Comparison between active and passive elements as shown below in the given Table 4.1.

Table 4.1: Comparison between active and passive elements

Active components	Passive components
Active elements supply power or energy to the circuit.	Passive elements consume power or energy from the circuit.
Examples of active are Diodes, Transistors, SCR, Integrated circuits etc.	Examples of passive are Resistors, Capacitors, Inductors etc.
These types of devices produce energy in the form of voltage or current.	These types of elements stores energy in the form of voltage or current.
They are able of providing power gain.	They are unable of providing power gain.
The flow of current can be controlled by active components.	The flow of current cannot be controlled by passive components.
They need an external source for the operations.	They do not need any external source for the operations.
They are known as energy donor.	They are known as energy acceptors.

Electric voltage: The voltage in a system of an electrical circuit is defined as the amount of energy needed for moving a unit charge between two points. The measurement unit is Volts and it represents by V. Most common examples of DC voltage are batteries and generators that produce the DC voltage from 1V to 24V DC for working for electrical systems, as shown in the given Figure 4.2.

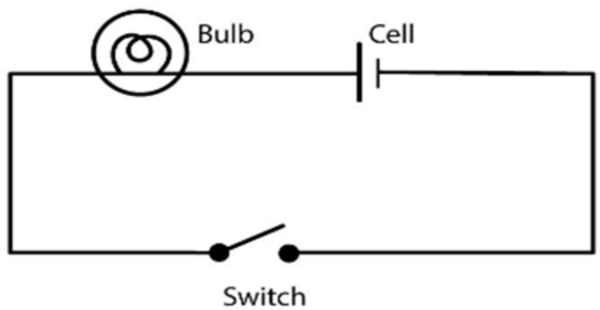


Figure 4.2: Diagram of electric voltage

Electric current: It is defined as the rate of change of electric charge with respect to the time. The measurement unit is Amperes or Amps, and also represents by 'I' or with small i. The electric current can be AC or DC. The flow of DC is only in one direction and it is generated by batteries, solar cells, thermocouples, etc. as shown in the below Figure 4.3.

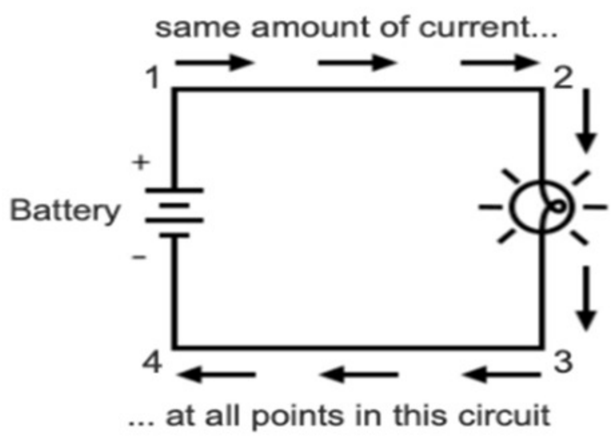


Figure 4.3: Diagram of electric current

Kirchhoff's laws

In every circuit I've looked at so far, Ohm's Law described the relationship between current, voltage, and resistance. These circuits were relatively simple in nature. Many circuits are too complex to be solved with the help of Ohm's law. These circuits have many current sources and branches that make the use of Ohm's Law impractical or impossible. In 1857, German physicist Gustav Kirchhoff through his experiments imported a method for solving complex circuits. Kirchhoff drew two conclusions that are now known as Kirchhoff's laws as explain below[4]–[6].

Law 1: The algebraic sum of the voltage drops around a closed loop is equal to the sum of the voltage sources of that loop (Kirchhoff's Voltage Law).

Law 2: The current coming at any junction point in a circuit is equal to the current leaving that junction (Kirchhoff's Current Law).

If we take a look at a circuit with only one load and source, we can see how Kirchhoff's laws is applicable for charge and energy conservation. Energy and charge are conserved because the load uses all of the power from the source. Kirchhoff's laws only restate the laws governing energy and charge conservation because voltage and current can be related to energy and charge.

Kirchhoff's voltage law (KVL)

Kirchhoff's first law is also called as "voltage law". The voltage law of Kirchhoff states that "the voltage drop around any closed loop in a circuit, and the voltage sources in that loop, the total of these two quantities is always equal". It can be explained in equation form as follows:

E source = E1 + E2 + E3 + etc. = I1R1 + I2R2 + I3R3 + etc.

KVL is only applicable for closed loops as shown in figure below but a closed loop should have two conditions and they must be followed as follows:

1. It should have been at least one or more voltage sources.

2. It should have been a whole path for current flow from any point which surrounds the loop, and back to that point.

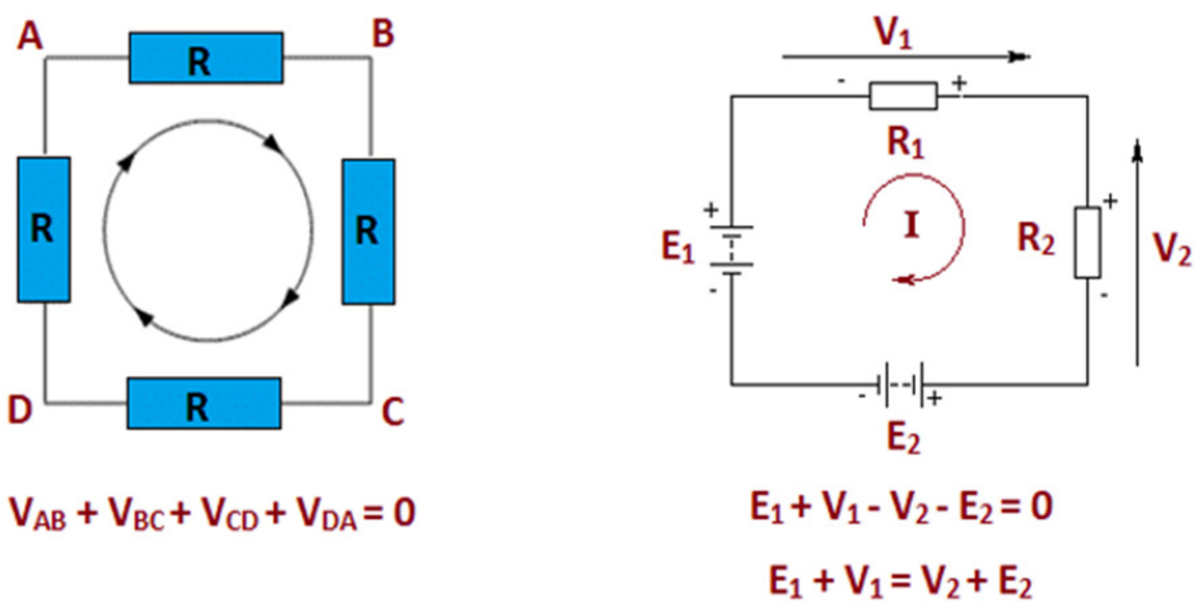


Figure 4.4: Diagram of KVL

We should remember that in a simple series circuit, the algebraic sum of the voltage drops around the circuit closed Loop is equal to the applied voltage. Actually, this KVL is applicable only for the easiest case where only one loop and one voltage source exist in the circuit as shown in the above Figure 4.4.

Kirchhoff's current law (KCL)

Kirchhoff's second law is known for his current law and according to KCL: "At any junction point in a circuit, the current arriving is equal to the current leaving in the circuit". Therefore, if 15 amperes of current coming at a junction with two paths away from it, 15 amperes shall split between the two branches, but the junction must be evacuated in its entirety. From parallel circuits, we already know that KCL states that the sum of the branch currents is equal to the total current entering and leaving the branches as you can see in the given Figure 4.5.

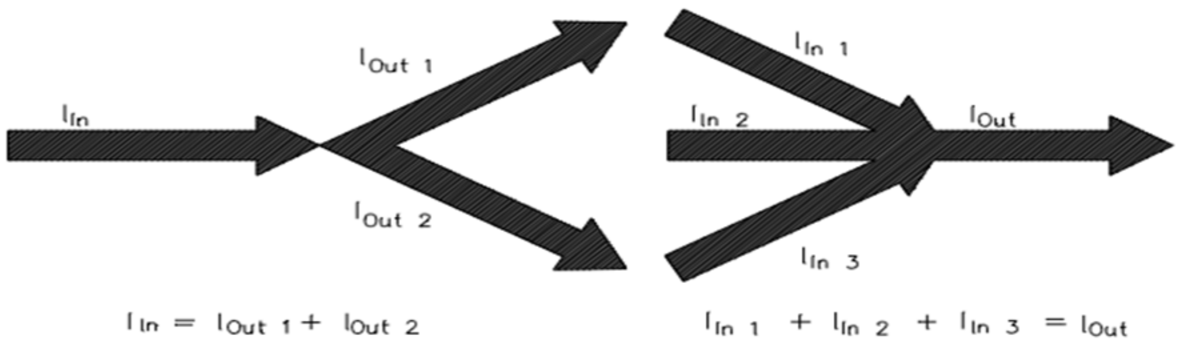


Figure 4.5: shows the Illustrations of Kirchhoff's current law

Let's express the KCL with the help of following equation given below:

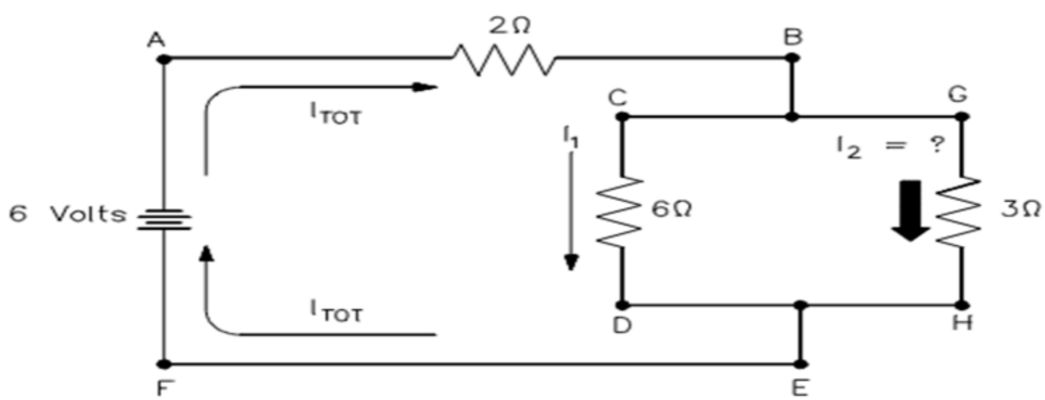
IIN - IOUT = 0

Or,

IIN = IOUT

But we can't use the KCL alone for solving the mathematical problem, but KVL is also used for this purpose with the help of both the laws you can solve the problem. Let's understand by taking a simple problem.

Example: Find I2 in the circuit given below shown in Figure using Kirchhoff's voltage and current laws.



Solution: by using the Current Law First, but apply KVL to both loops.

First taking Loop ABCDEF, ∑ IR = ∑ E source

2 I total +6I1 =6 ---------------------- (1)

Now taking another Loop ABGHEF, ∑ IR = ∑ E source

2I total +3I2 = 6 ----------------------- (2)

Since KCL states

I total = I1 + I2

Replace (I1 + I2) in the place of I total in both loop equations and simplified the loops.

Loop ABCDEF

2 (I1 + I2) + 6I1 = 6

2 I1 +2I2 +6I1 =6

8 I1 +2I2 =6 ------------------- (3)

Loop ABGHEF

2 (I1 + I2) + 3I2 = 6

2I1 +2I2 +3I2 = 6

2I1 +5I2 = 6 ---------------------- (4)

Now we have two equations and two unknowns and we have to put the value of I1 to find I2. Firstly multiply equation 4 by four, and then subtract the equation from the equation 5.

Multiply by 4:

4 (2 I1 +5I2) = 6x4

8I1 + 20 I2 = 24 ----------------- (5)

Subtract equation 3 from equation 5:

(8I1 + 20I2 – 24) - (8I1 + 2I2 - 6) = 18I2 - 18

18I2 – 18 = 0

I2 = 1 ampere

This is how we can calculate the value of I2 by using KVL and KCL.

Y and delta network calculation

T (tee) or Y (wye) network: The shape of both networks are the same but these are known as different names, due to its shape, the network show called a T (tee) or Y (wye) network. The same network have different names as shown in given below Figure 4.6.

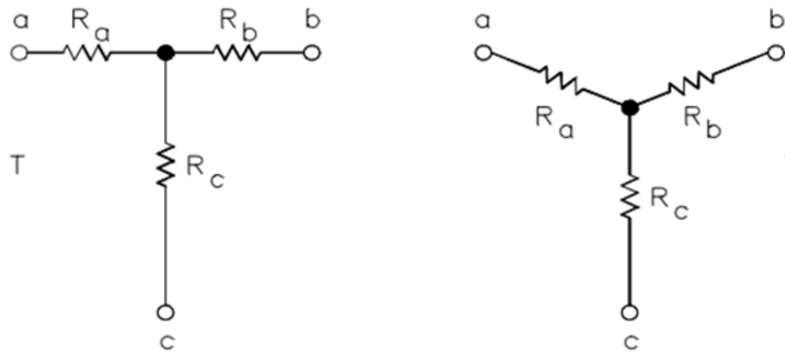


Figure 4.6: T (tee) or Y (wye) network

π (pi) or Δ (delta) network

In the figure, the network shown is called π (pi) or Δ (delta) due to the shapes that is been similar to Greek letters π and Ω. That why the same network have different names as shown in the given Figure 4.7.

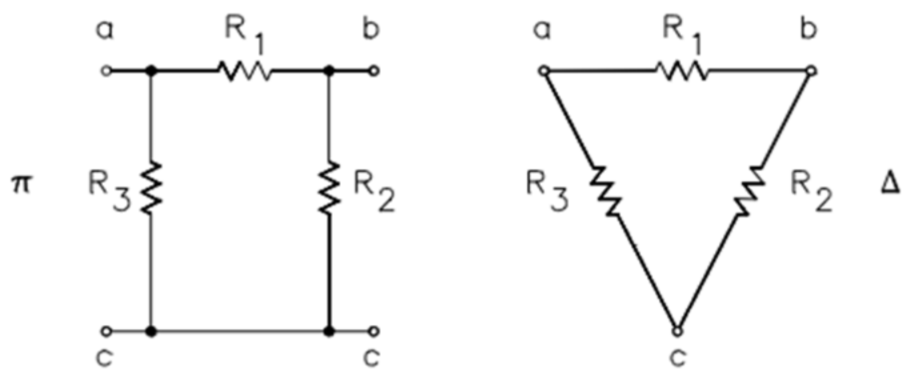


Figure 4.7: π (pi) or Δ (delta) network

Y to Δ network equivalent

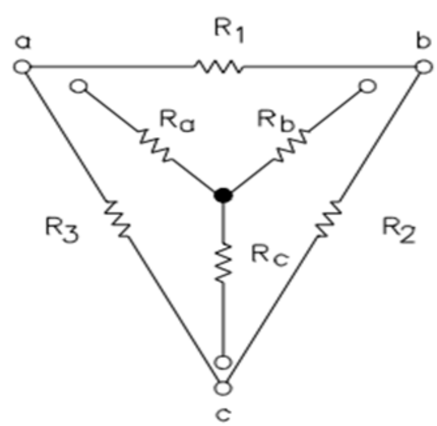


Figure 4.8: Y to Δ network equivalent

To simplify the solution, it may be helpful to convert Y to Δ or Δ to Y to in order to examine the circuits. The laws of Kirchhoff are the basis for the formulas that will be used for these conversions. A three-terminal network depicts the resistances in these networks. One pair of network is equivalent to the other after we use the conversion formulas because their resistances across any pair of terminals are the same. It is depicted in the given below Figure 4.8.

Δ to Y conversion:

Ra = R1R3 / R1 R2 R3

Rb = R1R2 / R1 R2 R3

Rc = R2R3 / R1 R2 R3

Rule 1: The sum of the three Δ resistances divided by the product of the two sides of a Y network that are adjacent determines the resistance of any branch.

Y to Δ conversion:

R1 = RaRb + RbRc + RcRa / Rc

R2 = RaRb + RbRc + RcRa / Ra

R3 = RaRb + RbRc + RcRa / Rb

Rule 2: Any side of a Δ network has a resistance that is the product of the Y network's resistance multiplied in pairs and divided by the Y network's opposite branch.

Networks theorem: The study notes on Network Theorems and Transformation can be covered below. They cover topics like the Super Position Theorem, Thevenin's Theorem, Norton's, and Maximum Power Transfer Theorem.The Electric circuit theory serves as the foundation for numerous subfields of electrical engineering, including electric power, electric machines, control, electronics, computers, communications, and instrumentation.

Superposition theorem: superposition theorem states that “The current flowing through any branch of a linear network with a number of voltage or current sources and resistances is the algebraic sum of the currents resulting from each source acting independently”.

Now we have to explain mesh current by analyzing the following conditions:

Let us consider the network as shown in figure below. The network have currents in different branches are I1, I2, and I as shown. Also I1 + I2 = I. as shown in Figure 4.9[7]–[10].

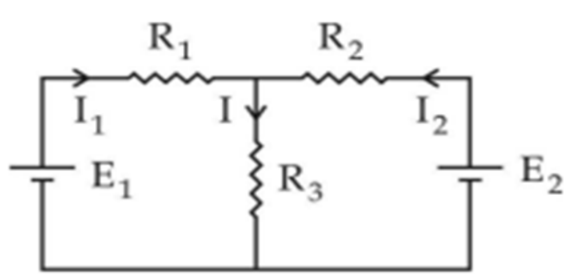


Figure 4.9: branches of currents

If we remove the cell E2 and the terminals are short as shown in the figure below. Now the branches have currents are I1′, I2′ and I′. Also I1′ + I2′ = I′, as you can see in the Figure 4.10.

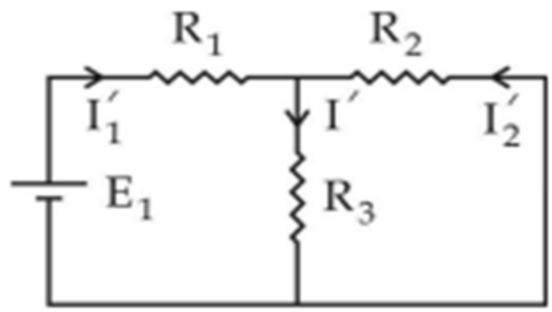


Figure 4.10: branches

When E1 section is displaced and the terminals are short as shown below in the figure. The currents are I1″, I2″ and I″. Also I1″ + I2″ = I″, as shown in the Figure 4.11.

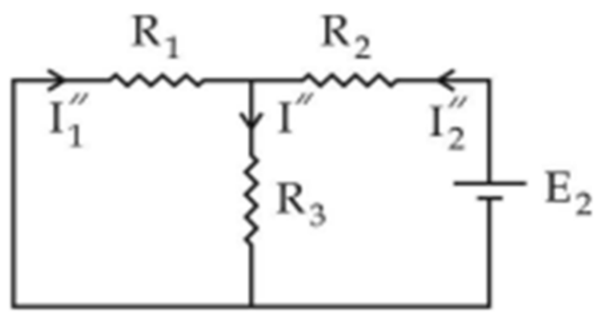


Figure 4.11: branches of current

On accordance with the superposition theorem: I1 = I1′ + I1″, I2 = I2′ + I2″ and I = I′ + I″

I = I1 + I2

Thevenin's theorem

Thevenin's theorem states that "A linear network consisting of a number of voltage sources and resistances can be replaced by an equivalent network having a single voltage source called Thevenin's voltage (Vth) and a single resistance called Thevenin's resistance (Rth)", as shown in the given Figure 4.12.

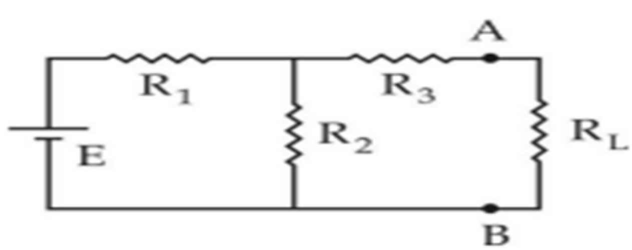


Figure 4.12: Thevenin's theorem

Let us consider a network or a circuit as shown in figure above. Let E will be the EMF of the cell whose internal resistance r = 0. Load resistance is RL in the above circuit across AB.If we have to find the thevenin voltage across AB, then we have according to the below Figure 4.13.

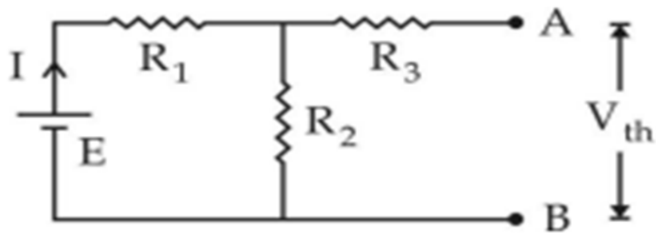


Figure 4.13: Networks of theorem

The voltage across AB = Thevenin's voltage VTh.

VTh = E x R2 / R1 + R2

There are various methods to find resistance and various theorems by which we find out the voltages and resistances. If we have to find the thevenin resistance Rth across AB, then we have according to the below Figure 4.14.

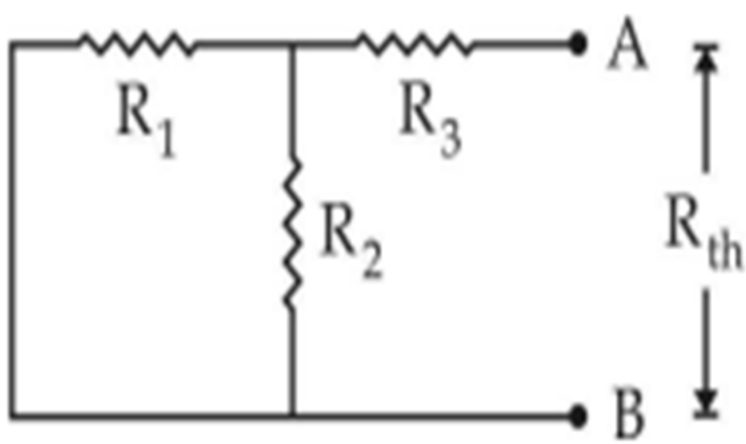


Figure 4.14: Find resistance by theorem

Thevenin resistance Rth is given below:

$$R_{Th} = R_3 + \frac{R_1 R_2}{R_1 + R_2}$$

Maximum power transfer theorem

Maximum power transfer theorem states that "the power transferred by a source to the load resistance in a network is maximum when the load resistance is equal to the internal resistance of the source". The given diagram shows the theorem below Figure 4.15.

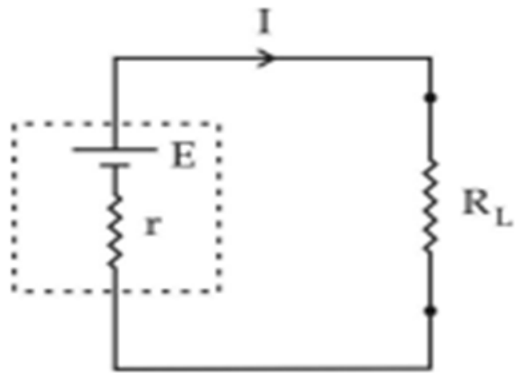


Figure 4.15: Maximum power transfer theorem

The total power through the theorem and having the values of power which is the maximum power distributed to the load is only half the power generated by the source or the maximum power transfers efficiency is 50%. The residual 50% of power is lost towards the internal resistance of the source.

$$\frac{P_{L\max}}{P}=\frac{E^2}{4R_L}\times\frac{2R_L}{E^2}=\frac{1}{2} \text{ or } P_{L\max}=\frac{P}{2}$$

In this article, we learn about the basic of AC and DC and it generally focused on DC circuits. In this series, we talk about the KVL and KCL and general description of these Kirchhoff laws. Later, we focused on the sections of Y and delta network calculation and also describe the theorems of network and in this we think about the implementation of those theorems and formulation of KVL and KCL.

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CHAPTER 5

METHODS OF IMPROVING COMMUTATION

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It is obvious that a brush can come into contact with two or more commutator segments simultaneously due to the thin insulation between them. Therefore, the brush will shortcircuited an armature coil whose ends are connected to two of these segments, and as the armature rotates, each coil will inevitably be shortcircuited. The term "period of commutation" refers to the time when the current is flowing from the affected commutator segments to the brush during this short-circuit period. The changes that occur in an armature coil when it is short-circuited by a brush are referred to as commutation. Those happen when these modifications, the winding being represented as a ring winding for simplicity's sake. The total current delivered by the brush is therefore 2I amps because the armature receives currents of magnitude I amp from the right and left. The coil B is carrying half of the armature's current to the brush from left to right and is on the verge of being short-circuited. The same coil is depicted in the middle of the short circuit period in the second diagram. From this, it can be seen that the current flowing from the right and left can reach the brush without passing through this coil.

As a result, we can see that the short-circuited coil's current must be brought back to its full value in the reverse direction during the short circuit. One of the fundamental tenets of using thyristors for control purposes is commutation. A thyristor can only function in one of two ways: It is either in the ON state, which indicates a short circuit, or the OFF state, which indicates an open circuit. It cannot regulate the voltage or current in a circuit on its own. Commutation is essential to the switching process, and it is the only way that control can be achieved by varying the time thyristors when they are turned ON and OFF. As a result, the cyclic or sequential switching of thyristors is involved in every thyristor circuit[1]–[3].

The alternating and reversing nature of AC is utilized in the simplest and most prevalent method of commutation voltages to change how the current moves. In AC, we know that in every half cycle in circuits, the current always goes through zero. A reverse voltage across the device will simultaneously appear as the current passes through natural zero. The device is immediately turned off by this. Since no external circuit is required for this purpose, this process is referred to as natural commutation. AC may be used in this method. Voltages from the mains or the AC voltages produced by resonant circuits or local rotating machines. This category includes line-commutated converters and inverters.

Commutation in DC machines

A DC generator's armature conductors are subjected to alternating currents. Commutation is defined as the process of turning off conducting SCR. Commutation is the process by which a generated AC is transformed into an applied DC. The induced current flows in one direction when the armature's conductors are below the North Pole. While they are beneath the South Pole, the current flows in the opposite direction. The conductor's current is flipped around as it enters the South Pole after passing through the North Pole’s influence. The MNA or brush axis is where the current is reversed. The winding element that is connected to the two commutator segments in the brush span is short-circuited. The change that occurs in a winding element during a brush short circuit is referred to as commutation. Let's us recognize the commutation process more reliably by takin simple ring winding shown below in the following figure A. We clearly seen that the I current flowing towards the brush in a clockwise direction from the left-hand side passes around the coil as shown in the given below Figure 5.1.

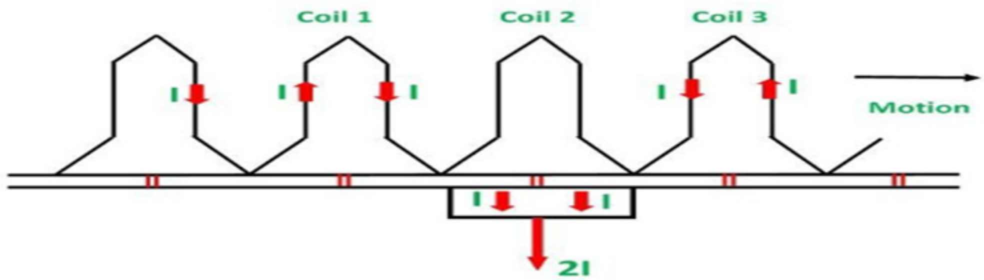

Figure 5.1

Now see below in which we see that the position of the coil in the figure below demonstrates that all of the coils carry the same amount of current in the same direction, but the brush is too close to the coil as shown in the below Figure 5.2.

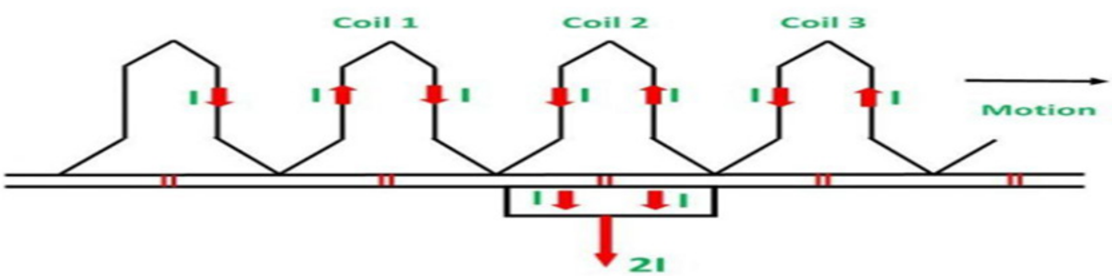

Figure 5.2

The brush makes contact with bars a and b in the below, short-circuiting coil 1 as a result. I remain from the left and I remain from the right in the current. It can be seen that these two currents are able to reach the brush without going through coil 1 as shown in the Figure 5.3.

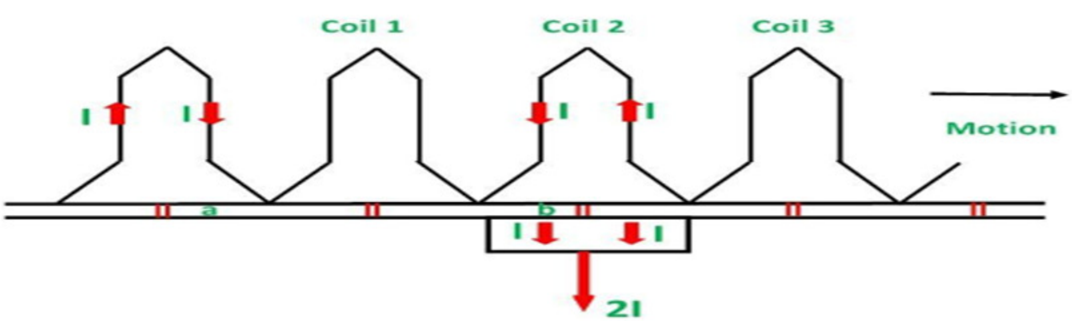

Figure 5.3

The bar (b) has just left the brush, completing coil one's short circuit, as depicted in below. For the current to reach the brush in an anticlockwise direction from the right side, it is now necessary as shown in below Figure 5.4.

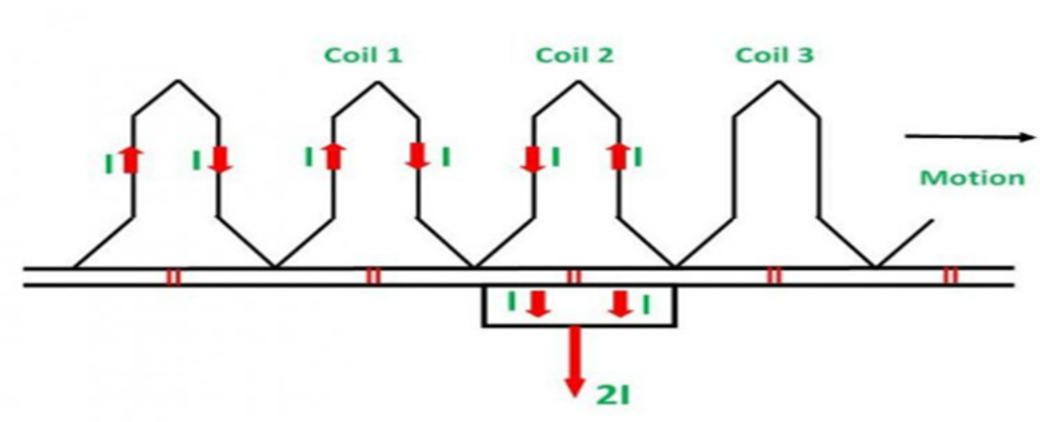

Figure 5.4

As can be seen from the preceding discussion, in order for a brush to short circuit an armature coil, the coil's current must be brought back to its full value in the opposite direction. The term "period of commutation" refers to the duration of the short circuit.

The variation in current in the short-circuited coil over the brief period of the short circuit is depicted in the figure below. The current moves linearly from +I to –I during the commutation period, as shown by curve b. Straight-line or Ideal Commutation are two names for this type of commutation as shown in the below Figure 5.5.

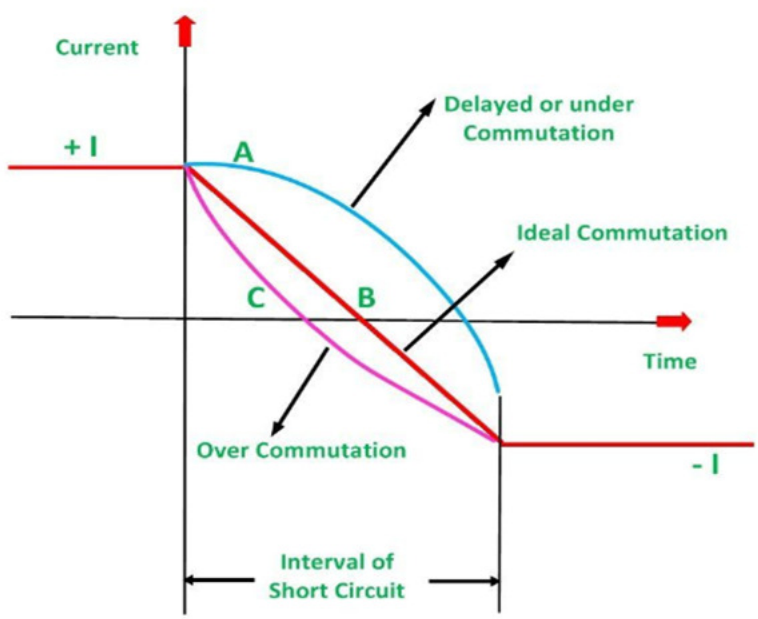

Figure 5.5: Commutation process

The difference between the currents flowing through elements 2 and 1 must leap from the commutator bar to the brush in the form of a spark if the current through coil 1 has not achieved its maximum value in the position shown in figure 5.4. As a result, the failure of the current in the short-circuited elements to reach the full value in the reverse direction at the end of the short circuit is what causes sparking at the commutator. Undercommutation or delayed commutation are terms used to describe this phenomenon.

In this scenario, the current of the commutating coils changes linearly from +I to –I during the commutation period in ideal commutation curve B, as shown in above figure E by curve A. After the commutation period, the short-circuited coil's current does not reach its full value in practice. This is because, in addition to its resistance, the short-circuited coil has self-inductance. The coil's self-inductance creates a back EMF to oppose the reversal due to the high rate of change in current.

The total change is 2I because the coil's current must change from +I to –I. Reactance voltage is the name given to this self-induced EMF, and its value can be calculated as shown below. This voltage, despite its small magnitude, results in a huge current flowing through the short-circuited coil, whose resistance is very low. Note that if the brushes are positioned so that there will still be the EMF of self-induction, which causes severe sparking at the brushes, even though the coils undergoing the short-circuit are in the magnetic neutral plane where they are cutting no flux and hence have no EMF induced in them owing to armature rotation. If tc = tc is the time of the short circuit and L is the inductance of the coil which is equal to the self-inductance of the short-circuited coil plus the mutual inductances of the neighboring coils, then the average self-induced voltage or Reactance voltage is defined as[4]–[6]:

$$L\frac{di}{dt} = \frac{L \times 2I}{t_c} = \frac{2LI}{t_c}$$

Sparking occurs at the machine's brushes as a result of the large voltage that exists between the commutator segments that the coil is connected to. The commutator's sparking is extremely harmful, causing damage to both the commutator's surface and the brushes. Its cumulative effect may result in a machine short circuit with a brush-by-brush arc around the commutator.

Methods of improving commutation

Improving commutation or obtaining sparkles commutation can be accomplished in three primary ways. Then winding is used for decreasing the spark in the circuit as well as make the circuit able to work smoothly without any disturbances in the process and it is only possible by reducing the spark in the circuit. Then the commutation can be improved by the following these methods and those methods are of dividing into three ways: Compensating Winding, Voltage Commutation, and Resistance Commutation are all examples of these. In addition, the voltage commutation consists of the commutating poles or inter poles method and the brush shift method, both of which are utilized to generate the injected voltage. As we can easily understand this by a simple diagram as given below Figure 5.6.

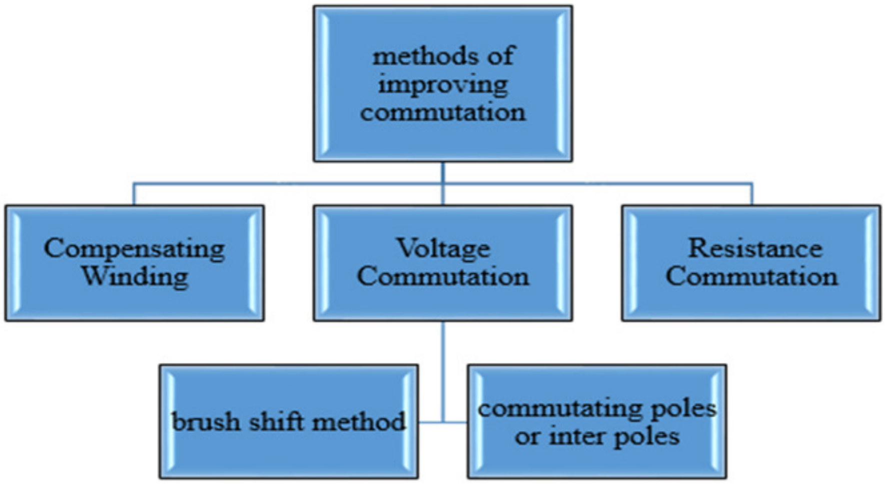

Figure 5.6: Methods of improving commutation

Resistance commutation

Carbon brushes are used to improve commutation in the Resistance Commutation method. Contact resistance between commutator segments and brushes is high when carbon brushes are used. The short-circuited coil's current tends to change in accordance with the commutation requirements because of the high contact resistance. Replace low-resistance Cu brushes with carbon brushes that have a higher resistance in order to improve commutation. Figure demonstrates that two parallel routes are available to current I as it approaches the commutator segment b from coil' C. The first section runs directly from bar ‘b’ to the brush, while the other parallel line goes through short-circuited coil B to bar ‘a’ before reaching the brush. When using Cu brushes, which have low contact resistance, the current is not compelled to take the second, longer path; instead, it prefers to take the first path as shown in below Figure 5.7.

However, when using carbon brushes with high resistance, then current I arriving from C will prefer to travel down the second path because

(i) resistance r1 of the first path will rise as a result of the bar ‘b’ decreasing area of contact with the brush, and

(ii) resistance r2 of the second path will fall as a result of the bar ‘a’

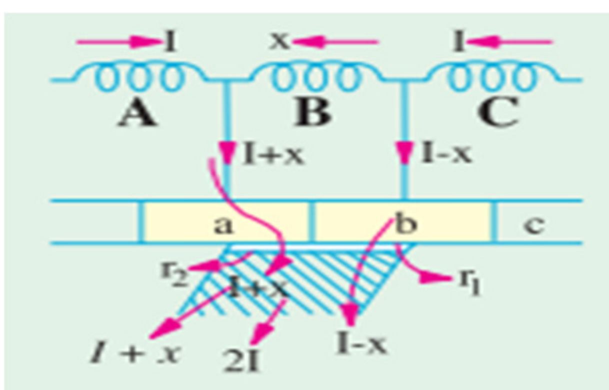

Figure 5.7: Resistance commutation

Benefits of Using Carbon Brushes:

(i) It makes our commutation easier.
(ii) It will Polish and lubricate the commutator.
(iii) It is easily find on the market.
(iv) It is very Economical to the circuit.

However, a few of their minor drawbacks include:

i. A loss of approximately 2 volts is experienced as a result of their high contact resistance, which is advantageous to spark commutation. As a result, they are unsuitable for use in small machines due to the significant loss of this voltage.
ii. In order to efficiently dissipate heat without increasing temperature, the commutator must be somewhat larger than with Cu brushes due to this significant loss.
iii. They require larger brush holders due to their lower current density (around 7-8 A/cm2) in comparison to Cu brushes' 25-30 A/cm2.
iv. Due to wear, it must be replaced.

Compensating windings

By balancing the armature MMF, the compensating windings are the most effective method for eliminating the armature reaction and flashover issue. The windings are inserted into the slots in the pole faces that are parallel to the conductors of the rotor. The armature windings and these windings are connected in series. The compensating winding's currents must flow in the opposite direction from those in the armature winding just below the pole faces. As a result, the armature MMF and the MMF produced by the compensating winding are equivalent and opposite. The armature flux produced by the armature conductors is neutralized or demagnetized by the compensating winding. The armature flux then has no effect on the flux per pole, regardless of the load conditions as shown in the below Figure 5.8. The compensating windings' most significant drawback is their high cost. The compensating winding is primarily used in the following situations[7]–[10]:

(i) In a massive machine susceptible to severe overloads or jamming.
(ii) In small motors that are susceptible to rapid reversals and rapid acceleration.

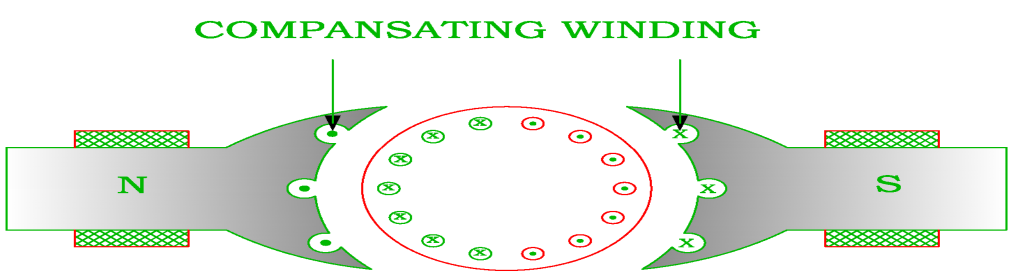

Figure 5.8: shows the compensating windings

Voltage Commutation

This technique creates a reversing EMF in the short-circuited coil during commutation in order to negate the reactance voltage. As its name implies, this reversing EMF is an EMF in opposition to the reactance voltage, and if its value is made equal to that of the latter, it will totally wipe it off, creating rapid reversal of current in the short-circuited coil which will result in commutation that sparkles. The arrangement of the Voltage Commutation method is to induce a voltage that will neutralize the reactance voltage in the coil that is undergoing the commutation process. The reactance voltage is opposed by this injected voltage. Sparkles commutation will occur if the reactance voltage and the injected voltage are made equal. This will cause a rapid reversal of current in the short-circuited coil.

There are two ways to create the reversing EMF:

(i) Either by providing the brushes a forward lead long enough to influence the following pole of the opposite polarity or
(ii) By utilizing interpoles.

Brush shift

The armature reaction causes the magnetic neutral axis (MNA) to shift in the generator's direction of rotation and the motor's direction of rotation. A flux is created in the neutral zone by the armor reaction. Because it reduces the flux, the commutating coil generates a small voltage as shown in the given below Figure 5.9.

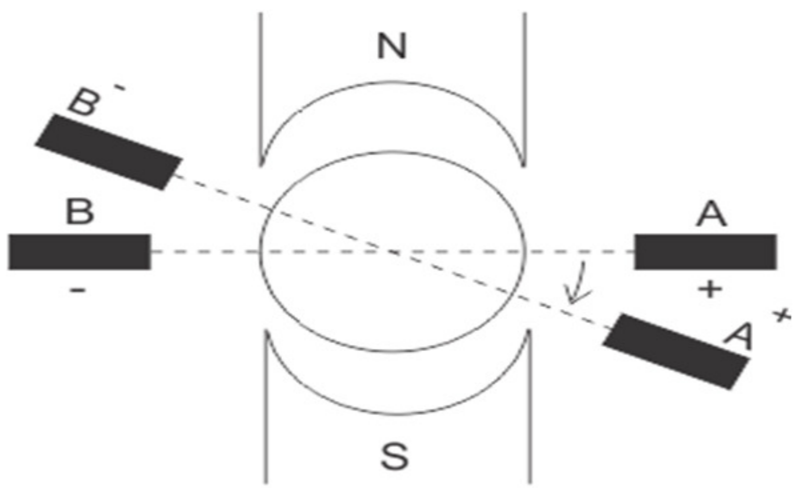

Figure 5.9: Brush shift in Generator

Commutating poles or interpoles

Interpoles, also known as commutating poles or Campoles, are short poles that are attached to the stator and are positioned in between the main poles. Because the interpoles must produce fluxes that are directly proportional to the armature current, their windings are connected in series with the armature.

The same armature current affects both the interpole mmfs and the armature simultaneously. Consequently, an appropriate component of interpole flux neutralizes the armature flux in the commutating zone, which tends to shift the magnetic neutral axis. The conductors going through commutation must experience a voltage from the interpoles that is in opposition to the voltage from the neutral plane shift and reactance voltage. As we can see that the poless and interpoles how it shows in the commutator circuit diagram given below in the Figure 5.10.

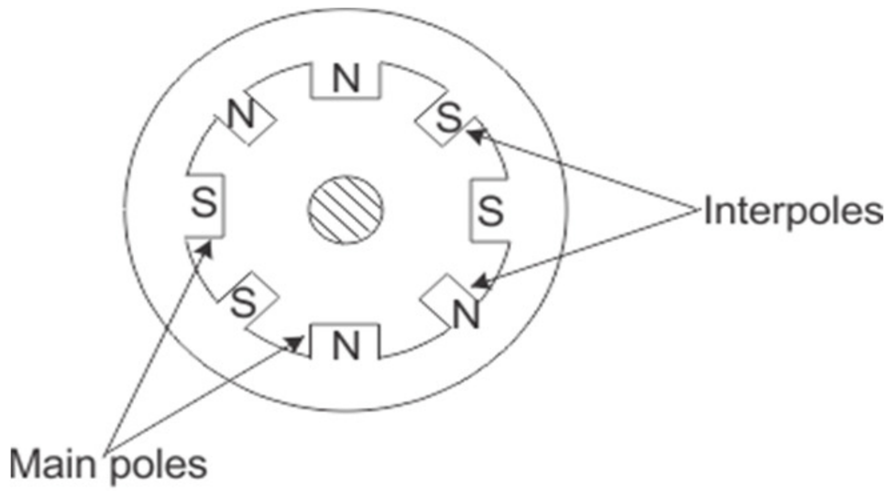

Figure 5.10: Commutating poles or interpoles

In case of generator:

The rotational direction is represented by the neutral plane shifts. As a result, the conductor going through the commutation needs its interpole to be polarized similarly to the next main pole in the rotational direction. The interpoles must have the opposite flux, which is the flux of the main pole ahead in the rotational direction, in order to counteract this voltage.

If a motor is present:

The conductors undergoing commutation have the same flux as the main pole, and the neutral plane shifts in opposition to the direction of rotation for a motor. The interpole must be polarized similarly to the previous main pole in order to oppose this voltage. In the direction of rotation, an interpole and a main pole are polar opposites.

As in the given below figure, we can see that the polarity of interpoles in the Figure 5.11.

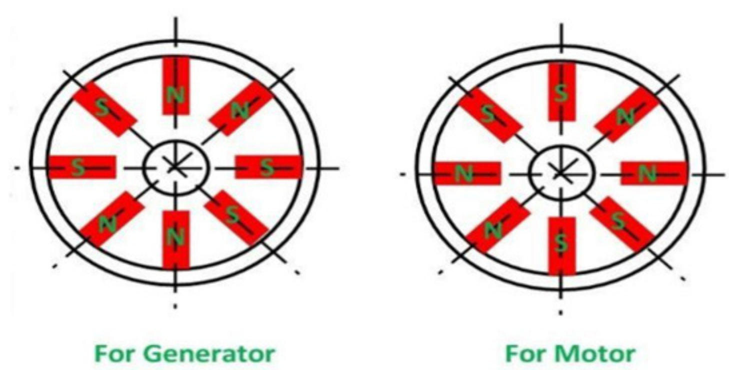

Figure 5.11: Polarity of interpoles in case of generator and motor

The differentiation between the interpoles and remunerating windings ought to be obviously perceived. Both have their MMFs connected in series and they are designed to eliminate the armature reaction. However, compoles also supply MMF for reducing the reactance voltage that is generated in the coil that is going through commutation. Additionally, the compoles localized action has little impact on the armature reaction that occurs on the remaining periphery of the armature.

The Interpoles only serve to ensure good commutation by providing sufficient flux. They can't get around the flux distortion caused by the armature's cross-magnetizing MMF. The voltage between adjacent commutator segments may rise to very high levels during severe overloads or rapidly changing loads. The air around the commutator becomes sufficiently conductive as a result of this ionization. From brush to brush, an arc is drawn. Flashover is the name given to this occurrence. The commutator segments can be melted by this arc's high temperature. It should be put out as soon as possible. Compensating windings are used to avoid flashover.

Interpoles of compoles

The EMF induced by compoles is called as commutating or reversing EMF. The EMF that combines neutralizes EMF's reactance thereby enhancing commutation. With a fixed brush position, sparkless commutation can be achieved with interpoles up to 20% to 30% overload. In point of fact, interpoles bring a machine's sparking limit nearly up to its heating limit. As a result, an interpole machine can be smaller and less expensive than a non-interpole machine for the same output.

(i) Interpoles' commutating EMF is caused by the fact that they carry armature current is proportional to the current in the armature. As a result, the reactance voltage, which is also caused by armature current, is automatically neutralized. Figure below depicts the connections for a shunt generator with interpoles, as shown in the Figure 5.12.

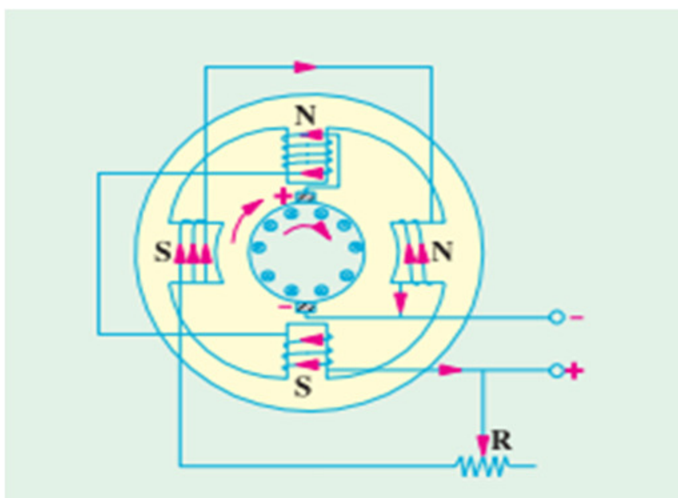

Figure 5.12: Connections for a shunt generator with interpoles

(ii) The neutralization of the armature reaction's cross-magnetizing effect is another function of the interpoles. As a result, brushes should not be moved from their initial position. As before, OF is depicted in the figure below as the MMF due to the main lines. The cross-magnetizing MMF is represented by OA due to the armour BC, which stands for MMF because of interpoles, clearly opposes OA, so they cancel each other out. Because both are generated by the same armature current, this cancellation of crossmagnetization occurs automatically for all loads as shown in the below Figure 5.13.

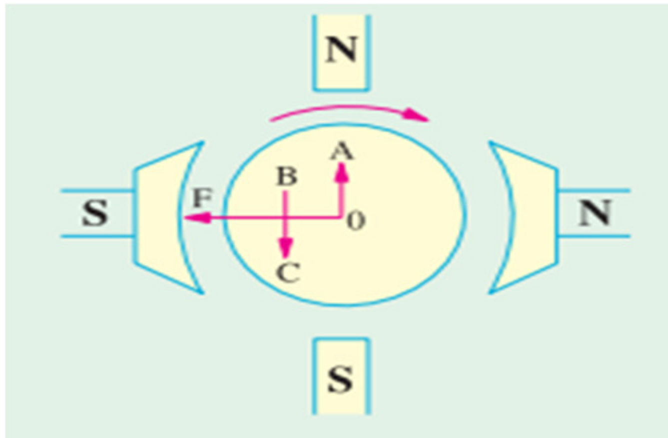

Figure 5.13: Cross-magnetizing effect

Equalizing Connections

Lap-winding is characterized by the placement of all conductors in any parallel path beneath a single pair of poles. EMF is true if all pole fluxes are identical induced in each parallel path is the same, and the current flowing through each path is the same. However, despite the best efforts, there will always be some flux inequalities because of either slight variations in the length of the air gap or steel's magnetic properties.

As a result, the EMF is always slightly off in the various paths that run parallel. As a result, conductors with stronger poles produce more electromagnetic fields and as a result, carry more current.

The brushes' current distribution becomes uneven. Overloaded brushes carry more current than their normal current, while underloaded brushes carry less. Whatever their position, overloaded brushes spark badly.

This causes poor commutation and may even limit the machine's output in given below Figure 5.14.

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CHAPTER 6

DC GENERATORS

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An instrument for electro-mechanical energy conversion is a DC machine. DC machines can be divided into two categories: DC motors and DC generators. In contrast to a DC motor, which transforms DC electrical power into mechanical power, a DC generator transforms mechanical power into DC electrical power. A DC motor is utilized in applications where a broad range of speeds and good speed regulation are necessary, such as in electric traction systems, while an AC motor is almost often used in the industry to convert electrical power into mechanical power. Generator and dc motor architecture is essentially identical. A very safe method of using the generator is used. There is therefore the open construction style. The generator is used in a very secure manner. Consequently, there is the open construction style. However, because the motor is utilized in an environment where it is exposed to dust and moisture, it needs enclosures that are, for example, dustproof, fireproof, etc., as needed. Despite being a significant source of DC electricity, the battery has a limited capacity to run any devices. Large amounts of DC electricity are necessary for various applications like electroplating, electrolysis, etc. As a result, DC generators are employed to provide power in these locations.

Basic structure of Electrical machines:

The Stator and Rotor are the two primary components of a rotating electrical or DC machine. An air gap separates the stator and rotor from one another. The machine's fixed outer frame is known as the stator. The internal component of the machine is the rotor, which is free to rotate. Ferromagnetic materials are used to create the stator and the rotor. Both the outer and inner peripheries of the rotor and stator have slots carved into them. In the slots of the stator or rotor, conductors are inserted. Windings are created by connecting them together. The Armature windings are the windings in which voltage is induced winding that a current is routed through to create the main flux is called field winding[1]–[3].

Despite the fact that AC machines make up a much higher proportion of electrical equipment in use, D.C. machines are still very important for industry. The main benefit of a DC machine, and especially a DC motor, is that speed can be controlled precisely. No AC motor makes this claim of a benefit. However, DC generators are less popular than they once were since rectifiers are mostly utilized to obtain direct current from an AC source when it is needed. However, a knowledge of DC generators is crucial since they provide as a logical introduction to DC motor behavior. In fact, a lot of DC motors used in industry briefly double as DC generators. This chapter will cover a variety of topics of DC generators.

Electromechanical System in Simplified Form as shown in the below diagram, as shown in below Figure 6.1.

Energy Distribution can be express as follows given below:

WE = total energy supplied by the electric source

WM = total energy supplied by the mechanical source

Figure 6.1: Electromechanical System in Simplified Form

WE = We + Wel + Wes

Wm = Wm + Wml + Wms

DC Generator

An electrical device known as a dc generator turns mechanical energy into direct current electricity. The idea behind this energy conversion is the creation of dynamically generated EMF.

Construction of DC machines:

Without making any structural alterations, a DC generator can function as a DC motor, and the opposite is also true. Therefore, a DC machine can be broadly defined as a DC generator or a DC motor. These fundamental constructional aspects apply equally to the building of a DC motor. A straightforward 4-pole DC machine's construction details are shown in the below diagram. The stator and rotor are the two fundamental components of a DC machine. The following list of a DC machine's fundamental components is provided as shown below in the Figure 6.2.

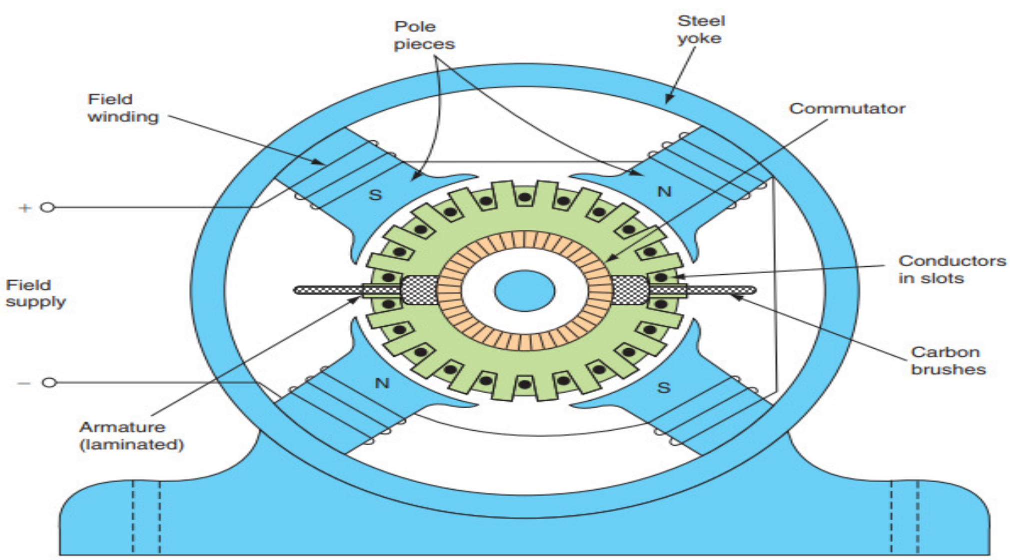

Figure 6.2:Construction of DC machines

There are various sections that which motor is divided, they are as follows as:

1. Yoke: A DC machine's yoke is its outside frame. Steel or cast iron make up its construction. It not only gives the entire assembly mechanical strength, but it also conveys the magnetic flux generated by the field winding.

2. Poles and pole shoes: Bolts or welding are used to attach the poles to the yoke. They are attached to pole shoes and carry field winding. Pole shoes have two functions: first, they support field coils, and second, they evenly distribute flux in the air gap.

3. Field winding: Copper is typically used to make them. Each pole has a field coil that has been previously wrapped, positioned there, and connected in series. They are constructed with a wound pattern that, when energized, north and south are formed become alternate.

4. Armature core: The rotor of a DC machine is the armature core. It has slots to carry the armature winding and is cylindrical in shape. To minimize eddy current losses, the armature is constructed from thin, circular steel discs that have been laminated. It might have air ducts for the axial air flow needed for cooling. The shaft is keyed to the armature as shown below in the Figure 6.3.

Figure 6.3: Armature core

5. Armature winding: Typically, an armature slot holds a former wrapped copper coil. The armature conductors are separated from one another and the armature core by an insulation layer. Either the lap winding method or the wave winding method can be used to wind an armature. In most cases, double layer lap or wave windings are used. In an armature with a double layer winding, there will be two distinct coils in each slot.

6. Commutator and brushes: Using a commutator-brush setup, the armature winding is physically connected. In a dc generator, a commutator's job is to collect the current produced in the armature conductors. In contrast, a DC motor's commutator aids in supplying current to the motor's forward conductors. A copper set of insulated from one another segments makes up a commutator.Graphite or carbon are typically used to make brushes. As the commutator rotates, they rest on the segments and slide along them, maintaining physical contact and collecting or supplying the current. Commutator is shown below in the given Figure 6.4.

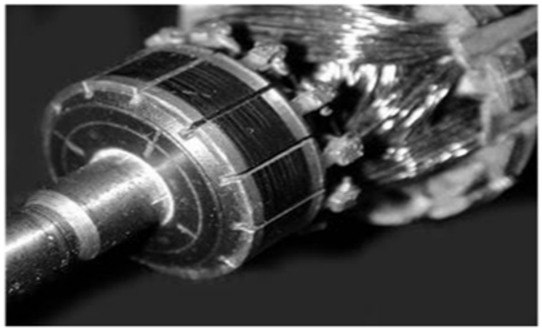

Figure 6.4: Commutator of DC

Working principle of DC generators:

According to Faraday's equations of electromagnetic induction, an EMF is induced in a conductor whenever it is exposed to a magnetic field that is changing. The induced EMF's magnitude can be determined using the dc generator's induced EMF equation. The induced current will flow along the conductor's closed path if one is present. The armature conductors are spun into the electromagnetic field created by the field coils in a DC generator. As a result, the conductors in the armature produce an electromagnetically induced EMF. Induced current's direction is determined by Fleming's right-hand rule.

The direction of induced current shifts anytime the conductor's motion direction shifts, according to Fleming's right hand rule. Think about a conductor travelling upward at the left and an armature spinning in the opposite direction. The motion of that specific conductor will change from upward to downward when the armature has completed one-half of its revolution. Every armature conductor will therefore have alternating current flow. You may see how the induced current's direction alternates in an ar mature conductor by looking at the above figure. However, when the current is reversed with a split ring commutator, the connections of the armature conductors also change. The result is that the terminals get unidirectional current as shown in the given below Figure 6.5.

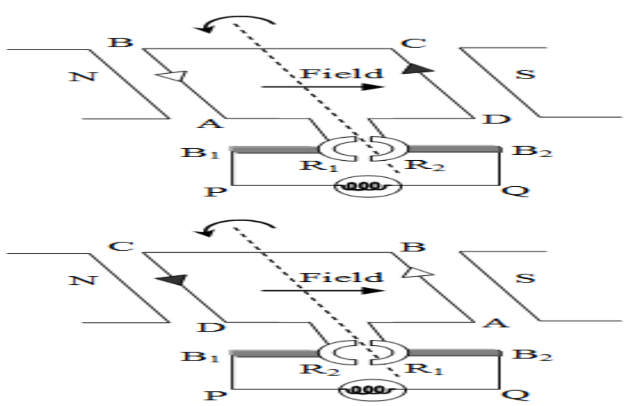

Figure 6.5: diagram of DC generator

Therefore, the necessary components of a generator are as follows:

(a) a magnetic field
(b) conductor or a group of conductors
(c) Motion of conductor w.r.t. magnetic field.

Types of DC generator: Based on how the field is excited, DC generators can be divided into three basic types: self-excited, separately excited, and permanent magnet generators. While the individually stimulated type uses an external force for excitation, the first kind uses permanent magnets to activate the field coils. A self-excited DC generator has its own field coils and another generator that is energized by it. The permanent magnet field is not shown in the diagram for the different types of DC generators because it is not frequently employed in the sector.Types of DC generator can be described as they are shown below in the Figure 6.6.

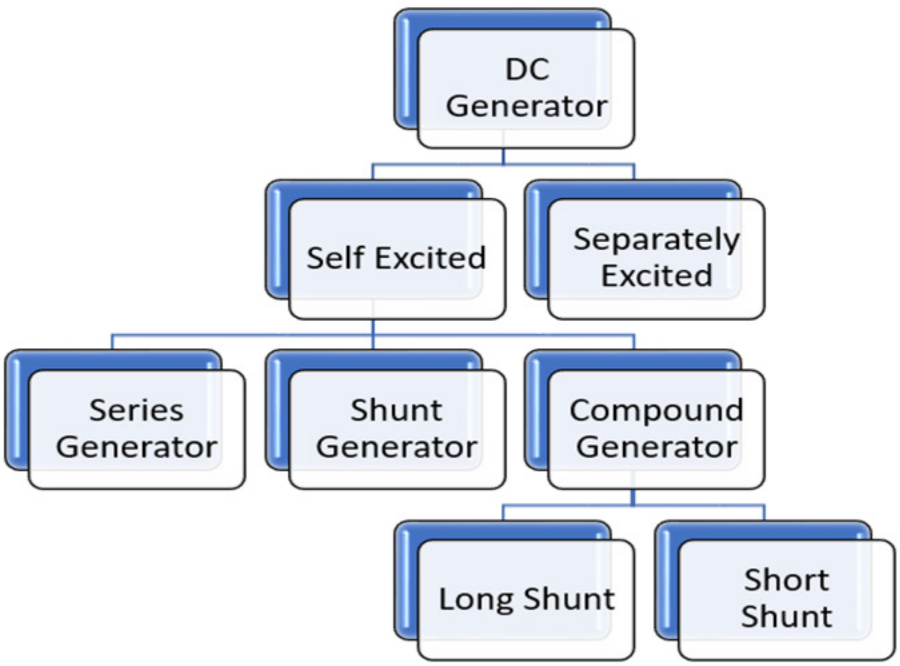

Figure 6.6: Types of DC generator

Permanent magnets DC generators

The most basic sort of generator is referred to as a permanent magnet DC generator because it uses permanent magnets to produce flux in the magnetic circuit. A permanent magnet or magnets are positioned all around an armature. Due to the generator's design, this kind cannot produce a lot of power and is not used in industrial applications. Like dynamos in bikes, permanent magnet DC generators are typically utilized in tiny applications. As is well known, voltage is produced when a wire crosses a magnetic field, and the amount depends on the wire loops and the field's rotational speed, below shows the fundamental design of a permanent magnet DC generator. Additionally, the angle between the magnetic flux and the moving surface affects how much voltage is present. The voltage varies with each loop's rotation from zero to its maximum amount as a function of angle, creating an absolute amount of sinusoidal voltage. The voltage becomes constant at its highest value as the number of loops at various angles increases, as shown in the Figure 6.7[4]–[6].

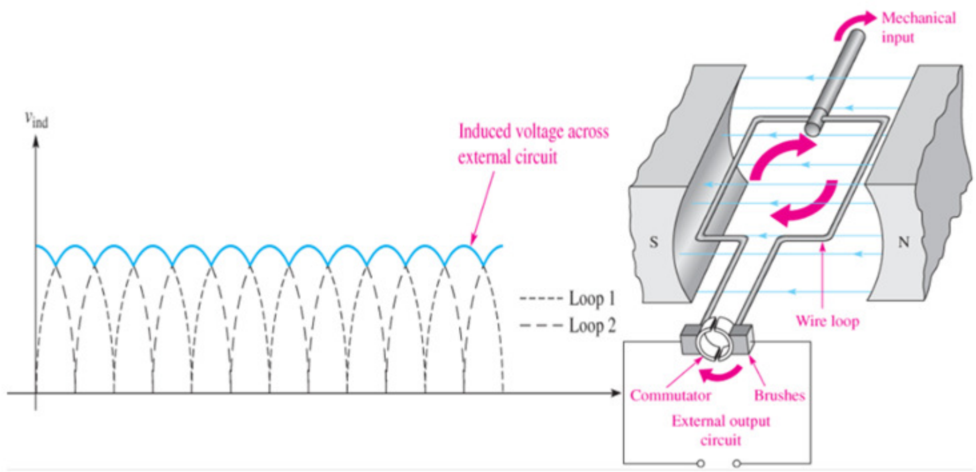

Figure 6.7: Permanent magnetic DC generators

Separately Excited DC Generators

This method uses an external DC source, such as a battery, to power the field magnets. A larger EMF and voltage in the output can be produced as the rotation speed rises. Figure shows the circuit diagram for the independently excited DC generators, as shown in the Figure 6.8.

The symbols are as follows:

- I_L = the current at the Load
- I_a = Armature current
- E_g = Generated EMF
- V = The voltage at the terminal

The generated power and the delivered power to the external force can be calculated as:

- Ia = Il = I
- V = I x Ra
- Pg = Eg × I
- Pl = V x I

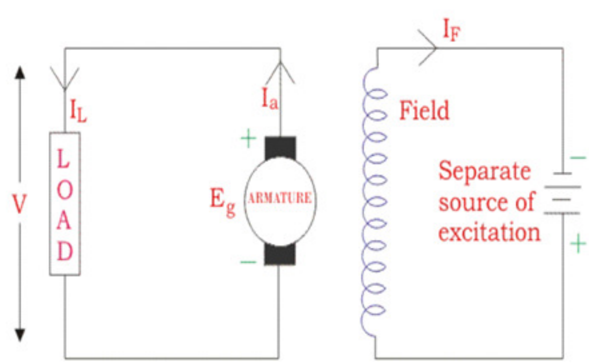

Figure 6.8: Separately Excited DC Generators

Self-Excited DC Generators

Field magnets in self-excited DC generators are powered by their own internal current, and the field coils are internally coupled to the armature. Due to the residual magnetism, there is flux in the poles all the time. A little amount of current is generated as the armature rotates, and this current travels through the field coils with the load to strengthen the pole flux. The current and EMF rise as a result of increasing the pole flux, and the accumulative process continues until excitation is required. Based on the field coils and their placement, self-excited DC generators are divided into the following categories:

1. Shunt Wound Generators
2. Compound Wound Generators
3. Series Wound Generators

1. Shunt Wound DC Generators

To excite the generator, the field windings are parallelly linked to the armature conductors. The insulated current-carrying coils known as field windings are what create the necessary magnetic field for the generator's excitation. The field windings of a shunt generator have the same voltage as the generator's terminals due to residual magnetism in the poles, but the voltage's real value varies depending on the load and its speed, as shown in the below Figure 6.9. The following is the circuit schematic for this type:

Where:

V = Terminal voltage
E_g = Generated EMF
I_{sh} = Current flowing through the shunt field
I_a = Armature current
I_L = Load current
R_{sh} = Shunt winding resistance
R_a = Armature resistance

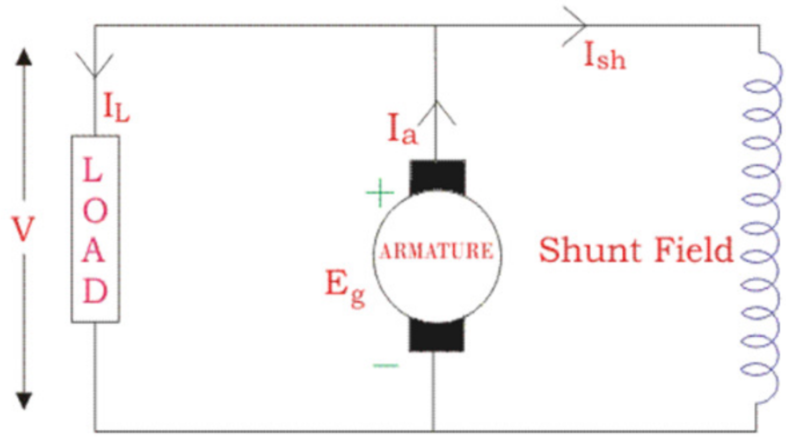

Figure 6.9: Circuit diagram of the Shunt Wound DC Generators

In this, when armature current is equal to the sum of shunt current and load current

Ia = Ish +Il

The most effective power for the load would be available when the IL is at its highest value. Therefore, it is preferable to maintain a minimal shunt current. Therefore, maintaining a high shunt resistance is reasonable.

Ish = V \ Rsh

V = Eg - IaRa

The power generated and the electricity sent to the load are:

Pg = Eg x Ig.

Pl = V x Il

2. **Series Wound DC generators**

In series-wound generators, the field winding is connected to the armature wires in series. The circuit diagram for this generator is shown in Figure below circuit diagram. The load and the current in the field coil both flow at the same rate. For low electrical resistance, field windings are made with few turns and thick wires. (Figure 6.10). The following is the circuit schematic for this type:

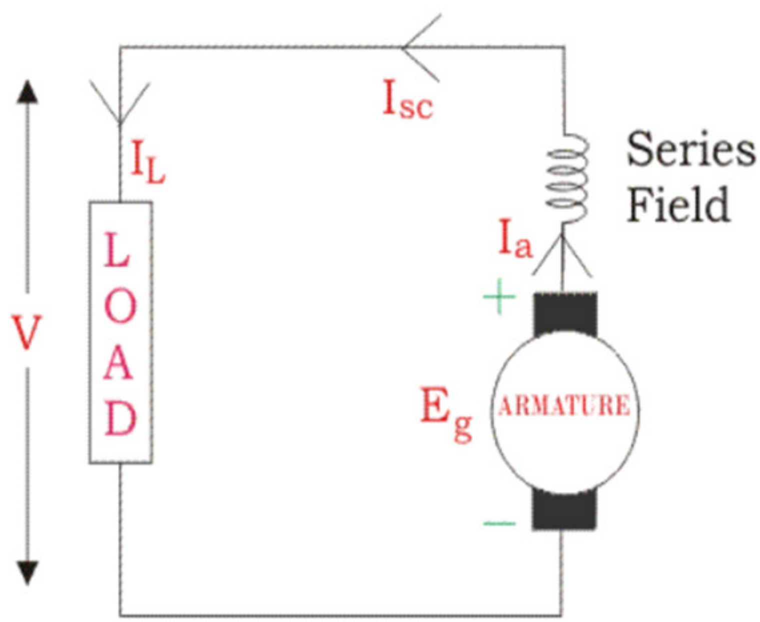

Figure 6.10: Circuit diagram of the series-Wound DC Generators

Let's consider the following equations by explained below:

Ia = Il = Isc = I

V = Eg – I^2 × Ra

The power Generated and the power delivered to the load are given below:

Pg = I x Eg

Pl = I x V

3. **Compound Wound DC generators**

In the series wound type, the output voltage and EMF are dependent on the load current, whereas in the shunt type, the output is proportional to the inverse of the load current. Compound wound generators, which combine both series and shunt, are available to get around both types' drawbacks. Both series and shunt field wounding are used in the compound wound generators' circuit. With the armature, there are two different types of short shunt compound wound generators and long shunt compound wound generators, as well as series and parallel windings as shown in the figure given below Figure 6.11[7]–[10].

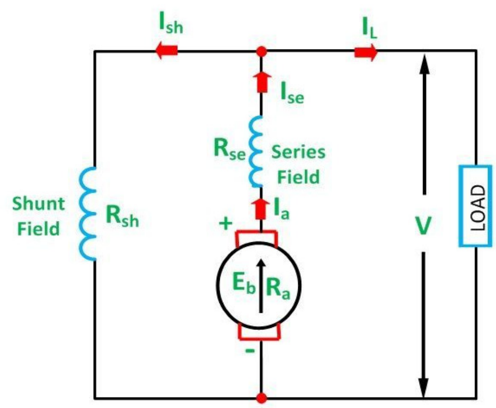

Figure 6.11: Compound Wound DC generators

Long shunt compound wound DC generators:

The shunt windings are parallel with both the series field and armature in long shunt compound DC generators. The following is the circuit schematic for this type, as shown in the given Figure 6.12.

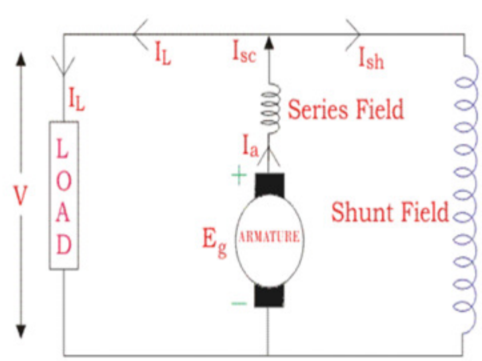

Figure 6.12: long shunt compound wound DC generators

- The currents in the circuit are:

  Ish = V / Rsh

  Ics = Il + Ish

  Ics = Ia

- The voltage of the load is equal to:

  V = Eg – Ia x (Ra - Rsc)

- The power Generated and the delivered power to the load are given below:

  Pg = IG x Eg

  Pl = IG x V

Short shunt compound wound DC generators:

As seen in the following image, an armature is parallel to the shunt field windings of short type, as shown in the below Figure 6.13.

The currents in this systems are:

Isc = Il

Ish = V + Isc x Rsc / Rsh

Ia = Isc + Il

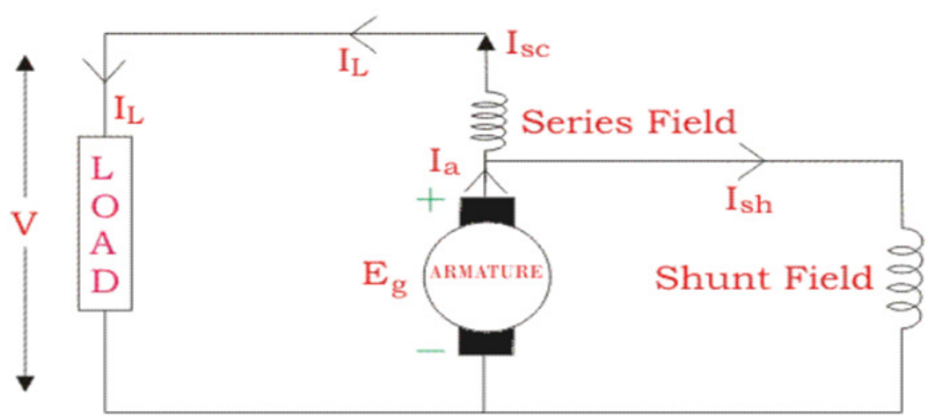

Figure 6.13: Short shunt compound wound DC generators

The voltage of the load, load power, and the generated power are given below:

V = Eg – IaRa - IscRsc

Pl = IG x V

Pg = IG x Eg

EMF Equation of a Dc Generator:

Let us calculate the equation of DC generator by using the following parameters as given below:

Ø = flux/pole in Wb (weber)

Z = total no. of armature conductors

P = no. of generator poles

A = no. of parallel paths in armature

N = rotational speed of armature in revolutions per min. (rpm)

E = EMF induced in any parallel path in armature

Now, we have to calculate the value of EMF equation,

Avg. emf generated per conductor= $\frac{dØ}{dt}$ volts

and flux cut per conductor in one revolution= dØ= Ø.P (Wb)

no. of revolutions per second (speed)= N/60

∴ time for one revolution = dt = 60/N

∴ emf generated / conductor = $\frac{dØ}{dt} = \frac{PØN}{60}$ volts

but generated emf (Eg) will be equal to generated emf in any parallel path

∴ Generated emf (Eg) = $\frac{PØN}{60}\ \frac{Z}{A}$ volts

Now, for simplex wave wound generator
no. of parallel paths = A = 2

∴ Eg= $\frac{PØN\ Z}{120}$ volts

and, for simplex lap wound generator
no. of parallel paths = A = no. of poles = P

∴ Eg= $\frac{PØN}{60}\ \frac{Z}{P}$ volts

This is known as the EMF equation of DC generator given above.

The output voltage is maintained by balancing the two fields so that the rise in the series field just offsets the drop in the shunt field. Figure illustrates this by displaying the voltage characteristics of generators that are series-, shunt-, and compound-wound, as shown in the Figure 6.14.

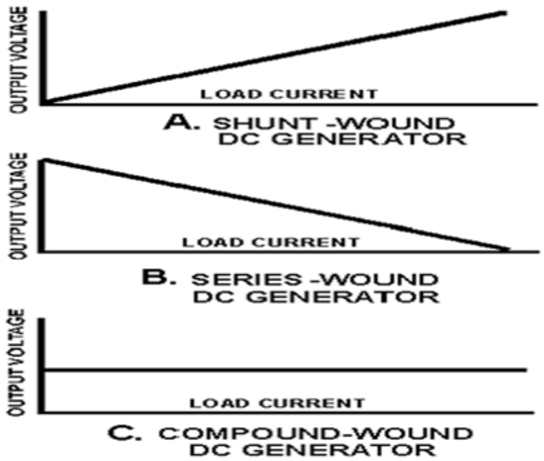

Figure 6.14: Voltage output characteristics of the series, shunt, and compound-wound dc

As you can see, a compound-wound generator produces a consistent output voltage under a variety of load circumstances by balancing the effects of the two fields. Curves in reality are rarely, if ever, as flawless as they appear. In this chapter we have covered the basic introduction of DC generator and working principle and construction of DC generator, types of DC and it focused on important parts and components of a DC generator. We have learnt about the EMF equation of DC and also the characteristics of shunt, series and compound generators.

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CHAPTER 7

SERIES AND COMPOUND DC GENERATORS

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An instrument for electro-mechanical energy conversion is a DC machine. DC machines can be divided into two categories: DC motors and DC generators. In contrast to a DC motor, which transforms DC electrical power into mechanical power, a DC generator transforms mechanical power into DC electrical power. A DC motor is utilized in applications where a broad range of speeds and good speed regulation are necessary, such as in electric traction systems, while an AC motor is almost often used in the industry to convert electrical power into mechanical power. Generator and dc motor architecture is essentially identical. A very safe method of using the generator is used. There is therefore the open construction style. The generator is used in a very secure manner. Consequently, there is the open construction style. However, because the motor is utilized in an environment where it is exposed to dust and moisture, it needs enclosures that are, for example, dustproof, fireproof, etc., as needed. Despite being a significant source of DC electricity, the battery has a limited capacity to run any devices. Large amounts of DC electricity are necessary for various applications like electroplating, electrolysis, etc. As a result, DC generators are employed to provide power in these locations.

Basic structure of Electrical machines:

The Stator and Rotor are the two primary components of a rotating electrical or DC machine. An air gap separates the stator and rotor from one another. The machine's fixed outer frame is known as the stator. The internal component of the machine is the rotor, which is free to rotate. Ferromagnetic materials are used to create the stator and the rotor. Both the outer and inner peripheries of the rotor and stator have slots carved into them. In the slots of the stator or rotor, conductors are inserted. Windings are created by connecting them together. The Armature windings are the windings in which voltage is induced. The winding that a current is routed through to create the main flux is called field winding[1]–[3].

Despite the fact that AC machines make up a much higher proportion of electrical equipment in use, D.C. machines are still very important for industry. The main benefit of a DC machine, and especially a DC motor, is that speed can be controlled precisely. No AC motor makes this claim of a benefit.

However, DC generators are less popular than they once were since rectifiers are mostly utilized to obtain direct current from an AC source when it is needed. However, a knowledge of DC generators is crucial since they provide as a logical introduction to DC motor behavior. In fact, a lot of DC motors used in industry briefly double as DC generators. This chapter will cover a variety of topics of DC generators.

DC Generator

An electrical device known as a dc generator turns mechanical energy into direct current electricity. The idea behind this energy conversion is the creation of dynamically generated EMF.

Construction of DC machines:

Without making any structural alterations, a DC generator can function as a DC motor, and the opposite is also true. Therefore, a DC machine can be broadly defined as a DC generator or a DC motor. These fundamental constructional aspects apply equally to the building of a DC motor. A straightforward 4-pole DC machine's construction details are shown in the below diagram. The stator and rotor are the two fundamental components of a DC machine. The following list of a DC machine's fundamental components is provided, as shown in the Figure 7.1.

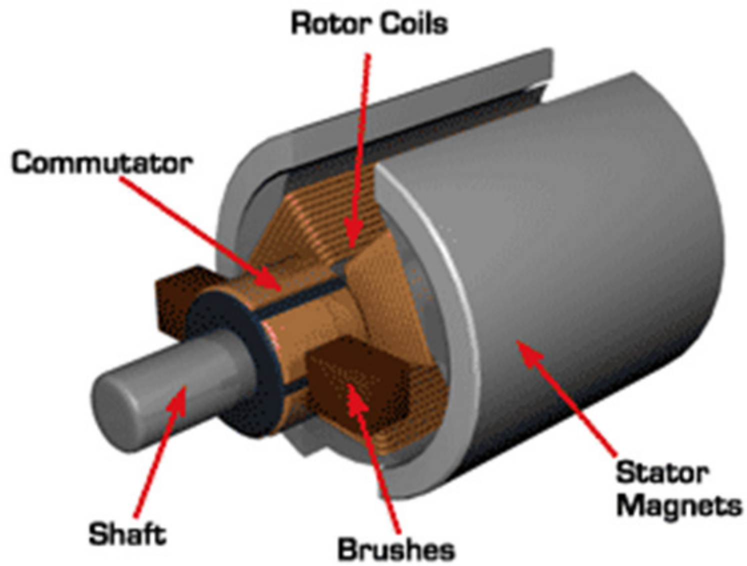

Figure 7.1:Construction of DC machines

There are various sections that which motor is divided; they are as follows as:

1. Yoke

2. Poles and pole shoes

3. Field winding

4. Armature core

5. Armature winding

6. Commutator and brushes

Working principle of DC generators:

According to Faraday's equations of electromagnetic induction, an EMF is induced in a conductor whenever it is exposed to a magnetic field that is changing. The induced EMF's magnitude can be determined using the dc generator's induced EMF equation. The induced current will flow along the conductor's closed path if one is present. The armature conductors are spun into the electromagnetic field created by the field coils in a DC generator. As a result, the conductors in the armature produce an electromagnetically induced EMF. Induced current's direction is determined by Fleming's right-hand rule.

The direction of induced current shifts anytime the conductor's motion direction shifts, according to Fleming's right-hand rule. Think about a conductor travelling upward at the left and an armature spinning in the opposite direction. The motion of that specific conductor will change from upward to downward when the armature has completed one-half of its revolution. Every armature conductor will therefore have alternated current flow. You may see how the induced current's direction alternates in an ar mature conductor by looking at the above figure. However, when the current is reversed with a split ring commutator, the connections of the armature conductors also change. The result is that the terminals get unidirectional current as shown in the given below Figure 7.2.

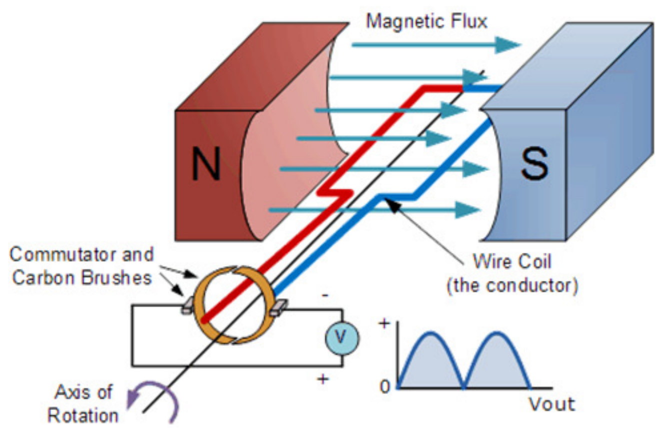

Figure 7.2: Diagram of DC generator

Therefore, the necessary components of a generator are as follows:

1. A magnetic field
2. Conductor or a group of conductors
3. Motion of conductor w.r.t. magnetic field.

Types of DC generator: Based on how the field is excited, DC generators can be divided into three basic types: self-excited, separately excited, and permanent magnet generators. While the individually stimulated type uses an external force for excitation, the first kind uses permanent magnets to activate the field coils. A self-excited DC generator has its own field coils and another generator that is energized by it. The permanent magnet field is not shown in the diagram for the different types of DC generators because it is not frequently employed in the sector.Types of DC generator can be described as they are shown in below Figure 7.3.

There are different types of DC generators, but in this we especially focused on the series and compound generators which are basically parts of self-excited generators. Now in the below flow chart you can clearly see that the self-excited DC generators is further divided into three types:

i. Shunt Wound Generators
ii. Compound Wound Generators
iii. Series Wound Generators

Now in this we clearly focused on the series and compound DC generators, working and characteristics of series and compound DC generators.

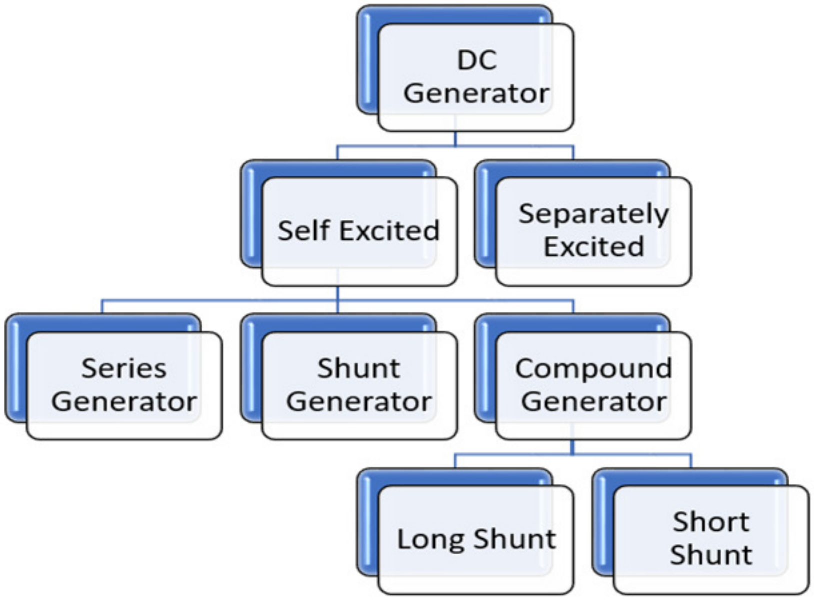

Figure 7.3: Types of DC generator

Self-Excited DC Generators

Field magnets in self-excited DC generators are powered by their own internal current, and the field coils are internally coupled to the armature. Due to the residual magnetism, there is flux in the poles all the time. A little amount of current is generated as the armature rotates, and this current travels through the field coils with the load to strengthen the pole flux. The current and EMF rise as a result of increasing the pole flux, and the accumulative process continues until excitation is required. Based on the field coils and their placement, self-excited DC generators are divided into the following categories:

1. Shunt Wound Generators
2. Compound Wound Generators
3. Series Wound Generators

Shunt Wound DC Generators

To excite the generator, the field windings are parallelly linked to the armature conductors. The insulated current-carrying coils known as field windings are what create the necessary magnetic field for the generator's excitation. The field windings of a shunt generator have the same voltage as the generator's terminals due to residual magnetism in the poles, but the voltage's real value varies depending on the load and its speed, as shown in the Figure 7.4[4]–[6].

The following is the circuit schematic for this type:

Where:

V = Terminal voltage

E_g = Generated EMF
I_{sh} = Current flowing through the shunt field
I_a = Armature current
I_L = Load current
R_{sh} = Shunt winding resistance
R_a = Armature resistance

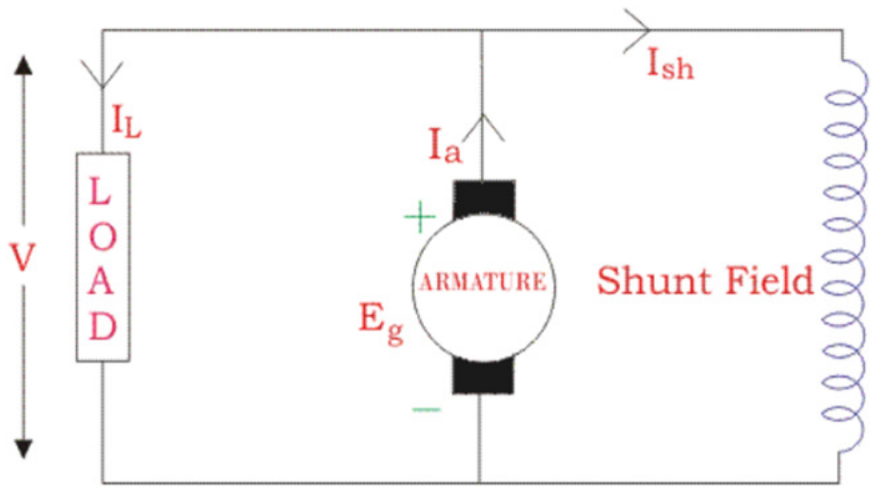

Figure 7.4: Circuit diagram of the Shunt Wound DC Generators

Series Wound DC generators

In series-wound generators, the field winding is connected to the armature wires in series. The circuit diagram for this generator is shown in Figure below circuit diagram. The load and the current in the field coil both flow at the same rate. For low electrical resistance, field windings are made with few turns and thick wires, as shown in the given Figure 7.5.

The following is the circuit schematic for this type:

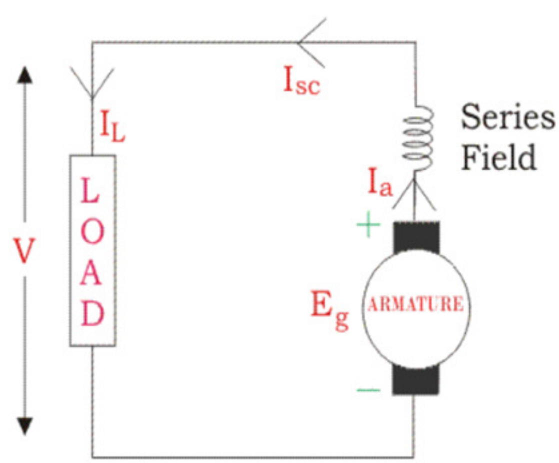

Figure 7.5: Circuit diagram of the Series-Wound DC Generators

Let's consider the following equations by explained below:

Ia = Il = Isc = I

V = Eg – I^2 × Ra

The power Generated and the power delivered to the load are given below:

Pg = I x Eg

Pl = I x V

Compound Wound DC generator: In the series-wound type, the output voltage and EMF are dependent on the load current, whereas in the shunt type, the output is proportional to the inverse of the load current. Compound wound generators, which combine both series and shunt, are available to get around both types' drawbacks. Both series and shunt field wounding are used in the compound wound generators' circuit. With the armature, there are two different types of short shunt compound wound generators and long shunt compound wound generators, as well as series and parallel windings.

i. **Long shunt compound wound DC generators:** The shunt windings are parallel with both the series field and armature in long shunt compound DC generators, as shown in the Figure 7.6.
The following is the circuit schematic for this type:

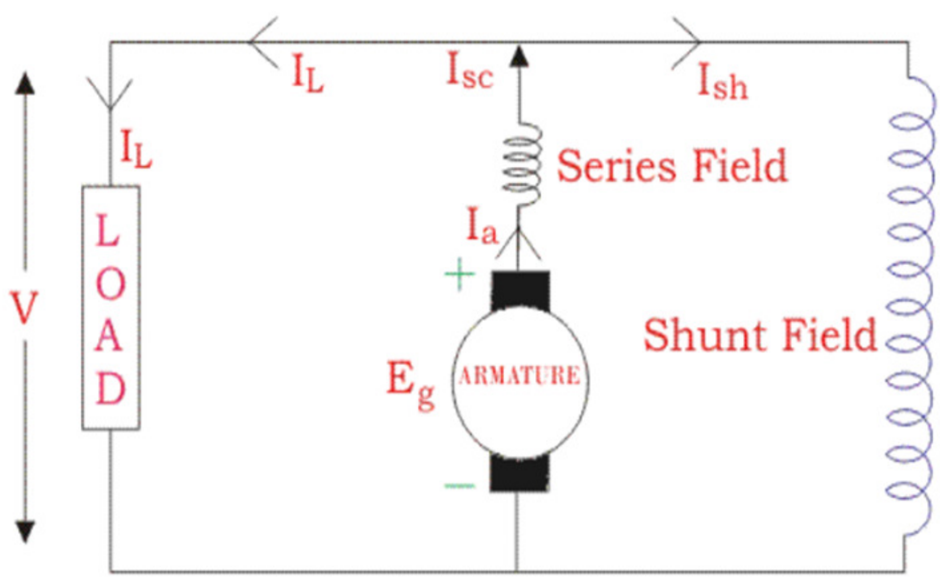

Figure 7.6: long shunt compound wound DC generators

➢ The currents in the circuit are:

Ish = V / Rsh

Ics = Il + Ish

Ics = Ia

- The voltage of the load is equal to:

V = Eg – Ia x (Ra - Rsc)

- The power Generated and the delivered power to the load are given below:

Pg = IG x Eg

Pl = IG x V

ii. **Short shunt compound wound DC generators:** As seen in the following image, an armature is parallel to the shunt field windings of short type, as shown in the Figure 7.7.

The currents in these systems are:

- Isc = Il
- Ish = V + Isc x Rsc / Rsh
- Ia = Isc + Il

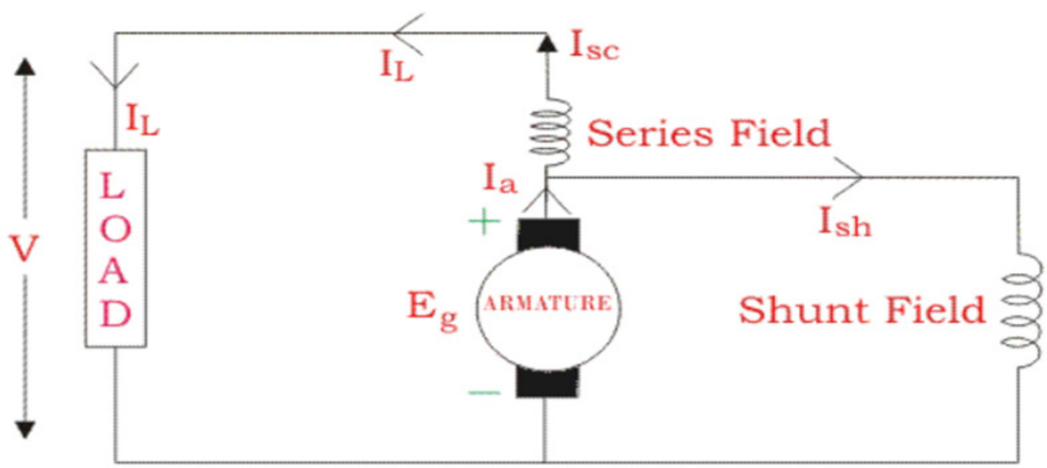

Figure 7.7: Short shunt compound wound DC generators

The voltage of the load, load power, and the generated power are given below:

V = Eg – IaRa - IscRsc

Pl = IG x V

Pg = IG x Eg

EMF Equation of a DC Generator: Let us calculate the equation of DC generator by using the following parameters as given below, waveform shown below in the Figure 7.8.

Ø = flux/pole in Wb (weber)

Z = total no. of armature conductors

P = no. of generator poles

A = no. of parallel paths in armature

N = rotational speed of armature in revolutions per min. (rpm)

E = EMF induced in any parallel path in armature

Now,

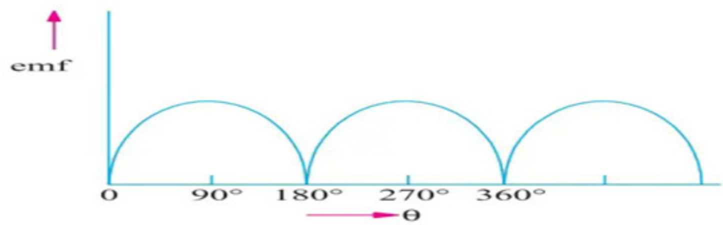

Figure 7.8: wave form of EMF vs angle

Avg. emf generated per conductor= $\frac{dØ}{dt}$ volts

and flux cut per conductor in one revolution= dØ= Ø.P (Wb)

no. of revolutions per second (speed)= N/60

∴ time for one revolution = dt = 60/N

∴ emf generated / conductor = $\frac{dØ}{dt} = \frac{PØN}{60}$ volts

but generated emf (Eg) will be equal to generated emf in any parallel path

∴ Generated emf (Eg) = $\frac{PØN}{60} \frac{Z}{A}$ volts

Now, for simplex wave wound generator
no. of parallel paths = A = 2

∴ Eg= $\frac{PØN\ Z}{120}$ volts

and, for simplex lap wound generator
no. of parallel paths = A = no. of poles = P

∴ Eg= $\frac{PØN}{60} \frac{Z}{P}$ volts

This is known as the EMF equation of DC generator given above.

Characteristics of DC generators:

The prime mover keeps a DC generator's speed constant. The relationship between the excitation, terminal voltage, and load reveals the generator's performance in these conditions. These relationships are depicted graphically in the form of curves, which are known as DC generator characteristics. The DC generator's behavior under various load conditions is demonstrated by these characteristics.

The main characteristics of a DC generator are as follows:

Open Circuit Characteristics or Magnetization Curve: Open Circuit Characteristics also known as the Magnetization Curve, is the graph that shows the relationship between the generated EMF at no load (E0) and the field current (If) at a certain constant speed. No-load saturation curve is another name for it. Its shape is nearly identical for both self-excited and separately-excited DC generators.

Internal Characteristics: This is the graph that shows the relationship between the armature current and the generated EMF (E) on-load. On-load magnetic flux will be lower than noload magnetic flux as a result of armature reaction. As a result, the generated EMF (E) at no load will be lower than the generated EMF (E0) under loaded conditions. The internal characteristics curve is positioned just below the open circuit characteristics as a result.

External Characteristics or Load Characteristics: The plot that exists between the load current (IL) and the terminal voltage (V) is known as the external characteristics or load characteristics. Due to armature and series field copper losses, the terminal voltage is lower than the generated voltage. As a result, the machine's copper losses will cause the external characteristics curve to fall below the internal characteristics curve by the same amount[7]–[10].

Characteristics of DC Series Generator

Only one current flows through the entire machine in a DC series generator. As a result, the excitation, load, and armature currents are all the same as shown in the given below Figure 7.9.

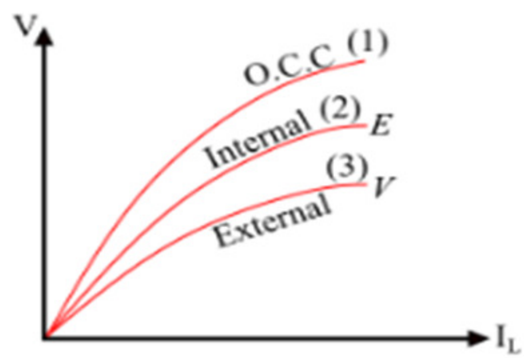

Figure 7.9: Characteristics of DC Series Generator

Open Circuit Characteristics (O.C.C.):

The O.C.C of a series DC generator is depicted by the curve (1) in the plot. It is the graph between the field current and the generated EMF at no load. Separately excited, the O.C.C. can be obtained by disconnecting the machine's field winding.

Internal Characteristics:

The graph that shows the relationship between the armature current and the generated EMF (E) on-load is the internal characteristic of a DC series generator. The magnetic flux at no load will be greater than the flux at load due to the influence of armature reaction. As a result, the generated EMF (E) at no load will be lower than the generated EMF (E0) when the system is loaded. The internal characteristics curve is therefore located just below the open circuit characteristics is depicted by the curve (2).

External Characteristics or Load Characteristics:

The plot that exists between the load current (IL) and the terminal voltage (V) is known as the external characteristics or load characteristics. Due to armature and series field copper losses, the terminal voltage is lower than the generated voltage, which is caused by,

V = E – Ia(Ra + Rse)

As a result, the voltage drop caused by copper losses in the machine will cause the external characteristics curve to fall below the internal characteristics curve by the same amount as you can see in the curve (3).

Characteristics of compound DC Generator

Both the series and shunt fields are combined in compound DC generators. The field winding connection with the armature determines whether the compound generators are shortshunt or longshunt. Most of the time, the cumulative compound generators are used. As a result, the characteristics of a cumulatively compound DC generator will be discussed. (Figure 7.10)

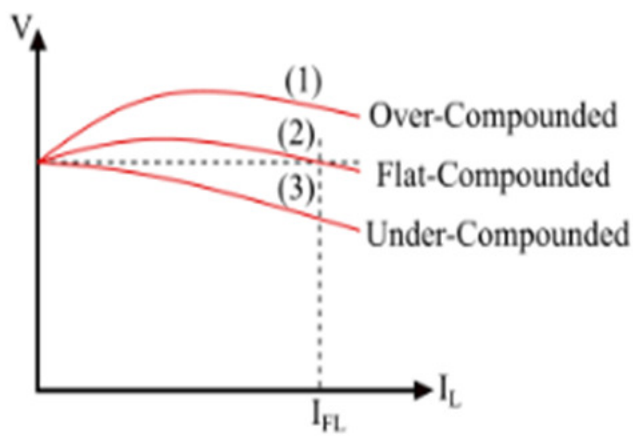

Figure 7.10: Characteristics of compound DC Generator

The shunt field is aided by the series field in a cumulatively compound DC generator. With an increase in load current, the degree of compounding varies with the series field excitation.

Over-Compounded Generator:

A generator is said to be over-compounded if the series field turns are adjusted in such a way that, as the load current rises, the full-load terminal voltage exceeds the no-load terminal voltage as you can see the curve (1).

Flat-Compounded Generator:

The generator is referred to as a flat-compounded generator or level compounded generator which is depicted by the curve (2), if the series field turns are adjusted in such a way that the full load terminal voltage is the same as the noload terminal voltage.

Under-Compounded Generator:

A generator is said to be under-compounded if the series field turns are adjusted in such a way that the terminal voltage at full load is lower than the terminal voltage at no load as you can see in the curve(3). Let understand the basic characteristics of series, shunt and compound DC generators. We have seen in the given below figure how current- voltage vs load current characteristics change with respect to series, shunt and compound generators. The output voltage is maintained by balancing the two fields so that the rise in the series field just offsets the drop in the shunt field. Figure illustrates this by displaying the voltage characteristics of generators that are series-, shunt-,and compound-wound, as shown in the Figure 7.11.

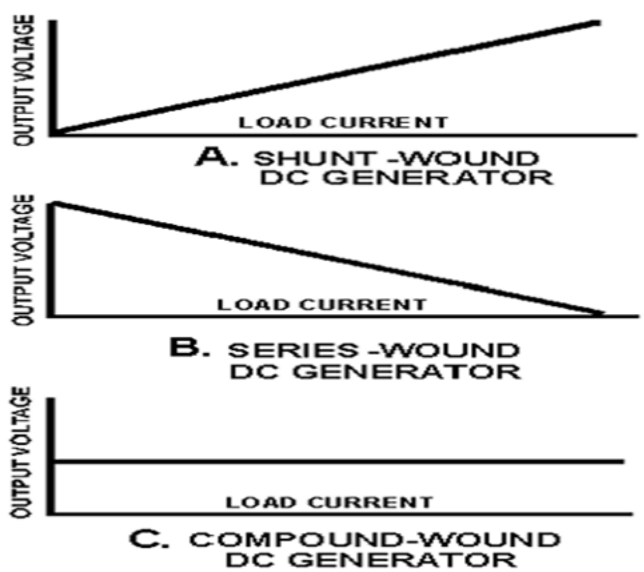

Figure 7.11: Voltage output characteristics of the series-, shunt-, and compound-wound dc generators.

As you can see, a compound-wound generator produces a consistent output voltage under a variety of load circumstances by balancing the effects of the two fields.

Curves in reality are rarely, if ever, as flawless as they appear. In this chapter we have covered the basic introduction of DC generator and working principle and construction of DC generator, types of DC and it focused on important parts and components of a DC generator. We have learnt about the EMF equation of DC and also the characteristics of shunt, series and compound generators.

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CHAPTER 8

DC MOTORS

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Although ac motors are utilized the majority of the time, DC motors are utilized for a variety of purposes.A rotating magnetic field is created when the coils are turned on and off sequentially. This field interacts with the various fields of the stator's stationary magnets to produce torque, which causes the stator to rotate. DC motors are able to transform electrical energy from direct current into mechanical energy through rotation, which can then be used for object propulsion thanks to these fundamental operating principles. In many ways, this amazing piece of electrical equipment has changed how we live, similar mechanisms were developed by a large number of people, as is the case with all significant innovations. In the United States, Thomas Davenport is widely regarded as the inventor of the first electric motor. He was also, without a doubt, the first to patent an electric motor that could be used in 1837.

However, Davenport was not the first person to construct an electric motor; by the time Davenport filed his patent, a number of European inventors had already developed versions that were more powerful. The first practical DC motor was invented in 1886 by Frank Julian Sprague, whose invention led to the first motor-powered trolley system in 1887 and the first electric elevator in 1892. In 1835, Sibrandus Stratingh and Christopher Becker were the first to demonstrate a practical application for an electric motor by running a small model car. In 1834, Moritz Jacobi had presented a motor that was three times as powerful as the one that Davenport would later patent. The DC motor developed by Sprague was a significant advance that led to a variety of applications that would alter the nature of manufacturing and industry. Industrial fans, pumps, machine tools, household appliances, power tools, automobiles, and a wide range of drives all make use of electric motors. As you can see, electric watches also have tiny motors. As a generator, electric motors can also be used to recover energy lost through friction and heat. Both linear and continuous rotation are supported by the electric motor[1]–[3].

Nowadays three-phase synchronous motor is usable in highly dynamic applications and electrical devices. In 1887, the synchronous motor was first developed by Friedrich August. Nowadays we can see that use of motors is increasing day by day and it will be very beneficial in any field. DC motors use magnetic fields that occur from the electrical generated, which powers the movement of a rotor fixed within the output shaft. The output torque and speed depends upon both the electrical input and the design of the motor. The term 'DC motor' is used to refer to any rotary electrical machine that converts direct current electrical energy into mechanical energy. DC motors can vary in size and power from minor motors in toys and appliances to large mechanisms that power vehicles, pull elevtors and hosts, and drive steel rolling mills.

DC motors

A direct current (DC) motor is a type of electric machine that converts electrical energy into mechanicl energy. DC motors take electrical power through direct current, and convert this energy into mechanical rotation. DC motors use magnetic fields that occur from the electrical generated, which powers the movement of a rotor fixed within the output shaft. The output torque and speed depends upon both the electrical input and the design of the motor. The term ‘DC motor’ is used to refer to any rotary electrical machine that converts direct current electrical energy into mechanical energy. DC motors can vary in size and power from minor motors in toys and appliances to large mechanisms that power vehicles, pull elevators and hosts, and drive steel rolling mills.

Principle of DC motor:

A machine that converts dc power into mechanical energy is known as dc motor. The principle of motor based on the fact that “when a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force. The direction of the force is given by Fleming’s left hand rule”, as shown in the Figure 8.1.

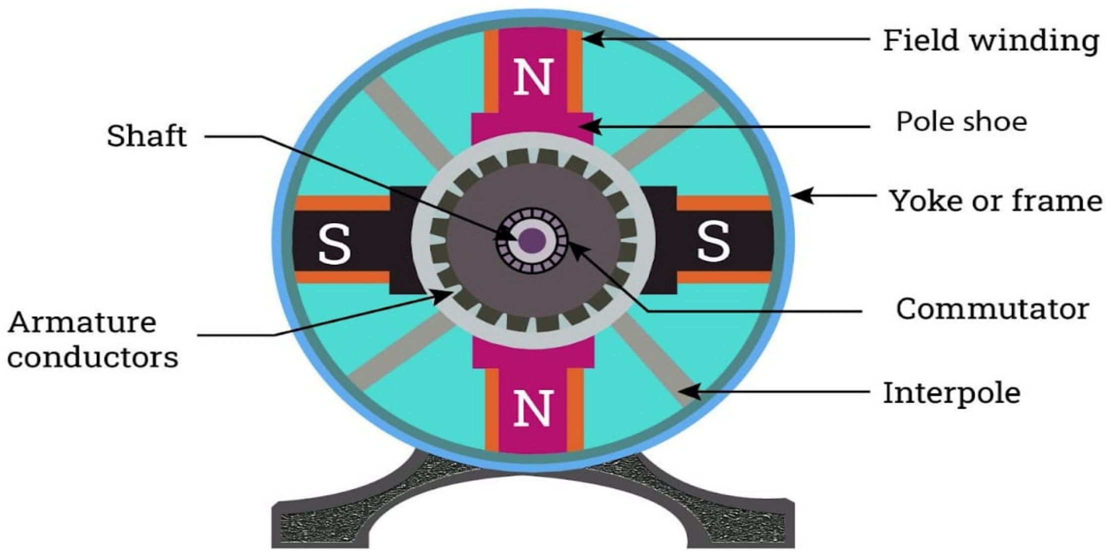

Figure 8.1: Construction of DC motor

There are six important construction parts of a simple motor, as they follows and explained in an expand version below:

Yoke or frame: The yoke is the hollow cylinder of cast or rolled steel that serves as the DC motor's outer frame. The field pole core is supported by the yoke, which also serves as a protective cover for the machine and also it provides a route for the field winding's magnetic flux.

Magnetic field winding: The machine's stationary component is the DC motor's magnetic field system. It is the primary source of the motor's magnetic flux. It consists of a field winding wound around an even number of pole cores that are bolted to the yoke. The pole shoe serves two purposes: first, it provides the field coils with support and secondly by increasing its cross-sectional area, it reduces the resistance of the magnetic circuit. To reduce eddy current loss, the pole cores are made of thin sheet steel laminations that are insulated from one another. The field coils are connected in series with one another so that the north and south poles change when current flows through them.

Armature core: The DC motor's armature core rotates between the field poles and is mounted on the shaft. The armature conductors are inserted into slots on its outer surface. Soft steel laminations that are tightly clamped together and insulated from one another make up the armature core. The laminations are mounted on a spider in large machines, whereas they are keyed directly to the shaft in small machines. The eddy current loss is reduced by using the laminated armature core as shown in below Figure 8.2.

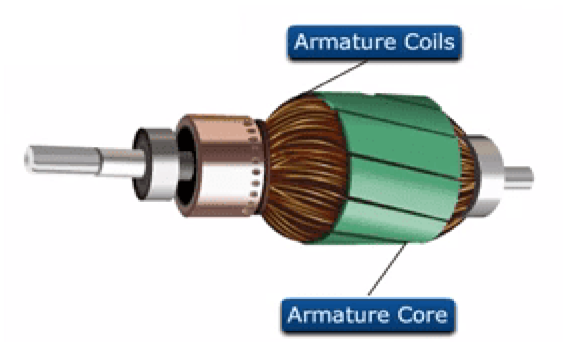

Figure 8.2: Armature core of DC Motors

Armature winding: The armature core's slots are filled with insulated conductors. The connections between the conductors are correct. The term "armature winding" refers to this connected arrangement of conductors. Wave winding and lap winding are the two types of armature windings that are utilized.

Commutator and Brushes: The mechanical rectifier known as a commutator transforms the direct current that is supplied to the motor by the DC source into alternating current that is carried by the armature winding. Copper segments in the shape of wedges make up the commutator, which is separated from the shaft and each other by mica sheets. The ends of the armature coils are connected to each segment of the commutator. The current from the DC source is injected into the armature windings by means of the brushes, which are mounted on the commutator. The carbon brushes are supported by a metal box known as the brush holder. With the help of springs, the commutator's pressure on the brushes can be changed and kept constant. Carbon brushes and a commutator carry the current from the external DC source to the armature winding. The diagram shown below shows the commutator and brushes in the Figure 8.3[4]–[6].

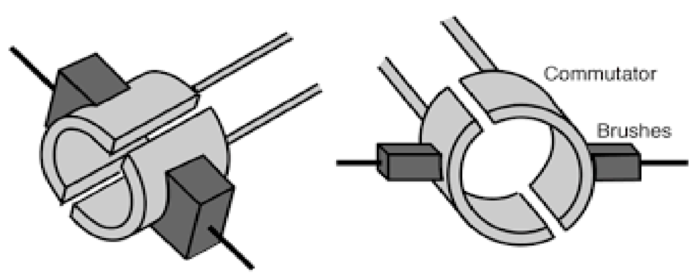

Figure 8.3: Commutator and Brushes of DC motors

Principle of Working of DC Motor

Let's understand a DC motor with two poles, as depicted in the figure given below. The field coils are excited, resulting in the formation of alternate N and S poles, and a current flows through the armature windings when the DC motor is connected to an external DC supply, as shown in the Figure 8.4.

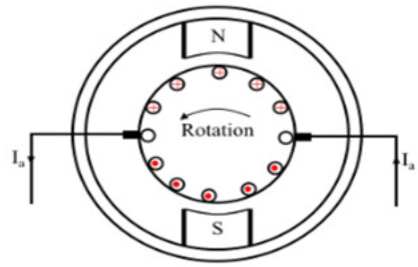

Figure 8.4: Working of DC motor

While all of the armature conductors at the N pole carry current in one direction, all of the conductors at the S pole carry current in the opposite direction. A mechanical force is exerted on each conductor because it is subjected to a magnetic field and is carrying a current.

Applying Fleming's left hand rule reveals that the armature tends to move in an anticlockwise direction due to the force exerted on each conductor. The torque that causes the armature to rotate is the result of the combined force exerted on each conductor. The conductor's current is reversed and influenced by the next pole of the opposite polarity when the conductor moves from one side of a brush to the other. The direction of force exerted on the conductor remains unchanged as a result. As a result, the motor is reversing its course.

Types of DC motor: In today's engineering and technology, a DC motor, also known as a direct current motor, can be used for many different things. DC motors are found in everything, from automobiles to electric shavers. Different kinds of DC motors are used for different kinds of applications to cover this wide range as shown in Figure 8.5.

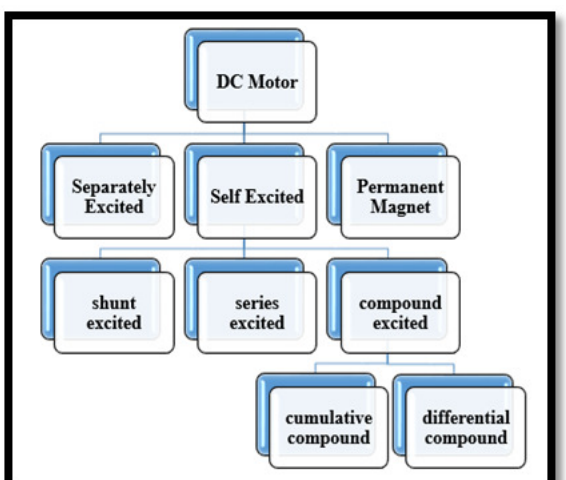

Figure 8.5: Different types of DC motor

There are following different types of DC motor:

1) Permanent Magnet DC Motors
2) Separately-Excited DC Motors
3) Self-Excited DC Motors:
4) Self-motors are further classified into three types:
    a. Series Wound DC Motor
    b. Shunt Wound DC Motor
    c. Compound Wound DC Motor

Permanent Magnet DC Motors

Permanent magnet DC motors are DC motors in which the main field flux is generated by permanent magnets. For the purpose of providing electrical power to the armature, this kind of DC motor requires only one external DC supply source. DC permanent magnet motors are typically utilized in toys and other small-scale applications. Permanent magnet can be shown in the given below in the Figure 8.6.

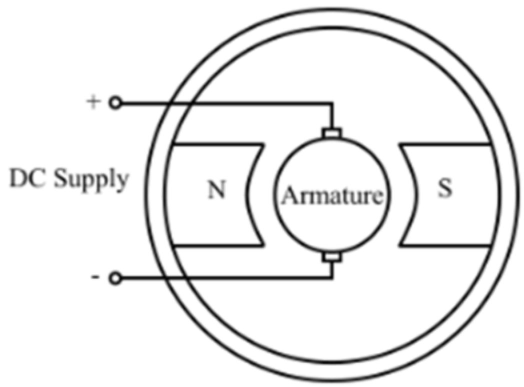

Figure 8.6: Permanent Magnet DC Motors

Separately-Excited DC Motors

The main field winding of a separately excited DC motor is excited by an external DC supply. A doubly-excited motor, the separately-excited dc motor requires two DC supply sources—one for the armature and another for the field winding's excitation as shown in below Figure 8.7.

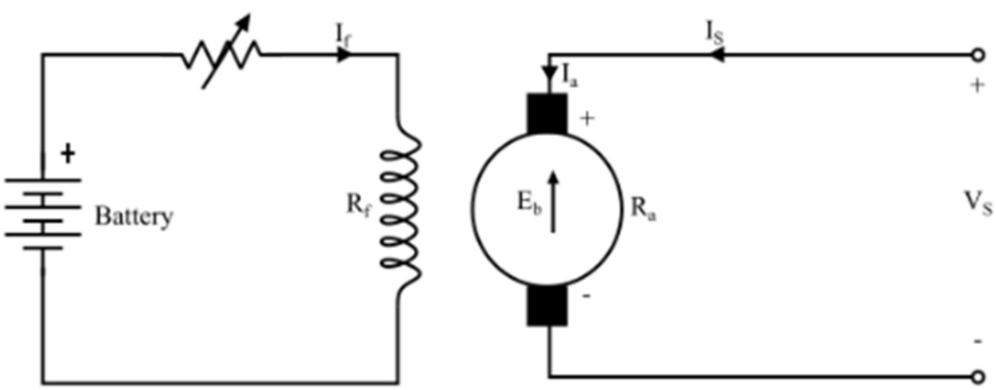

Figure 8.7: Separately-Excited DC Motors

Here,
Armature current, Ia = Is

The Supply voltage, Vs = Eb + IaRa

The developed Electric power in armature is given as = EbIa

Self-Excited DC Motors

This can be broken down into the following sections as given below because the shunt winding is connected to the armature winding in series or parallel, either partially or completely.

1. **Series Wound DC Motor**
   A series-wound DC motor is one in which the field winding and the armature winding are connected in series because the entire armature current is carried by the series field winding. As a result, the series field winding should have a low resistance due to the small number of turns of thick wire. Because it is connected in series to the armature winding in this instance, the entire armature current flows through the field winding. For better comprehension, the self-excited dc motor that is wound in series is depicted in a diagram. The speed of a series-wound dc motor varies with load. Additionally, this is its primary operational distinction from a shunt wound dc motor, as shown in the Figure 8.8.

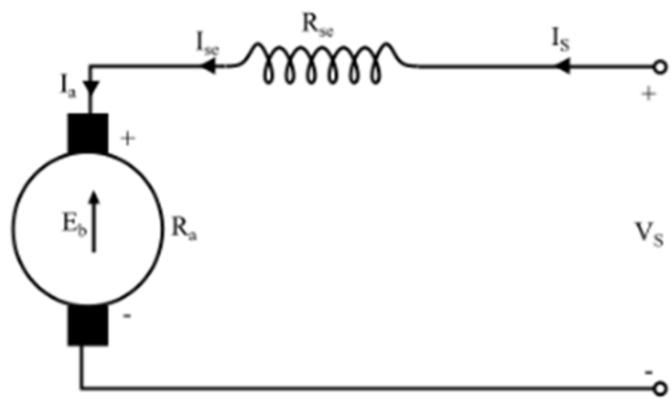

Figure 8.8: Series Wound Self-Excited DC Motor

Here,

Armature current, Ia = Ise

The voltage supply of series wound DC, VS = Eb + IseRse + IaRa = Eb + Ia(Ra+Rse)

Applications of series-wound DC motor: The variable speed of the series DC motors means that their speed is low at high torque and vice versa. Despite this, the motor travels at a dangerously high speed even when only lightly loaded. The starting torques of the series motors are high. As a result, they are utilized in the following contexts:

1) It is used in elevators, electric traction systems, cranes, and other devices requiring a significant starting torque.

2) It is used in situations where the load is subject to significant fluctuations and the speed needs to be automatically adjusted to meet load requirements.
3) Additionally utilized in vacuum cleaners, hair dryers, sewing machines, and air compressors.

2. Shunt Wound DC Motor

The field winding and the armature winding are connected in parallel in a shunt wound DC motor. In a shunt wound motor, the field winding is connected in parallel with the armature. The shunt field windings are designed to have high resistance, i.e., a large number of turns of fine wire, so that the shunt field current is relatively smaller than the armature current. The armature current and the current that flows through the shunt field winding are not the same thing. Shunt field windings are constructed to generate the required MMF by means of a relatively large number of high-resistance wire turns. As a result, the armature current is significantly larger than the shunt field current, as shown in the Figure 8.9[7]–[10].

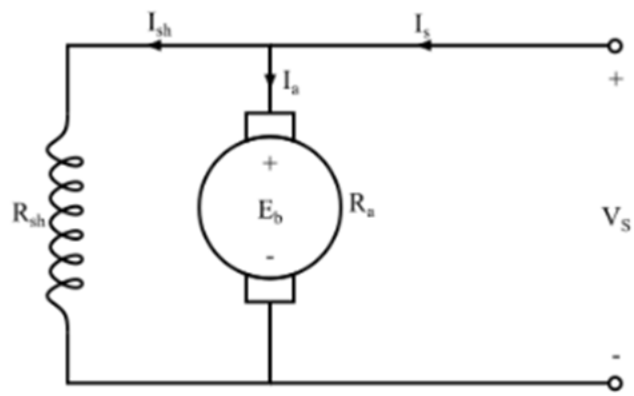

Figure 8.9: Shunt Wound DC Motor

Because they are connected in parallel to the armature winding as depicted in the figure, the field windings in this instance are exposed to the entire terminal voltage. The shunt wound dc motor has a constant speed because the mechanical load on the output does not change its speed. It falls under the Self-excited DC Motor category.

Here,

The Armature current, Ia = Is – Ish

The current in the Shunt field in shunt DC motor, Ish = Vs x Rsh

The voltage is supplied by Shunt DC motor, Vs = Eb + IaRa

Applications of Shunt DC motor:

Shunt motors operate at a constant speed. As a result, the following applications call for their use:

i. It is applicable in a situation in which speed must remain constant from no load to full load.
ii. It is utilized in boring mills, lathes, drills, sharpeners, spinning and weaving machines, and so on.

3. **Compound Wound DC Motor**

A compound wound DC motor is one in which the series field and the shunt field are combined. Combining the operational characteristics of the shunt and series excited DC motors yields the compound excitation characteristic of a DC motor. The field winding is connected to the armature winding in both series and parallel in the compound wound self-excited DC motor, also known as the compound wound DC motor.

Combining the operational characteristics of the shunt and series-excited dc motors results in the compound excitation characteristic of a dc motor. The field winding is connected to the armature winding in both series and parallel in the compound wound self-excited dc motor, or simply the compound wound dc motor as shown below in the Figure 8.10.

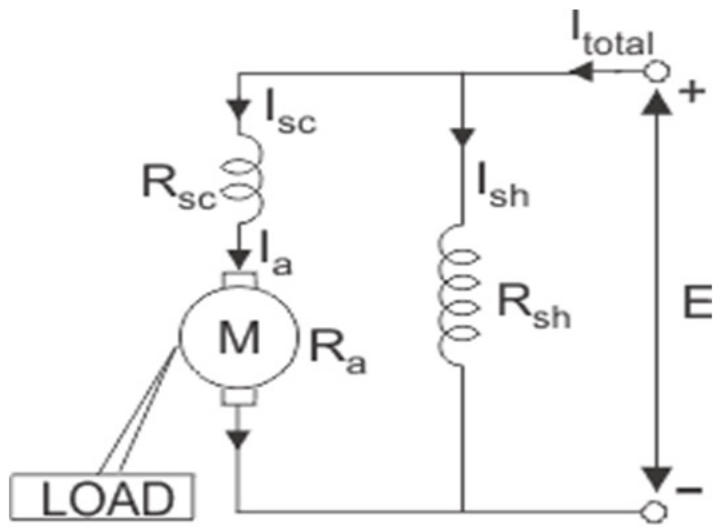

Figure 8.10: Compound Wound DC Motor

Depending on the nature of the compounding, the compounded dc motor can excite in two ways.

Cumulative Compound DC Motor:

Shunt field flux helps the main field flux produced by the main field connected in series to the armature winding in a cumulative compound DC motor.

Φ total = φ series + φ shunt.

Differential compound dc motor:

A differential compound dc motor has shunt and series windings arranged in such a way that the effect of flux from the main series field winding is lessened by the shunt field flux. Since the net flux produced in this instance is less than the initial flux, its application is limited.

Φ total = φ series – φ shunt

Depending on the arrangement, the cumulative compound and differential compound dc motors can be **short shunt** or **long shunt**.

i. **Short Shunt compound DC Motor:** If the armature winding is only parallel to the shunt field winding and not the series field winding, the motor is also known as a short shunt type compound wound dc motor. A short shunt DC motor is nothing more than a pair of parallel arms. DC shunt motors are used in devices that require speed control, as depicted in the below Figure 8.11.

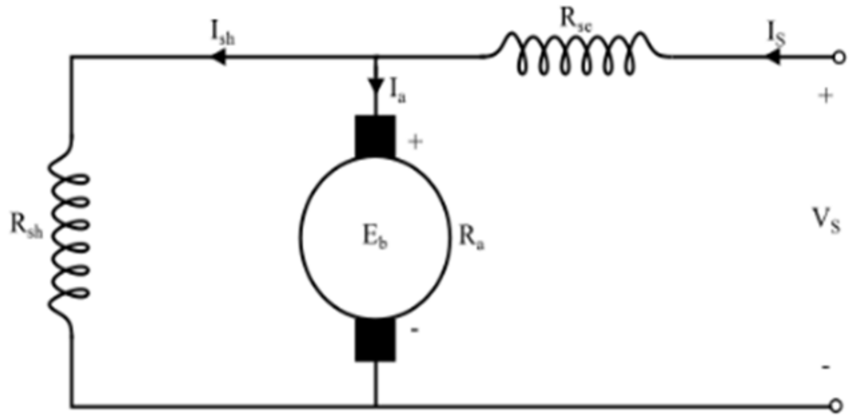

Figure 8.11: Short Shunt compound DC Motor:

ii. **Long Shunt compound DC Motor:** If the shunt field winding is parallel to both the armature winding and the series field winding, then it is referred to as a long shunt type compounded wound dc motor or simply long shunt dc motor. Its primary application is in centrifugal pumps, which produce constant flux.The motor is referred to as a long-shunt compound motor when the shunt field winding is connected parallel to the series combination of the armature winding and the series field winding as shown in the given below Figure 8.12.

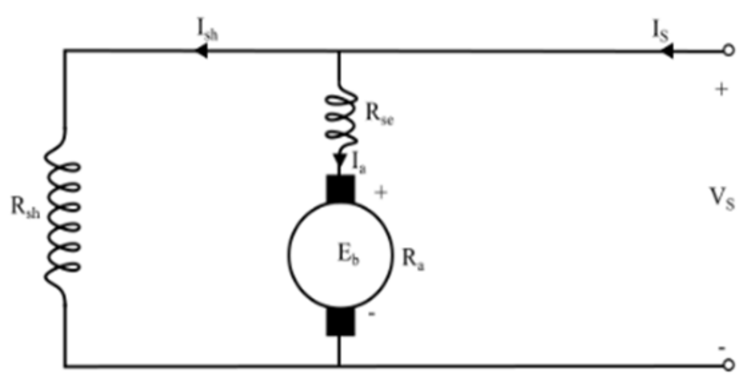

Figure 8.12: Long Shunt compound DC Motor

A compound motor is referred to as a cumulative compound motor when both the series field flux and the shunt field flux are moving in the same direction. On the other hand, a differential compound motor is referred to when both the series field flux and the shunt field flux are moving in the opposite direction. The magnetic flux produced by the shunt field winding is always greater than that produced by the series field winding in compound DC machines either motor or generators.

Applications of compound excited DC motor:

Due to their poor torque characteristics, differentially-compound motors are rarely utilized. However, applications requiring constant speed and sudden application of heavy loads, such as presses, reciprocating machines, and shears, utilize cumulatively-compound motors.

Commutation in a DC Motor

To exert unidirectional force (or torque) on a motor's armature conductors, the conductors under any pole must always carry the same current. In a dc motor, the commutator and brush gear reverse the current flowing through a conductor as it moves from one side of a brush to the other.

Voltage Equation of Motors

Let us calculate the voltage equation in a DC motor, as follows given below in the Figure 8.13.

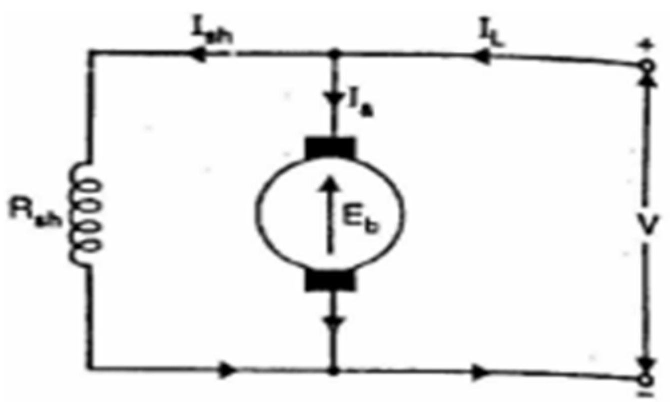

Figure 8.13: voltage equation of DC motor

As per the diagram shown above. Let's consider the following parameters:

V = the applied voltage

Eb = back EMF

Ra = armature resistance of DC motor

Ia = armature current Since back EMF

Eb acts opposite to the applied voltage V, the net voltage across the armature circuit is V- Eb.

The armature current Ia is given by: Ia = V- Eb / Ra --------------- (1)

V = Eb + IaRa ------------ (2)

The equation 2 is known as voltage equation of the DC motor.

Condition for maximum power:

Because V and Ra are fixed, the motor's mechanical power is dependent on the armature current. dPm / dIa should be zero for maximum power. As a result, the motor generates the most mechanical power when operating backwards is equivalent to half the voltage applied.

So, Pm = Eb x Ia

dPm / dIa = 0

$$\frac{dP_m}{dI_a} = V - 2I_aR_a = 0$$

$$I_aR_a = \frac{V}{2}$$

$$V = E_b + I_aR_a = E_b + \frac{V}{2} \quad \therefore \quad E_b = \frac{V}{2}$$

The following are the Characteristics of a DC motor:

The relationship between the speed, torque, and current in the armature of a DC motor indicates its performance. These relationships are represented graphically in the form of curves, which are known as DC motor characteristics. The DC motor's behavior under various load conditions is demonstrated by these characteristics.

I. **Torque and armature current characteristics (Ta / Ia):** It shows the curve between armature torque and armature current of a dc motor.It is also called as electrical characteristics of the DC motor as shown in the given below Figure 8.14.

Ta ∝ φIa
Ta ∝ Ia

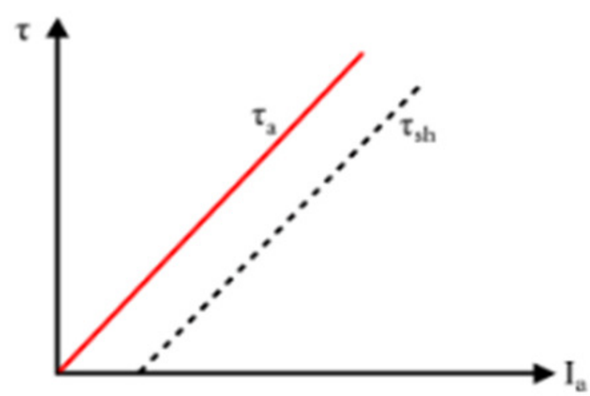

Figure 8.14: Ta / Ia characteristics

II. **Speed and armature current characteristics (N / Ia):** It is the graph plot between speed and armature current, as shown in the given Figure 8.15.

N ∝ Eb

∵ Eb = V−IaRa

$\therefore N \propto (V - I_a R_a)$

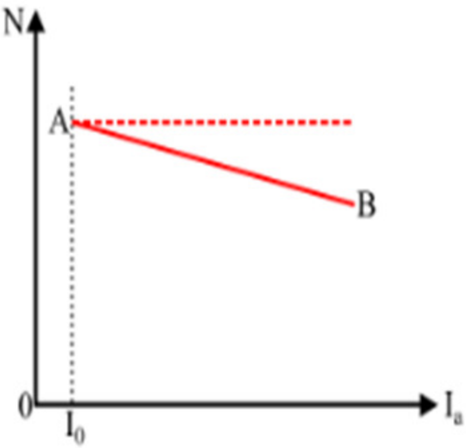

Figure 8.15: N / Ia characteristics

III. **Speed and torque characteristics (N / Ta):** It is the graph plot between speed and armature torque. It is clearly shows the speed of the shunt motor reduces as the load torque increases as shown in the given below Figure 8.16.

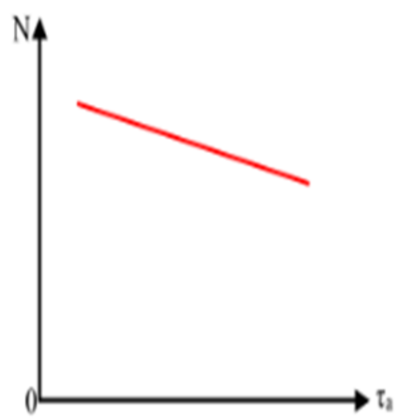

Figure 8.16: N / Ta characteristics

In this chapter we learn about the basic introduction of DC motors and construction and working of DC motors. Later we focused on the components or parts of DC motors and we learn about the basic types of DC motors and characteristics of DC motors. Motors play a vital role in today's engineering and technology, a DC motor is used for various purpose and it proves to be very useful for the electrical technology.

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CHAPTER 9

CHARACTERISTICS OF SERIES, SHUNT AND COMPOUND DC MOTORS

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In this we basically discussed about the characteristics of series, shunt and compound motors. The relationship between the speed, torque, and current in the armature of a DC motor indicates its performance. These relationships are represented graphically in the form of curves, which are known as DC motor characteristics. The DC motor's behavior under various load conditions is demonstrated by these characteristics. Although ac motors are utilized the majority of the time, DC motors are utilized for a variety of purposes. A rotating magnetic field is created when the coils are turned on and off sequentially. This field interacts with the various fields of the stator's stationary magnets to produce torque, which causes the stator to rotate. DC motors are able to transform electrical energy from direct current into mechanical energy through rotation, which can then be used for object propulsion thanks to these fundamental operating principles. In many ways, this amazing piece of electrical equipment has changed how we live, similar mechanisms were developed by a large number of people, as is the case with all significant innovations[1]–[3].

A compound motor is referred to as a cumulative compound motor when both the series field flux and the shunt field flux are moving in the same direction. On the other hand, a differential compound motor is referred to when both the series field flux and the shunt field flux are moving in the opposite direction. The magnetic flux produced by the shunt field winding is always greater than that produced by the series field winding in compound DC machines (motors or generators). Industrial fans, pumps, machine tools, household appliances, power tools, automobiles, and a wide range of drives all make use of electric motors. As you can see, electric watches also have tiny motors. As a generator, electric motors can also be used to recover energy lost through friction and heat. Both linear and continuous rotation are supported by the electric motor. Nowadays we can see that use of motors is increasing day by day and it will be very beneficial in any field. DC motors use magnetic fields that occur from the electrical generated, which powers the movement of a rotor fixed within the output shaft. The output torque and speed depends upon both the electrical input and the design of the motor. The term 'DC motor' is used to refer to any rotary electrical machine that converts direct current electrical energy into mechanical energy. DC motors can vary in size and power from minor motors in toys and appliances to large mechanisms that power vehicles, pull elevtors and hosts, and drive steel rolling mills.

DC motors

A direct current (DC) motor is a type of electric machine that converts electrical energy into mechanicl energy. DC motors take electrical power through direct current, and convert this energy into mechanical rotation. DC motors use magnetic fields that occur from the electrical generated, which powers the movement of a rotor fixed within the output shaft. The output torque and speed depends upon both the electrical input and the design of the motor. The term

‘DC motor’ is used to refer to any rotary electrical machine that converts direct current electrical energy into mechanical energy. DC motors can vary in size and power from minor motors in toys and appliances to large mechanisms that power vehicles, pull elevtors and hosts, and drive steel rolling mills.

Principle and Construction of DC motor:

A machine that converts dc power into mechanical energy is known as dc motor. The principle of motor based on the fact that “when a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force. The direction of the force is given by Fleming’s left hand rule”, as shown in the given Figure 9.1.

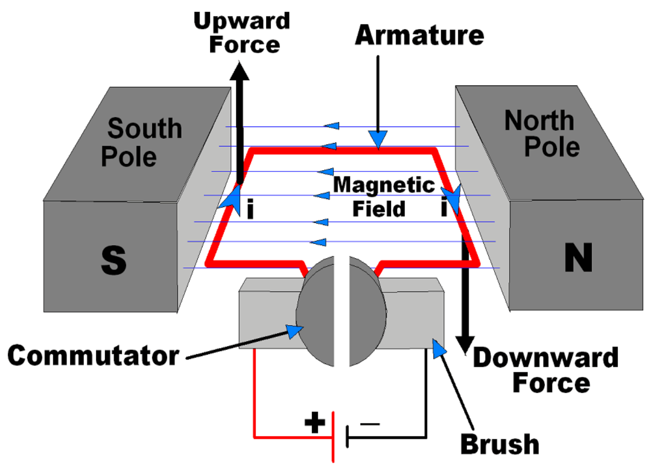

Figure 9.1: Construction of DC motor

There are six important construction parts of a simple motor:

Yoke or frame: The yoke is the hollow cylinder of cast or rolled steel that serves as the DC motor's outer frame.

Magnetic field winding: The machine's stationary component is the DC motor's magnetic field system. It is the primary source of the motor's magnetic flux. It consists of a field winding wound around an even number of pole cores that are bolted to the yoke.

Armature core: The DC motor's armature core rotates between the field poles and is mounted on the shaft. The armature conductors are inserted into slots on its outer surface. Soft steel laminations that are tightly clamped together and insulated from one another make up the armature core. The laminations are mounted on a spider in large machines, whereas they are keyed directly to the shaft in small machines. The eddy current loss is reduced by using the laminated armature core.

Armature winding: The armature core's slots are filled with insulated conductors. The connections between the conductors are correct. The term "armature winding" refers to this connected arrangement of conductors. Wave winding and lap winding are the two types of armature windings that are utilized.

Commutator and Brushes: The mechanical rectifier known as a commutator transforms the direct current that is supplied to the motor by the DC source into alternating current that is carried by the armature winding. Copper segments in the shape of wedges make up the commutator, which is separated from the shaft and each other by mica sheets. The ends of the armature coils are connected to each segment of the commutator. The current from the DC source is injected into the armature windings by means of the brushes, which are mounted on the commutator. The carbon brushes are supported by a metal box known as the brush holder. With the help of springs, the commutator's pressure on the brushes can be changed and kept constant. Carbon brushes and a commutator carry the current from the external DC source to the armature winding. The diagram shown below shows the commutator in the Figure 9.2.

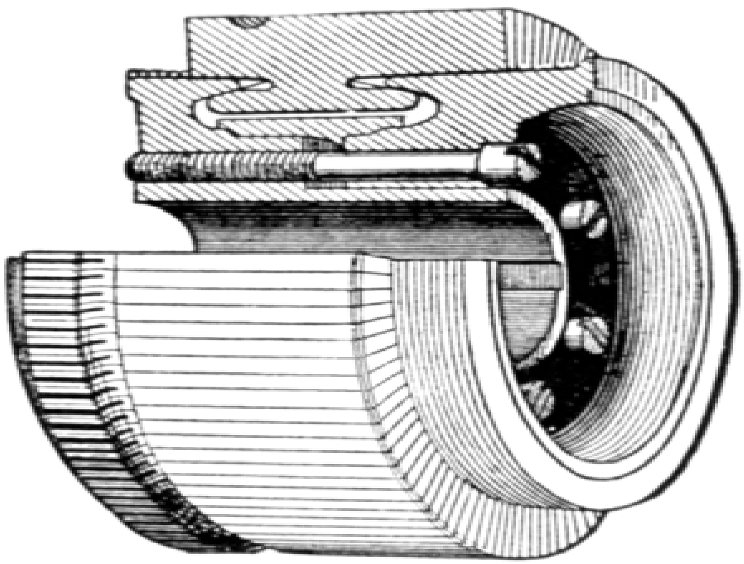

Figure 9.2: Commutator of DC Motor

Working of DC motor

Let's understand a DC motor with two poles, as depicted in the figure given below. The field coils are excited, resulting in the formation of alternate N and S poles, and a current flows through the armature windings when the DC motor is connected to an external DC supply, as shown in the Figure 9.3.

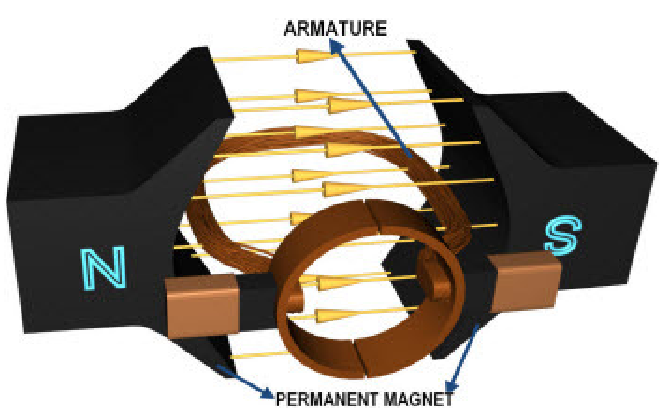

Figure 9.3: Working of DC motor

While all of the armature conductors at the N pole carry current in one direction, all of the conductors at the S pole carry current in the opposite direction. A mechanical force is exerted on each conductor because it is subjected to a magnetic field and is carrying a current.

Applying Fleming's left hand rule reveals that the armature tends to move in an anticlockwise direction due to the force exerted on each conductor. The torque that causes the armature to rotate is the result of the combined force exerted on each conductor. The conductor's current is reversed and influenced by the next pole of the opposite polarity when the conductor moves from one side of a brush to the other. The direction of force exerted on the conductor remains unchanged as a result. As a result, the motor is reversing its course[4]–[6].

Types of DC motor: In today's engineering and technology, a DC motor, also known as a direct current motor, can be used for many different things. DC motors are found in everything, from automobiles to electric shavers. Different kinds of DC motors are used for different kinds of applications to cover this wide range as shown below Figure 9.4.

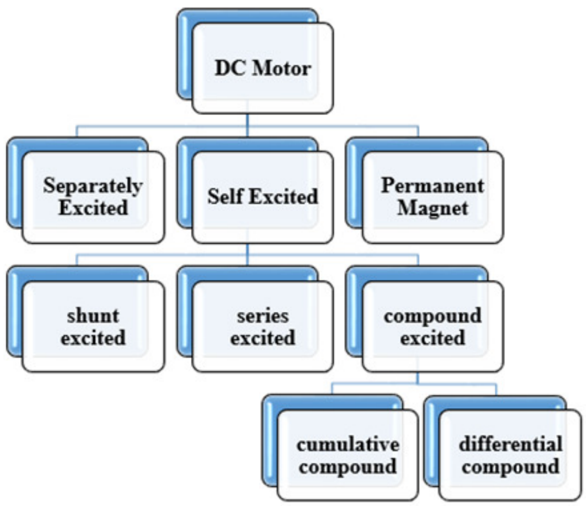

Figure 9.4: Different types of DC motor

There are following different types of DC motor:

- Permanent Magnet DC Motors
- Separately-Excited DC Motors
- Self-Excited DC Motors
    1. Series Wound DC Motor
    2. Shunt Wound DC Motor
    3. Compound Wound DC Motor

In this we basically discussed about the characteristics of series, shunt and compound motors.

Self-Excited DC Motors

This can be broken down into the following sections as given below because the shunt winding is connected to the armature winding in series or parallel, either partially or completely.

1) Series Wound DC Motor

A series wound DC motor is one in which the field winding and the armature winding are connected in series because the entire armature current is carried by the series field winding. As a result, the series field winding should have a low resistance due to the small number of turns of thick wire. Because it is connected in series to the armature winding in this instance, the entire armature current flows through the field winding. For better comprehension, the self-excited dc motor that is wound in series is depicted in a diagram. The speed of a series wound dc motor varies with load. Additionally, this is its primary operational distinction from a shunt wound dc motor, as shown in the Figure 9.5.

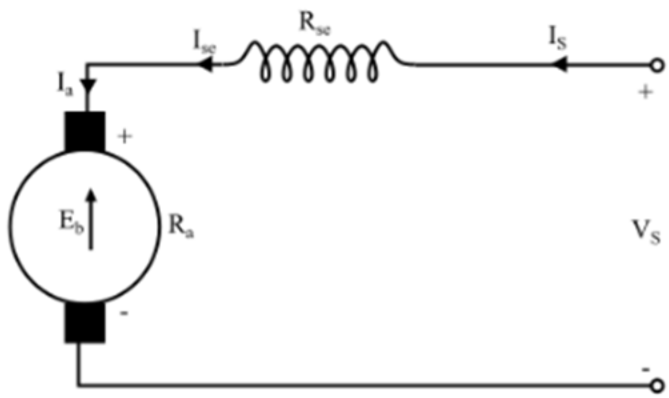

Figure 9.5: Series Wound Self-Excited DC Motor

Here,

Armature current, Ia = Ise

The voltage supply of series wound DC, VS = Eb + IseRse + IaRa = Eb + Ia(Ra+Rse)

Applications of series wound DC motor: The variable speed of the series DC motors means that their speed is low at high torque and vice versa. Despite this, the motor travels at a dangerously high speed even when only lightly loaded. The starting torques of the series motors are high. As a result, they are utilized in the following contexts:

- **a.** It is used in elevators, electric traction systems, cranes, and other devices requiring a significant starting torque.
- **b.** It is used in situations where the load is subject to significant fluctuations and the speed needs to be automatically adjusted to meet load requirements.
- **c.** Additionally utilized in vacuum cleaners, hair dryers, sewing machines, and air compressors.

2) Shunt Wound DC Motor

The field winding and the armature winding are connected in parallel in a shunt wound DC motor. In a shunt wound motor, the field winding is connected in parallel with the armature. The shunt field windings are designed to have high resistance, i.e., a large number of turns of fine wire, so that the shunt field current is relatively smaller than the armature current. The armature current and the current that flows through the shunt field winding are not the same thing. Shunt field windings are constructed to generate the required MMF by means of a relatively large number of high-resistance wire turns. As a result, the armature current is significantly larger than the shunt field current, as shown in the Figure 9.6.

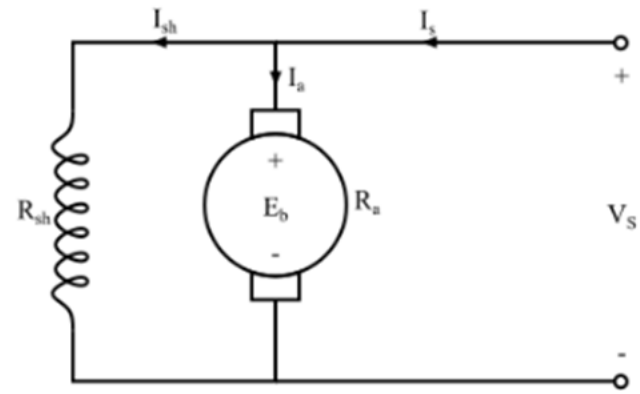

Figure 9.6: Shunt Wound DC Motor

Because they are connected in parallel to the armature winding as depicted in the figure, the field windings in this instance are exposed to the entire terminal voltage. The shunt wound dc motor has a constant speed because the mechanical load on the output does not change its speed. It falls under the Self-excited DC Motor category.

Here,

The Armature current, Ia = Is – Ish

The current in the Shunt field in shunt DC motor, Ish = VsRsh

The voltage is supplied by Shunt DC motor, Vs = Eb + IaRa

Applications of Shunt DC motor:

Shunt motors operate at a constant speed. As a result, the following applications call for their use:

- **a.** It is applicable in a situations in which speed must remain constant from no load to full load.
- **b.** It is utilized in boring mills, lathes, drills, sharpeners, spinning and weaving machines, and so on.

3) Compound Wound DC Motor

A compound wound DC motor is one in which the series field and the shunt field are combined. Combining the operational characteristics of the shunt and series excited DC motors yields the compound excitation characteristic of a DC motor.

The field winding is connected to the armature winding in both series and parallel in the compound wound self-excited DC motor, also known as the compound wound DC motor. Combining the operational characteristics of the shunt and series-excited dc motors results in the compound excitation characteristic of a dc motor. The field winding is connected to the armature winding in both series and parallel in the compound wound self-excited dc motor, or simply the compound wound dc motor as shown below in the Figure 9.7.

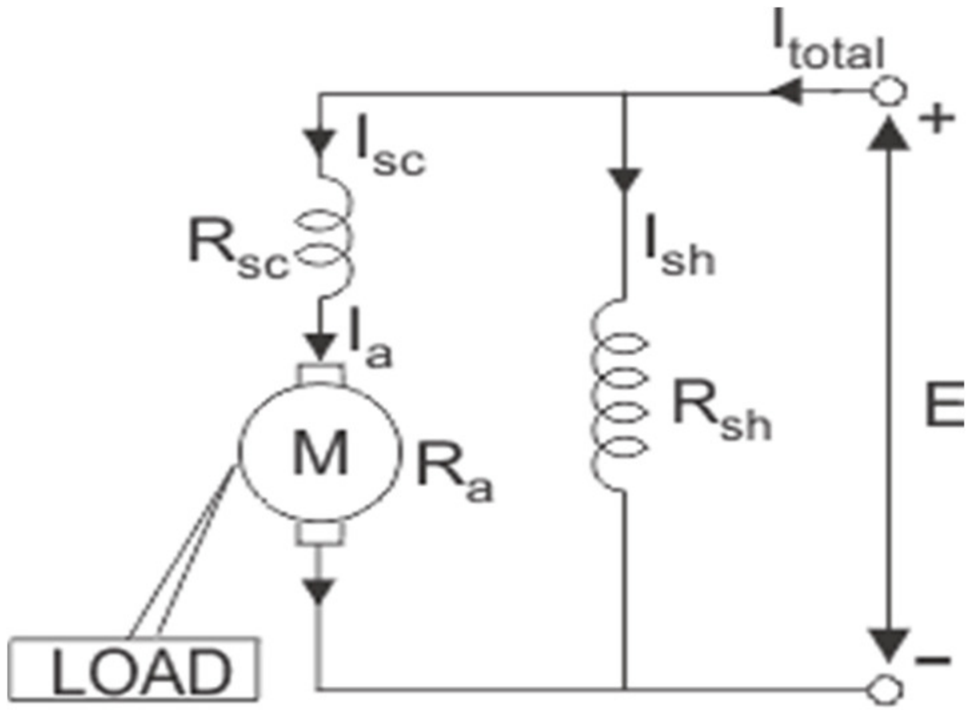

Figure 9.7: Compound Wound DC Motor

Depending on the nature of the compounding, the compounded dc motor can excite in two ways.

Cumulative Compound DC Motor:
Shunt field flux helps the main field flux produced by the main field connected in series to the armature winding in a cumulative compound DC motor.

Φ total = φ series + φ shunt.

Differential compound dc motor:
A differential compound dc motor has shunt and series windings arranged in such a way that the effect of flux from the main series field winding is lessened by the shunt field flux. Since the net flux produced in this instance is less than the initial flux, its application is limited.

Φ total = φ series – φ shunt

Depending on the arrangement, the cumulative compound and differential compound dc motors can be **short shunt** or **long shunt**.

i. **Short Shunt compound DC Motor:** If the armature winding is only parallel to the shunt field winding and not the series field winding, the motor is also known as a short shunt type compound wound dc motor. A short shunt DC motor is nothing more than a pair of parallel arms. DC shunt motors are used in devices that require speed control, as depicted in the Figure 9.8.

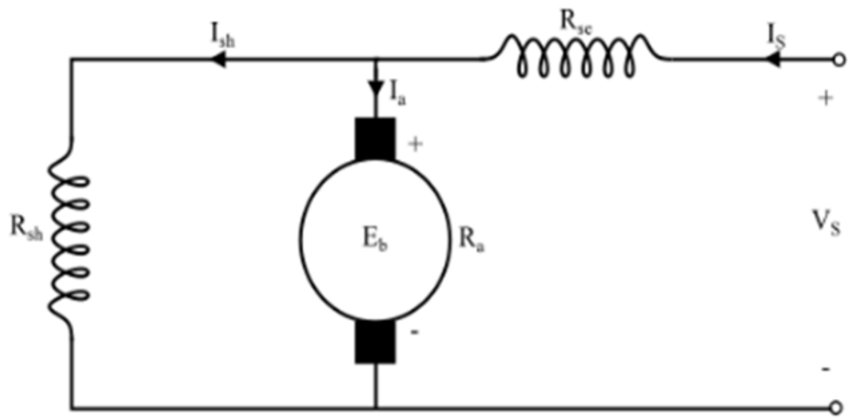

Figure 9.8: Short Shunt compound DC Motor:

ii. **Long Shunt compound DC Motor:** If the shunt field winding is parallel to both the armature winding and the series field winding, then it is referred to as a long shunt type compounded wound dc motor or simply long shunt dc motor. Its primary application is in centrifugal pumps, which produce constant flux.The motor is referred to as a long-shunt compound motor when the shunt field winding is connected parallel to the series combination of the armature winding and the series field winding as shown given below Figure 9.9.

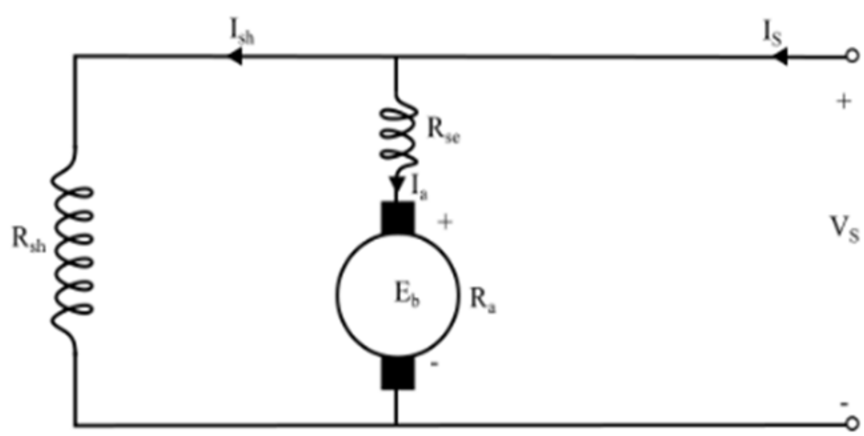

Figure 9.9: Long Shunt compound DC Motor

A compound motor is referred to as a cumulative compound motor when both the series field flux and the shunt field flux are moving in the same direction. On the other hand, a differential compound motor is referred to when both the series field flux and the shunt field flux are moving in the opposite direction. The magnetic flux produced by the shunt field winding is always greater than that produced by the series field winding in compound DC machines.

The following are the Characteristics of a DC motor:

The relationship between the speed, torque, and current in the armature of a DC motor indicates its performance. These relationships are represented graphically in the form of curves, which are known as DC motor characteristics. The DC motor's behavior under various load conditions is demonstrated by these characteristics.

The three most important characteristics of a DC motor are:

Torque and armature current characteristics: A DC motor's armature torque (a) and armature current (Ia) are plotted on a graph. It is also known as the DC motor's electrical characteristics.

Speed and Armature Current Characteristics: The Characteristics of Speed and Armature Current as discussed when a DC motor's speed (N) and armature current (Ia) are plotted on a graph. This characteristic curve is mostly used to choose a motor for a specific use.

Speed and Torque Characteristics: A DC motor's speed-torque characteristics are the graph that shows the relationship between the speed (N) and the armature torque (a). It is also known as the DC motor's mechanical characteristics[7]–[10].

Characteristics of DC Shunt Motor:

Shunt motors are constant flux machines because their field winding is directly connected across the supply voltage, which is assumed to be constant. This means that their magnetic flux remains constant.

i. **Torque and armature current characteristics (Ta / Ia):** It shows the curve between armature torque and armature current of a dc motor.It is also called as electrical characteristics of the DC motor. A DC motor's armature torque is directly proportional to the flux and armature current, as shown in the given below Figure 9.10.

   $Ta \propto \varphi Ia$

   If talking to the shunt motor, flux is also fixed, then
   $Ta \propto Ia$

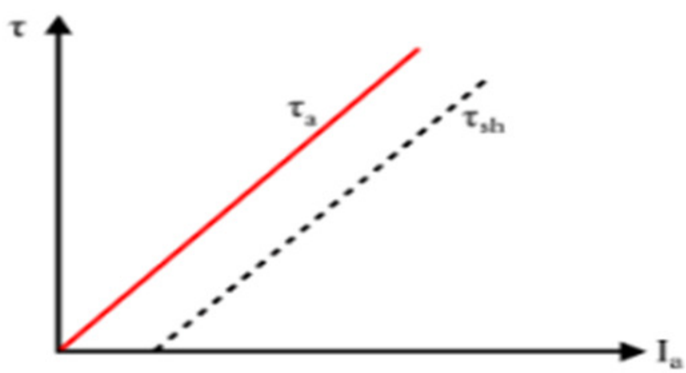

Figure 9.10: Illustration of characteristics of Ta / Ia of dc shunt motor

As a result, the DC shunt motor's torque and armature current characteristics are represented in the figure as a straight line passing through the origin. The armature torque, as shown by the dotted line, is greater than the shaft torque in the above figure. It is evident from the characteristics that a significant current is required to initiate a heavy load. As a result, heavy loads should not cause the shunt motor to start.

ii. **Speed and armature current characteristics (N / Ia):** It is the graph plot between speed and armature current, as shown in Figure 9.11.

$$N \propto Eb$$

$\because$ Eb = V−IaRa

$\therefore$N ∝ (V−IaRa)

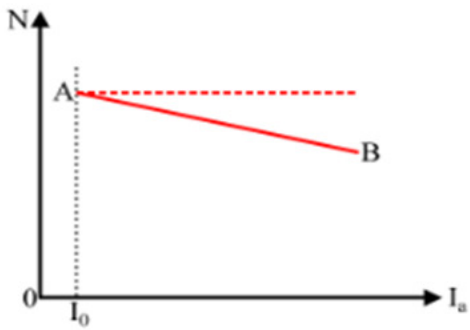

Figure 9.11: Illustration of characteristics of N / Ia of dc shunt motor

Under normal operating conditions, the back EMF and flux of a DC shunt motor are constant. As a result, the dotted line indicates that the speed of a shunt motor will remain constant in relation to the armature current. Back EMF and flux, on the other hand, decrease as load increases due to changes in armature reaction and resistance, respectively. Despite the fact that the flux decreases more rapidly than the back EMF, motor speed decreases slightly with load as line AB is shown in the above figure.

iii. **Speed and torque characteristics (N / Ta):** It is the graph plot between speed and armature torque. It is clearly shows the speed of the shunt motor reduces as the load torque increases as shown in the given below Figure 9.12.

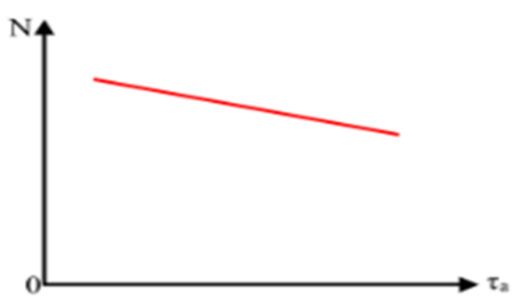

Figure 9.12: Illustration of characteristics of N / Ta of dc shunt motor

Characteristics of DC Series Motor:

The field winding of a DC series motor is connected in series with the armature, carrying the entire armature current in a DC series motor. The armature current also rises in tandem with the motor's shaft load. As a result, when the armature current rises, so does the flux in a series motor.

i. **Ta and Ia Characteristics:**

In a DC motor, characteristics is given below in the Figure 9.13

Ta ∝ φIa

Magnetic saturation, φ ∝ Ia; so that Ta ∝ Ia^2

After magnetic saturation φ is becomes constant so that Ta ∝ Ia

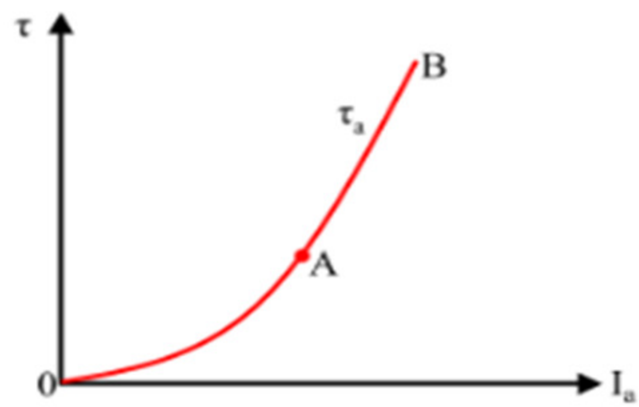

Figure 9.13: Illustration of characteristics of Ta / Ia of DC Series Motor

ii. **N / Ia characteristics:** The speed of a DC series motor can be calculated by,

N ∝ Ebφ; Where, Eb = V – Ia(Ra+Rse)

The flux goes up as the armature current goes up, but the back EMF goes down as a result of the ohmic drop in armature and series field resistances. Despite the fact that the resistance drop is negligible under typical operating conditions, as shown in Figure 9.14.

N ∝ 1/φ ∝ 1/ Ia ; Up to saturation point of magnetic

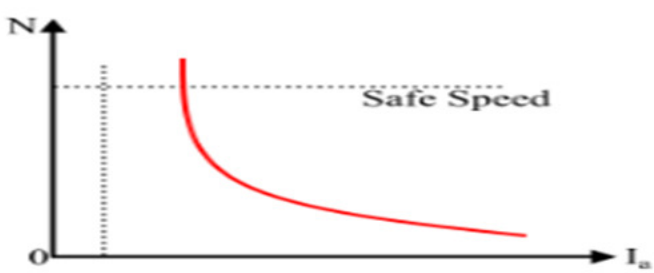

Figure 9.14: Illustration of characteristics of N / Ia of DC Series Motor

iii. **Speed and torque characteristics (N / Ta):** A DC series motor's speed-armature current and torque-armature current characteristics can be used to determine its speed-torque characteristics as follows: For a given value of Ia, deduce a from the curve of the torque-armature current and N from the curve of the speed-armature current. A point (Ta, N) on the speed-torque curve will result from this. Determine the speed and torque values (T1, N1), (T2, N2), and so on by repeating this procedure for various armature current values.

The speed and torque characteristics of a DC series motor can be seen in the figure when these points are plotted on the graph, shown below Figure 9.15.

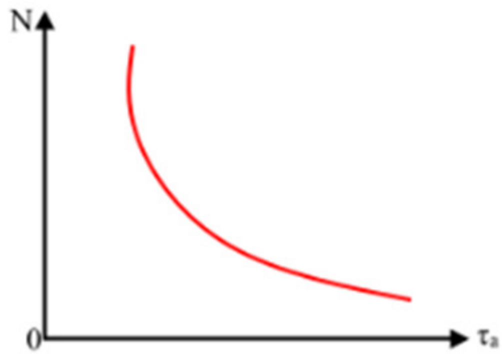

Figure 9.15: Illustration of characteristics of N / Ta of DC Series Motor

The flux and armature current are extremely small at no load. As a result, the speed rises to a dangerously high level, which has the potential to harm the machine. As a result, a series motor shouldn't be started with no load at all.

Characteristics of Compound wound DC Motor:

i. **Ta and Ia Characteristics:** The series field goes up when the armature current goes up, but the shunt field stays the same. Consequently, the armature torque and overall machine flux both rise as shown in the Figure 9.16.

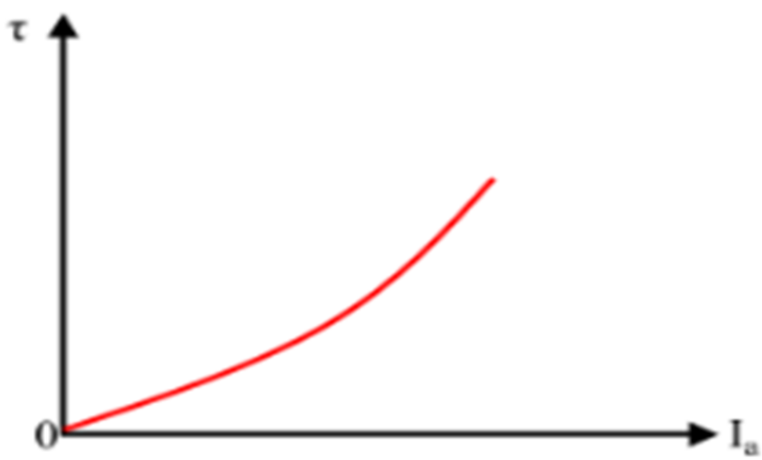

Figure 9.16: Illustration of characteristics of Ta / Ia of Compound DC Motor

ii. **N and Ia characteristics:** The flux per pole goes up when the load goes up and so does the armature current. As a result, as the load increases, the motor's speed decreases. As a result, a cumulative compound motor lacks control over speed as shown in given below Figure 9.17.

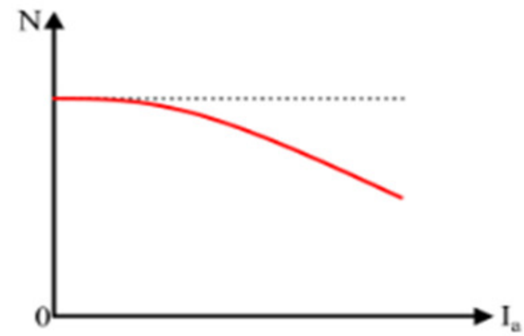

Figure 9.17: Illustration of characteristics of N / Ia of Compound DC Motor

iii. **N / Ta characteristics:** A cumulative compound motor has more torque than a shunt motor for the same armature current, but less torque than a series motor as shown in the given Figure 9.18.

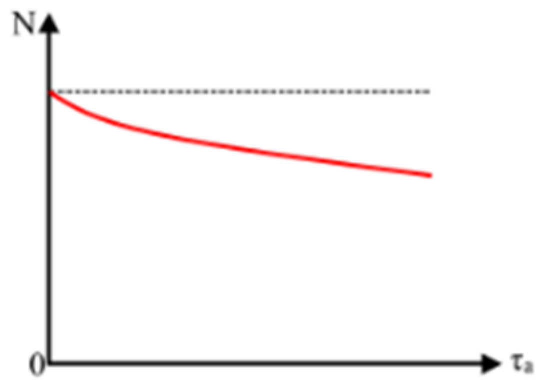

Figure 9.18: Illustration of characteristics of N / Ta of Compound DC Motor

In this chapter we learn about the basic introduction of DC motors and construction and working of DC motors. We especially focused on the characteristics of series, shunt and compound of DC motors and we learn about the basic types of DC motors. Motors play a vital role in today's engineering and technology, a DC motor is used for various purpose and it proves to be very useful for the electrical technology. As above we discussed all the characteristics in an explained way.

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CHAPTER 10

FIELD AND ARMATURE CONTROL METHODS OF MOTORS

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Due to their ability to deliver a high starting torque, motors are utilized in numerous industrial settings, including rolling mills, the paper industry, and electric railway traction. The range of speed control is the major practical advantage of DC motors over AC motors. Using a variety of approaches, we are able to regulate the speed below and above the rated speed in a DC motor. The field current control method can be used to control the speed above the rated speed, and the armature voltage control method can control the speed below the rated speed. A DC motor's speed is inversely proportional to the field current (If) and directly proportional to the armature voltage (Va). The range of speed control in armature voltage control is zero to rated speed. Speed control ranges from constant reference speed to 120-130% rated can be achieved using field control, but motor-developed torque is lost. Electric trains, industrial fans, pumps, machine tools, household appliances, power tools automobiles, cranes, and robotic manipulators all make use of DC motors. To complete their tasks, they need to control their speed. In the beginning, voltage control was used to control the speed of a DC motor. However, switching devices like MOSFET, IGBT, and GTO have also been used to control speed. Although ac motors are utilized the majority of the time, DC motors are utilized for a variety of purposes. A rotating magnetic field is created when the coils are turned on and off sequentially. This field interacts with the various fields of the stator's stationary magnets to produce torque, which causes the stator to rotate. DC motors are able to transform electrical energy from direct current into mechanical energy through rotation, which can then be used for object propulsion thanks to these fundamental operating principles.

A wide range of options have developed for the use of DC motors as machines with adjustable speeds over time. To achieve the desired results in these situations, the motor should be precisely controlled. For speed control of DC motors, numerous control schemes, including proportional (P), proportional integral (PI), proportional derivative integral (PID), and adaptive and fuzzy logic controllers (FLCs), have been developed. Speed control refers to the deliberate adjustment of the drive speed to the value required to carry out a particular work process. Speed regulation, in which a change in the shaft's load causes a natural change in speed, is different from speed control. The operator can either manually control the speed or use an automatic control device. The ease with which a DC motor's speed can be controlled is one of its most important characteristics[1]–[3].

Speed control of Motors

The speed of a DC motor can be controlled either manually or automatically. This is not the same as speed regulation, which allows the speed to be controlled against the natural change in speed caused by a change in the shaft load. A direct current (DC) motor is a type of electric machine that converts electrical energy into mechanical energy. DC motors take electrical power through direct current, and convert this energy into mechanical rotation. DC motors use magnetic fields that occur from the electrical generated, which powers the movement of a rotor fixed within the output shaft. The output torque and speed depends upon both the electrical input and the design of the motor. The term ‘DC motor’ is used to refer to any rotary electrical machine that converts direct current electrical energy into mechanical energy. DC motors can vary in size and power from minor motors in toys and appliances to large mechanisms that power vehicles, pull elevators and hosts, and drive steel rolling mills. The basic diagram of motor shown in the given below Figure 10.1.

Figure 10.1: Diagram of motors

Hence the speed of motor can be varying by changing the following parameters:

A DC motor's back EMF or Eb, is nothing more than the induced EMF in the conductors of the armature as a result of the armature rotating in a magnetic field. As a result, the EMF equation for a DC generator can be used to determine Eb's magnitude.

$Eb = P\varphi NZ/60A$,

Where,

V = the terminal voltage of the armature.

Ra = the external resistance in armature circuit.

φ = the flux per pole

P = No. of the poles,

N = it is the speed in revolutions per minute (rpm), and

Z = no. of armature conductors, where

A = A denotes parallel paths,

Eb can also be expressed as $Eb = V - IaRa$;

Consequently, from the above mentioned equations, $N = Eb\ 60A / P\varphi Z$, however, for a DC motor, A, P, and Z are constants;

Consequently, N = K Eb / φ

where K = K is constant

then we demonstrates that the speed of a DC motor is directly proportional to the back EMF and inversely proportional to the flux per pole.

Speed control methods of Motors

Changes in terminal voltage and external resistance have an impact on the armature circuit, whereas flux has an impact on the magnetic field. As a result, DC motor speed control can be divided into:

1. Armature Control Methods

2. Field Control Methods

Both methods is applicable for different motors for series DC motors as well as for shunt DC motors.

I. Speed Control Methods for a DC Series Motor:

Speed control methods for a DC series motor can be classified as:

1. Armature Control Methods
2. Field Control Methods

Armature Control Methods

An Armature Controlled DC Series Motor can be classified again as given below as a DC series motor by armature control can be explained:

1. Armature Resistance Control Method
2. Shunted Armature Control Method
3. Armature Terminal Voltage Control

Armature Resistance Control Method: This is the approach taken the most frequently. The motor supply and the controlling resistance are directly connected in series here. Because this control method is utilized for a significant portion of the time to reduce the speed under conditions of light load, the power loss in the control resistance of a DC series motor can be ignored. For constant torque, this speed control method is the most cost-effective. This speed control method is used to control cranes, hoists, trains, and other DC series motors as shown below in the Figure 10.2.

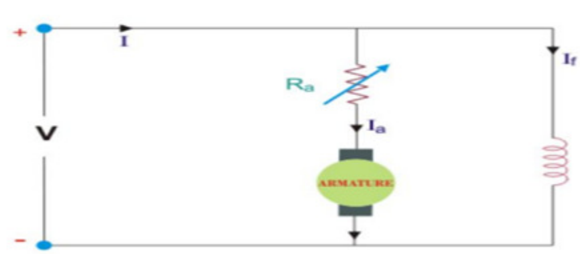

Figure 10.2: Armature Resistance Control Method

Shunted Armature Control Method:

This method of controlling speed involves a rheostat shunting the armature and a rheostat in series with the armature. Variable series rheostat R1 alters the voltage applied to the armature. The armature shunting resistance R2 can be changed to change the exciting current. Due to significant power losses in the resistances controlling speed, this method of speed control is not cost-effective. Here, control of speed is achieved over a large range but below normal speed as shown in the given below Figure 10.3.

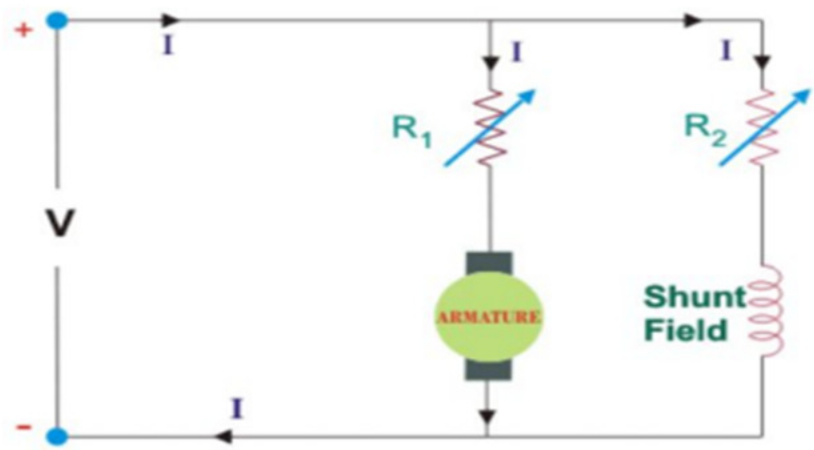

Figure 10.3: Shunted Armature Control Method

Armature Terminal Voltage Control:

The voltage across the armature can be decreased by adding resistance to the armature in series. As a result, speed decreases in line with it, as shown below Figure 10.4.

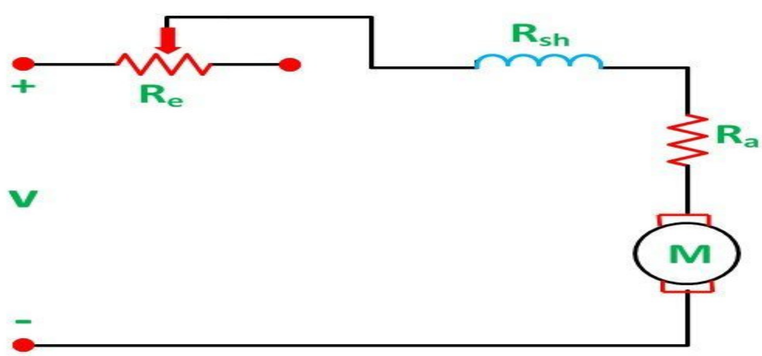

Figure 10.4: Armature Terminal Voltage Control

Field Control Methods: The Speed alteration of a DC series motor by controlling the field may be done by:

1. Field Diverter Method
2. Tapped Field Control

Field Diverter Method:A diverter is used in this method. Shunting a portion of the motor current around the series field can reduce the field flux here. The field current, flux, and speed decrease as the diverter resistance decreases. This method gives a speed that is higher than normal, and it is used in electric drives whose speed should sharply increase when the load is reduced. As depicted in the figure given below, a variable resistance is connected parallel to the series field. Because it is possible to divert the desired amount of current through this variable resistor, reducing the current flowing through the field coil, this resistor is referred to as a diverter. As a result, speed can be increased while flux can be reduced to the desired level, as shown in Figure 10.5.

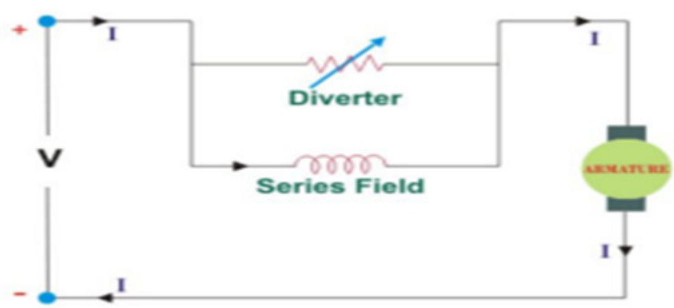

Figure 10.5: Field Diverter

Tapped Field Control:

Another strategy for reducing flux while increasing speed is to reduce the number of turns per field winding through which current flows. A number of tappings from field winding are brought outside using this method. Electric traction employs this approach as shown in the given below Figure 10.6.

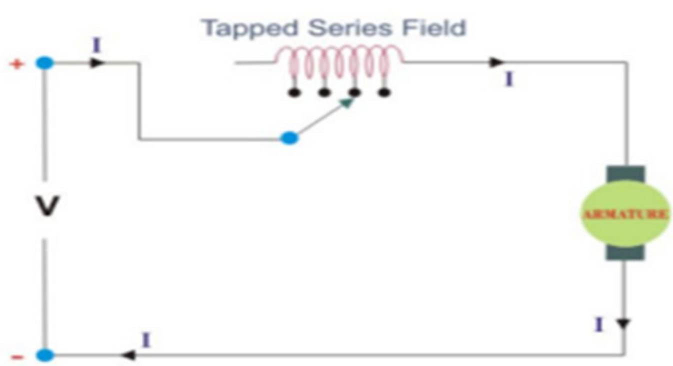

Figure 10.6: Tapped Field

Speed Control Methods for a DC Shunt Motor:

Speed control methods for a DC shunt motor can be classified as:

1. Armature Control Methods
2. Field Control Methods

Armature Controlled DC Shunt Motor:

Armature-controlled DC shunt motor can be distinguished in two ways:

1. Armature Resistance Control
2. Armature Voltage Control

Armature Resistance Control:

The back EMF, Eb, is directly proportional to the speed of a dc motor, and Eb = V - IaRa. This indicates that the speed is directly proportional to the armature current Ia when the supply voltage V and the armature resistance Ra remain constant. As a result, if we add resistance in series with the armature, Ia decreases, and the speed also decreases. The slower it goes, the more resistance there is in series with the armature. A variable resistance is added to the armature circuit in armature resistance control. Because the field is directly connected to the supply, changes in series resistance won't affect the flux. This can be used with a DC shunt motor. This approach is utilized in printing presses, cranes, and hoists when speeds below rated are utilized for a brief period of time only as shown in the given below Figure 10.7[4]–[6].

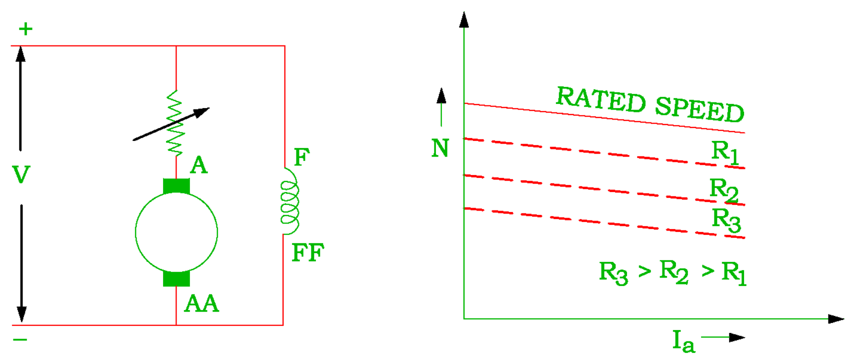

Figure 10.7: Armature Resistance Control

Armature Voltage Control:

This method of controlling the speed requires a variable voltage source that is separate from the source that supplies the field current. Poor speed regulation and low efficiency of armature-resistance control methods are avoided by this approach.

Multiple voltages control:

The armature is supplied with a variety of voltages while the shunt field is connected to a fixed exciting voltage. The appropriate switchgear is used to alter the voltage across the armature. The voltage across the armature is roughly proportional to the speed.

The Ward-Leonard Method:

The ward-Leonard system is used for dc motor speed control in applications requiring extremely sensitive motor speed control, such as electric excavators and elevators. The motor that requires speed control is M2. Any AC or DC motor with a constant speed can be M1. G is a generator connected to M1 directly. The motor M2's armature is fed the output from generator G, whose speed is to be controlled. With the help of the generator G's field regulator, the armature voltage of the motor M2 can be changed very smoothly from zero to its maximum value. This means that the dc motor's speed can be controlled very smoothly using this method. This system is arranged as depicted in the below Figure 10.8.

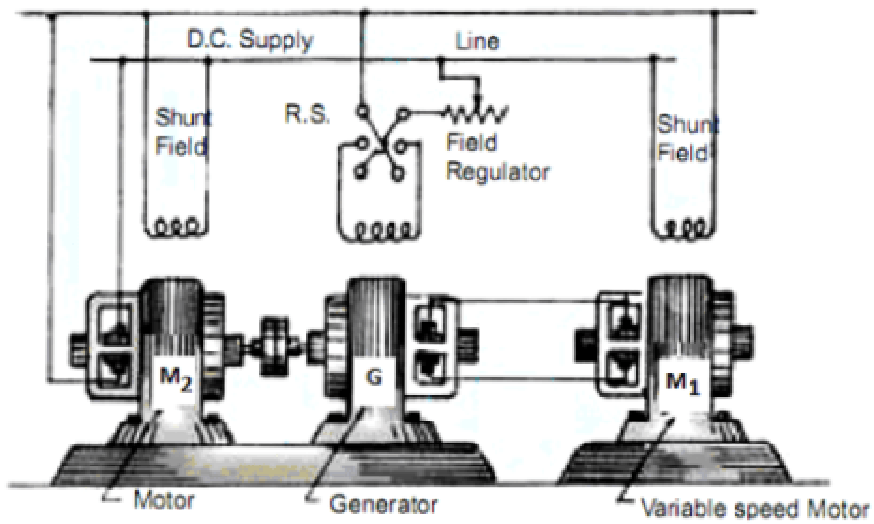

Figure 10.8: Ward-Leonard Method

Field-Controlled DC Shunt Motor:

DC shunt motor controlled by a field rheostat. This method uses a variable resistance connected to the shunt field to change the speed. The field current decreases in flux and speed when the controlling resistances are increased. The motor's load is not a factor in this method of controlling speed. Because the field current is so small, there is very little power wasted controlling resistance. In DC compound motors, this method of controlling speed is also utilized. Due to the limitations of the traditional approach, solid-state speed control static Ward Leonard drives are increasingly being utilized. DC motor speed is controlled by solid state converters rather than rotating M-G sets. In the case of an AC supply, choppers or controlled rectifiers serve as the converters. Intermittent loads are not suitable for this method.

Voltage Equation of Motors:

Let us calculate the voltage equation in a DC motor, as follows given below Figure 10.9.

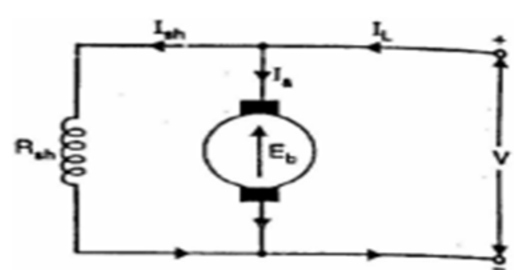

Figure 10.9: Voltage Equation of Motors

As per the diagram shown above. Let's us consider the following parameters:

V = the applied voltage

Eb = back EMF

Ra = armature resistance of DC motor

Ia = armature current Since back EMF

Eb acts opposite to the applied voltage V, the net voltage across the armature circuit is V- Eb.

The armature current Ia is given by: Ia = V- Eb / Ra --------------- (1)

V = Eb + Ia x Ra ------------ (2)

The Equation 2 is known as the voltage equation of the DC motor.

Condition for maximum power:

Because V and Ra are fixed, the motor's mechanical power is dependent on the armature current. dPm / dIa should be zero for maximum power. As a result, the motor generates the most mechanical power when operating backwards is equivalent to half the voltage applied.

So, Pm = Eb x Ia

dPm / dIa = 0

$$\frac{dP_m}{dI_a} = V - 2I_aR_a = 0$$

$$I_aR_a = \frac{V}{2}$$

$$V = E_b + I_aR_a = E_b + \frac{V}{2} \qquad \therefore \qquad E_b = \frac{V}{2}$$

Speed equation of a Motor:

Because a three-phase induction motor is essentially a constant speed motor, controlling its speed can be somewhat challenging. Induction motor speed control comes at the expense of reduced efficiency and a low electrical power factor. Because the methods for controlling the speed of a three-phase induction motor are based on these formulas, it is important to understand the fundamental formulas for speed and torque before discussing the control strategies.

The speed of a motors is defined as:

$$N_s = \frac{120f}{P}$$

Here, f = frequency of the motor

P = no. of poles

The speed of induction motor is given by, N = Ns (1-s)

Torque equation of a Motor:

Three phase induction motor produced torque which is given by:

$$T = \frac{3}{2\pi N_s} X \frac{sE_2^2 R_2}{R_2^2 + (sX_2)^2}$$

Where,

E2 = it is the EMF of rotor

Ns = it is the synchronous speed

R2 = it is the rotor resistance

X2 = it is the reactance of inductive rotor

Speed control of an AC Motor:

The induction motor's speed can be altered from both the rotor and the stator sides. The stator-side speed control of a three-phase induction motor is further broken down into the following categories:

- Control of the voltage or frequency.
- It also adjusting the stator pole count.
- It regulating the voltage of the supply.
- Incorporating a rheostat into the stator circuit

The following further groups the rotor-side three-phase induction motor speed controls:

- On the rotor side, adding external resistance.
- Method of controlling cascades
- Slip frequency EMF is injected into the rotor side

BACK EMF

Energy conversion is impossible unless there is something to stop it, according to fundamental laws of nature. This opposition is provided by magnetic drag in generators, whereas back emf exists in dc motors.

According to Faraday's law of electromagnetic induction, an EMF is induced in the armature conductors when the motor's armature is rotating because the conductors are also cutting the magnetic flux lines. The armature current (Ia) is opposed by this induced EMF's direction. The armature current and back EMF are oriented in the following circuit diagram. The EMF equation for a DC generator can be used to determine the Back EMF's magnitude as shown in the given below Figure 10.10.

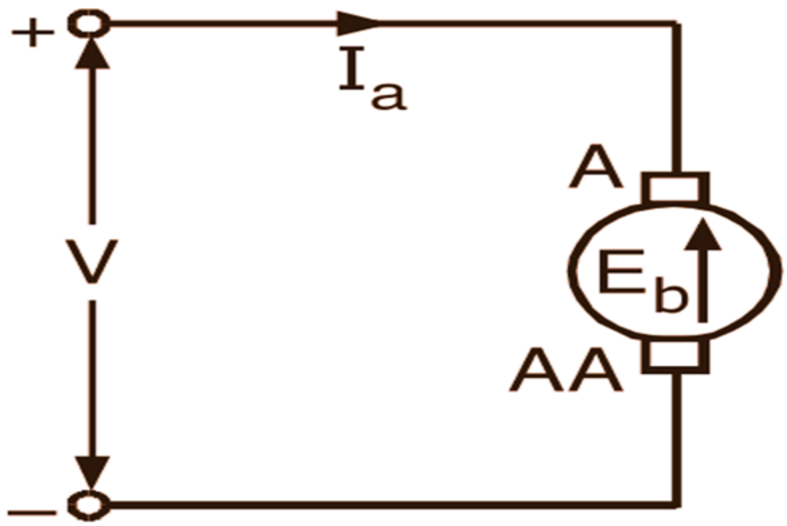

Figure 10.10: illustration of back EMF

Significance of back EMF:

The motor's speed directly correlates with the magnitude of the back EMF. Take for instance the sudden reduction of a dc motor's load. The required torque will be less than the current torque in this scenario.

The excessive torque will cause the motor's speed to begin increasing. As a result, the magnitude of the back EMF will also rise in proportion to speed. The armature current will begin to decrease as back EMF increases. Since torque is inversely proportional to armature current, it will decrease until it meets the load. As a result, the motor's speed will control.

On the other hand, the speed of a dc motor will decrease when it is suddenly loaded. As speed decreases, back EMF also decreases, allowing for increased armature current. To meet the load requirement, an increased armature current will result in an increase in torque. As a result, a DC motor becomes "self-regulating" when the back EMF is present[7]–[10].

In this chapter we learn about the basic introduction of Field and armature control of DC motors. Later we focused on the components or parts of DC motors and we learn about the basic types of control of speed of DC motors and characteristics of armature of DC motors. Motors play a vital role in today's engineering and technology; a DC motor is used for various purpose and it proves to be very useful for the electrical technology.

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CHAPTER 11

STARTING OF DC MOTORS

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A device used to start and accelerate a DC motor is known as Stator. A controller is a device for starting, controlling, reversing, and stopping the DC motor. The DC motor draws a lot of current when it starts, which damages the motor. The heavy current is reduced and the system is shielded from damage by the starter. A motor starter is a safe electrical device for starting and stopping a motor. The motor starter, like a relay, turns the power on and off, but unlike a relay, it also protects against low voltage and overcurrent. A motor starter is a safe electrical device for starting and stopping a motor. The motor starter, like a relay, turns the power on and off, but unlike a relay, it also protects against low voltage and overcurrent. The primary purpose of a motor starter is to protect a motor from low voltage and overcurrent, to safely start a motor, stop a motor, and reverse its direction. A device used to start and accelerate a motor is called a starter. A controller is a device for starting, controlling, reversing, and stopping the DC motor. The DC motor draws a lot of current when it starts, which damages the motor. Although ac motors are utilized the majority of the time, DC motors are utilized for a variety of purposes. A rotating magnetic field is created when the coils are turned on and off sequentially. This field interacts with the various fields of the stator's stationary magnets to produce torque, which causes the stator to rotate. Industrial fans, pumps, machine tools, household appliances, power tools, automobiles, and a wide range of drives all make use of electric motors.

As you can see, electric watches also have tiny motors. As a generator, electric motors can also be used to recover energy lost through friction and heat. Both linear and continuous rotation are supported by the electric motor. Nowadays we can see that use of motors is increasing day by day and it will be very beneficial in any field. DC motors use magnetic fields that occur from the electrical generated, which powers the movement of a rotor fixed within the output shaft. The output torque and speed depend upon both the electrical input and the design of the motor. The term 'DC motor' is used to refer to any rotary electrical machine that converts direct current electrical energy into mechanical energy[1]–[3].

STARTING OF DC MOTORS

A device used to start and accelerate a DC motor is known as Stator. A controller is a device for starting, controlling, reversing, and stopping the DC motor. The DC motor draws a lot of current when it starts, which damages the motor. The heavy current is reduced and the system is shielded from damage by the starter. A motor starter is a safe electrical device for starting and stopping a motor. The motor starter, like a relay, turns the power on and off, but unlike a relay, it also protects against low voltage and overcurrent. A motor starter is a safe electrical device for starting and stopping a motor. The motor starter, like a relay, turns the power on and off, but unlike a relay, it also protects against low voltage and overcurrent. The primary purpose of a motor starter is to protect a motor from low voltage and overcurrent, to safely start a motor, stop a motor, and reverse its direction. The starter can shown below in the given Figure 11.1.

Figure 11.1: Starter of dc motors

Starting Methods of DC Motors:

The fundamental operational voltage equation for a DC motor is given as E = Eb + IaRa, and consequently, Ia = (E - Eb) / Ra. However, the back EMF Eb = 0 when the motor is at rest. As a result, the starting armature current can be expressed as Ia = E / Ra. Because the armature resistance is typically very low around 0.5ohm in practical DC machines, a significant current flow through it during startup.

The armature circuit could be damaged by this significant current are as follows:

i. Fuses and armature winding and/or commutator brush arrangement damage may result from this excessive starting current.
ii. Due to the fact that torque is directly proportional to the armature current, a very high starting torque will be generated. This high starting torque may result in a significant centrifugal force, which may cause the armature winding to be thrown off.
iii. The terminal voltage of other loads connected to the same source might drop.

Due to the large rotor's inertia, a large DC motor will accelerate slowly. As a result, the level of high starting current was maintained for quite some time as the back EMF was gradually increased. This could result in severe damage. A suitable DC motor starter must be used to avoid this. However, using a contactor or a switch to connect very small dc motors to the supply, they can be started immediately. Because of the small rotor inertia, they quickly gain speed, so it doesn't hurt. Due to the rapid rise in the back EMF, the large starting current will quickly diminish in this instance.

Need of starters for DC Motors:

Starting an induction motor requires a motor starter. It is because of the low impedance of its rotor. The slip of the induction motor, which is the difference in speed between the rotor and stator, affects the rotor impedance. The slip is inversely correlated with the impedance. The impedance of the induction motor is at its lowest and it draws a significant amount of current known as inrush current because the slip of the motor is at its maximum at standstill (rest position). The air gap that separates the rotor and stator is magnetized by the high inrush current, resulting in an EMF in the rotor winding. To generate torque in the rotor, this electromagnetic field causes an electrical current to flow through the rotor winding. The motor's slip decreases and its current consumption decreases with increasing rotor speed. There is no back EMF in the dc motor. The armature current is controlled by the circuit's resistance when the motor starts. The armature has a low resistance, so when the motor is at a standstill and the full voltage is applied, the armature current becomes extremely high, causing damage to the motor's components. At the beginning, the armature circuit experiences additional resistance as a result of the high armature current. When the machine speeds up, the circuit is cut off from the machine's starting resistance. A motor's armature current is determined by:

$$I_a = \frac{V - E}{R_a} \quad \ldots\ldots\ldots \quad (1)$$

As a result, Ia is dependent on E and Ra if V remains constant. The armature remains stationary when the motor is turned on for the first time. As a result, Eb, the back EMF, is also zero. The following equation describes the initial starting armature current Ias:

$$I_{as} = \frac{V - 0}{R_a} = \frac{V}{R_a} \quad \ldots\ldots\ldots\ldots \quad (2)$$

Because a motor's armature resistance is extremely low, typically less than one ohm. As a result, the current starting armature Ias would be quite large. The difference (V – E) continues to decrease as the motor speed increases, resulting in an increase in the back EMF. As a result, the motor's armature current gradually decreases until it reaches its stable speed and the corresponding back EMF. The armature current reaches the desired level under this circumstance. As a result, it has been discovered that the armature resistance is aided in limiting the current that flows through the armature by the back EMF.

Due to the large starting current encountered when the DC motor is started. Except for very small DC motors, an additional resistance must be connected in series with the armature when the motor starts.

The motor's safe value is maintained by adding this additional resistance, which also limits the motor's starting current until it reaches its stable speed. As the motor's speed increases and the back EMF increases, the series resistance is divided into sections that are cut out one at a time. When the motor's speed reaches its normal value, the extra resistance is removed. The normal rated full load current is 5-8 times higher than the high inrush current. Therefore, a current of this magnitude can harm or burn the motor's windings, rendering the machine useless, and it can result in a significant drop in supply line voltage, which can harm other appliances connected to the same line. We use a starter that limits the initial current for a short time at startup to protect the motor from such high currents. Once the motor reaches a certain speed, the normal power supply to the motor is resumed. During normal operation, they also offer protection against fault conditions like low voltage and overcurrent as shown in below Figure 11.2.

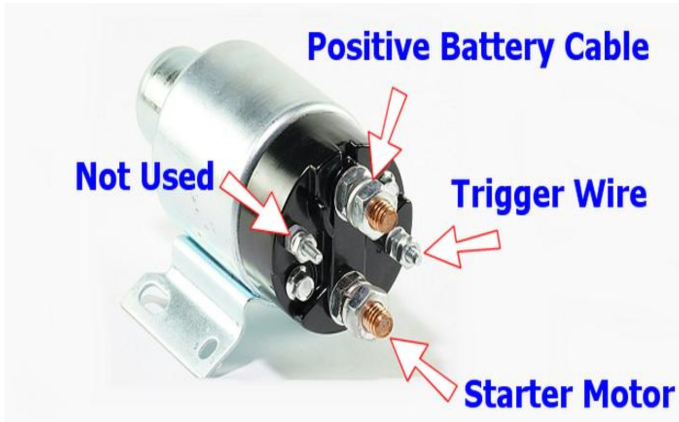

Figure 11.2: Automotive Engine Starter

Motor starter work

A starter is a control device that can manually or automatically switch the motor. It is used to safely make or break the contacts of electrical motors to turn them ON or off. For smaller motors, the manual starter is used because the lever must be manually moved to the ON or OFF position. The fact that these starters need to be turned on after power goes out is a drawback. In other words, each ON or OFF operation necessitates manual control. This operation may occasionally result in high currents flowing through the motor winding, which could burn the motor. Because of this, it is not recommended in most situations when automatic starters or other motor starters with protection are used as shown in the given below Figure 11.3.

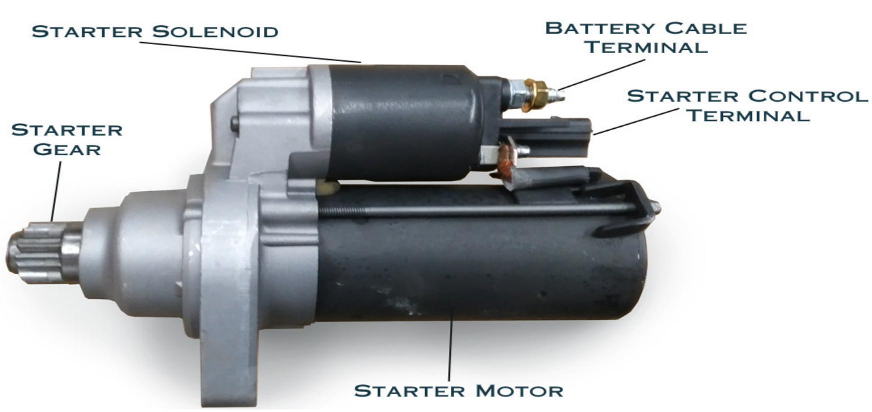

Figure 11.3: Starter motor starting system

As again we discussed, the motor's ON/OFF operation is controlled by electromechanical relays and contactors in automatic starters. The contactor coils are energized and produce an electromagnetic field when current flows through them, pulling or pushing the contacts to connect motor windings to the power supply[4]–[6].

Motors can be turned ON and OFF with the help of the start and stop pushbuttons that are connected to the starter and motor. Pushing the stop button will de-energize the contactor coils, allowing them to be de-energized. The motor is turned off as a result of the contactor contacts returning to their normal position as a result of the spring arrangement. The motor won't start automatically unless we manually start it by pressing the "start push button" in the event of a power failure or manual shutoff. The operation of an ON/OFF DOL motor starter is explained properly.

Types of Motor Starters Based on Starting Methods & Techniques:

An induction motor can be started in a variety of ways in businesses. Here are some of the methods utilized in motor starters before we get into the different kinds of motors.

1) **Full Voltage or Across the Line Starter:** These types of starters connect the motor directly to the power line, supplying the entire voltage. Due to their low power ratings, these starters' motors do not cause a significant voltage drop in the power line. They are utilized in a situation in which motors have low ratings and must operate in a single direction.
2) **Full Voltage Reversing Starter:** By switching any two phases, a three-phase induction motor can have its direction reversed. Two mechanically interlocked magnetic contactors with switched phases for forward and reverse direction make up this kind of starter. It is used in a situation where contactors are used to control a motor that must run in both directions.
3) **Multispeed Starter:** Multispeed Starter Changing the AC supply frequency or the number of poles is required to alter the speed of an AC motor. These kinds of starters operate the motor at a few predetermined speeds depending on the application.
4) **Reduced Voltage Starter:** The most common method of starting a motor is to reduce the voltage at the motor's start in order to cut down on the inrush current, which can damage the motor's windings and cause a significant drop in voltage. High-powered motors require these starters.

Type of Motor Starters:

Based on the aforementioned motor starting methods, we will discuss the following motor types and their starting methods, along with their advantages and disadvantages.

1. Direct Online Starter (DOL)
2. Stator Resistance starter
3. Rotor Resistance or Slip Ring Motor Starter
4. Autotransformer Starter
5. Star Delta Starter
6. Soft Starter
7. Variable frequency drive (VFD)

There are many different kinds of motor starters, but most of them fall into two categories.

Manual Starter: This kind of starter works by hand and doesn't need any experience. The motor that is connected to it can be turned OFF and ON with a push button. A mechanical switch is part of the button's mechanism, causing the circuit to break or cause the motor to start or stop. Additionally, they offer overload protection. However, these starters lack LVP, or low voltage protection, which prevents the circuit from being damaged in the event of a power outage. Because the motor restarts when power is restored, it can be dangerous for some applications. As a result, a low-power motor makes use of them. A manual starter known as the Direct On-Line (DOL) starter features overload protection.

Magnetic Starter: Magnetic starters are the most prevalent kind of starter, and high-power AC motors typically make use of them. Similar to a relay that uses magnetism to make or break the contacts, these starters operate electromagnetically. It includes protection against low voltage and overcurrent as well as a lower and safer voltage for starting. The magnetic starter automatically interrupts the circuit when there is no power. It includes an automatic and remote operation that does not involve the operator, in contrast to manual starters.

Direct Online Starter (DOL): The simplest motor starter is the Direct Online (DOL) Starter, also known as a Direct Online Starter. This type of starter connects the motor directly to the power supply. It consists of an overload relay to prevent overcurrent and a magnetic contactor to connect the motor to a supply line. Safe motor start requires no voltage reduction. As a result, the starter motor is rated at less than 5 hp. The motor can be started and stopped with just two simple push buttons. The coil that pulls the contactors together to close the circuit is energized when the start button is pressed. Additionally, pressing the stop button breaks the circuit by pushing the contactor's coil apart and de-energizes it. Any kind of switch—rotary, level, float, etc.—can be used to turn the power supply ON or OFF. Even though this starter does not provide a safe voltage for starting, the overload relay prevents overheating and overcurrent. The coil of the contactor is energized by the overload relay's typically closed contacts. The contactor's coil is de-energized and the circuit is severed when the relay trips as depicted in the given Figure 11.4.

The advantages of the DOL Motor Starter include:

i. Its low price and straightforward design.
ii. It is very simple to use and comprehend.
iii. Due to the high starting current, it provides high starting torque

The Disadvantages of the DOL Motor Starter include:

i. The power line's voltage dips as a result of the high inrush current, which can damage the windings.
ii. Heavy motors should not use it because it can shorten a motor's lifespan.

Stator Resistance starter: To get a motor started, a stator resistance starter makes use of the RVS (reduced voltage starter) method. In a three-phase induction motor, each phase of the stator receives additional external resistance in series. The function of the resistor is to reduce the stator's initial current by lowering the line voltage. The variable resistor is initially maintained at its highest position, providing the greatest resistance. Because of the voltage drop across the resistor, the voltage across the motor is at its lowest (safe level). The starting inrush current, which can cause damage to the motor windings, is limited by the low stator voltage. The stator phase is directly connected to the power lines and the resistance decreases as the motor speeds up. Since torque is proportional to the square of the current and the current is directly proportional to the voltage, a voltage decrease of two times will result in a torque decrease of four times. Because of this, the starter's starting torque is extremely low and must be maintained as shown below in the given Figure 11.5.

TheAdvantages of stator resistance motor starter includes:

i. It gives starting characteristics flexibility.
ii. Smooth acceleration is made possible by the variable voltage supply,
iii. It can be connected to either a star or delta motor.

TheDisadvantages of stator resistance motor starter includes:

i. The starting torque is very low as a result of the voltage reduction
ii. The resistors are quite pricey for large motors.

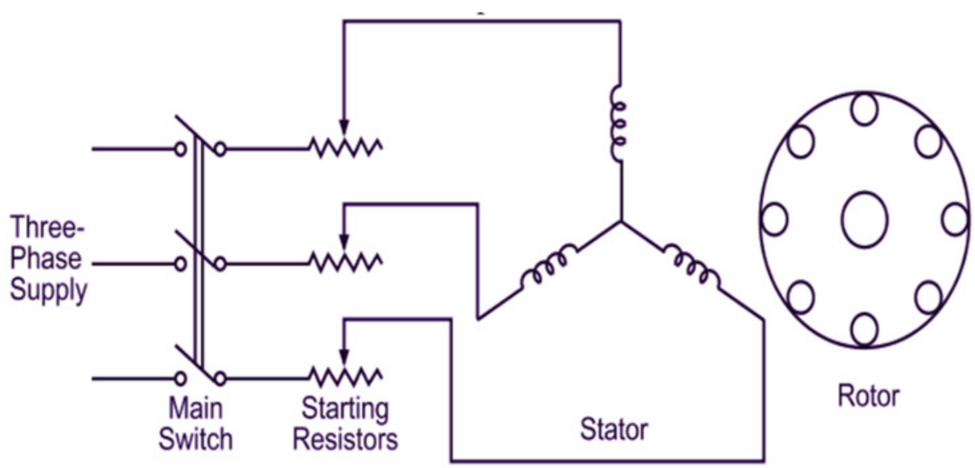

Figure 11.5: Stator Resistance starter

Rotor Resistance or Slip Ring Motor Starter: The full voltage motor starting method is utilized by this kind of motor starter. It is also known as a slip ring motor starter because it only works with slip ring induction motors. Through the slip ring, external resistances are connected to the rotor in a star combination. The torque is increased and the rotor current is limited by these resistors. The starting stator current decreases as a result of this. Power factor is also improved because resistors are only used to start the motor and are removed once it reaches its maximum speed, as shown in given below Figure 11.6.

TheAdvantages of rotor resistance or slip ring motor starter include:

i. Using full voltage, it provides a low starting current.
ii. The motor can be started under load thanks to its high starting torque.
iii. This method raises the power factor.
iv. It offers numerous speed control options.

TheDisadvantages of rotor resistance or slip ring motor starter includes:

i. The rotor is more costly and weightier
ii. It only works with slip-ring induction motors.

Autotransformer Starter: An autotransformer serves as a step-down transformer in these motor starters, lowering the voltage that is applied to the stator during the starting stage. It can be connected to delta- and star-connected motors in the same way.

Each motor phase is connected to the secondary of the autotransformer. The autotransformer's multiple tapings only provide a small portion of the rated voltage. The relay is positioned at the start position, or tap point, providing a reduced startup voltage. To increase the voltage in accordance with the motor's speed, the relay switches between the tap points. It finally connects it to the full recommended voltage. It provides a higher voltage for a particular starting current than other methods of reducing voltage. It contributes to the improvement of the starting torque as shown in the given below Figure 11.7.

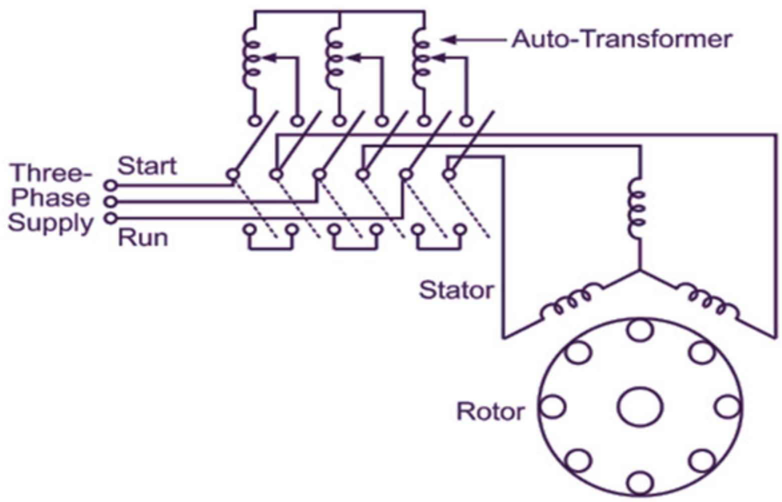

Figure 11.7: Diagram of Autotransformer Starter

TheAdvantages of autotransformer starter include:

i. It gives you more torque for starting.
ii. It is used to start large motors that have a lot of load on them.
iii. It also lets you control the speed manually.
iv. Additionally, it provides starting characteristics flexibility.

TheDisadvantages of autotransformer starter include:

i. Such a starter takes up too much space due to the autotransformer's size.
ii. Compared to other starters, the circuit is complicated and relatively expensive.

Star Delta Starter: In industries that deal with large motors, this is yet another common starting method. To start a three-phase induction motor, the windings are switched between a star and a delta connection. A triple pole, double throw relay is used in star to start the induction motor. In a star connection, the starting current and torque are both reduced by one-third of their normal rated values, and the phase voltage is decreased by a factor of one-third.

A timer relay changes the stator windings' star connection to the delta connection as the motor accelerates, allowing full voltage to flow through each winding. The motor operates at its maximum speed as shown in the given below Figure 11.8.

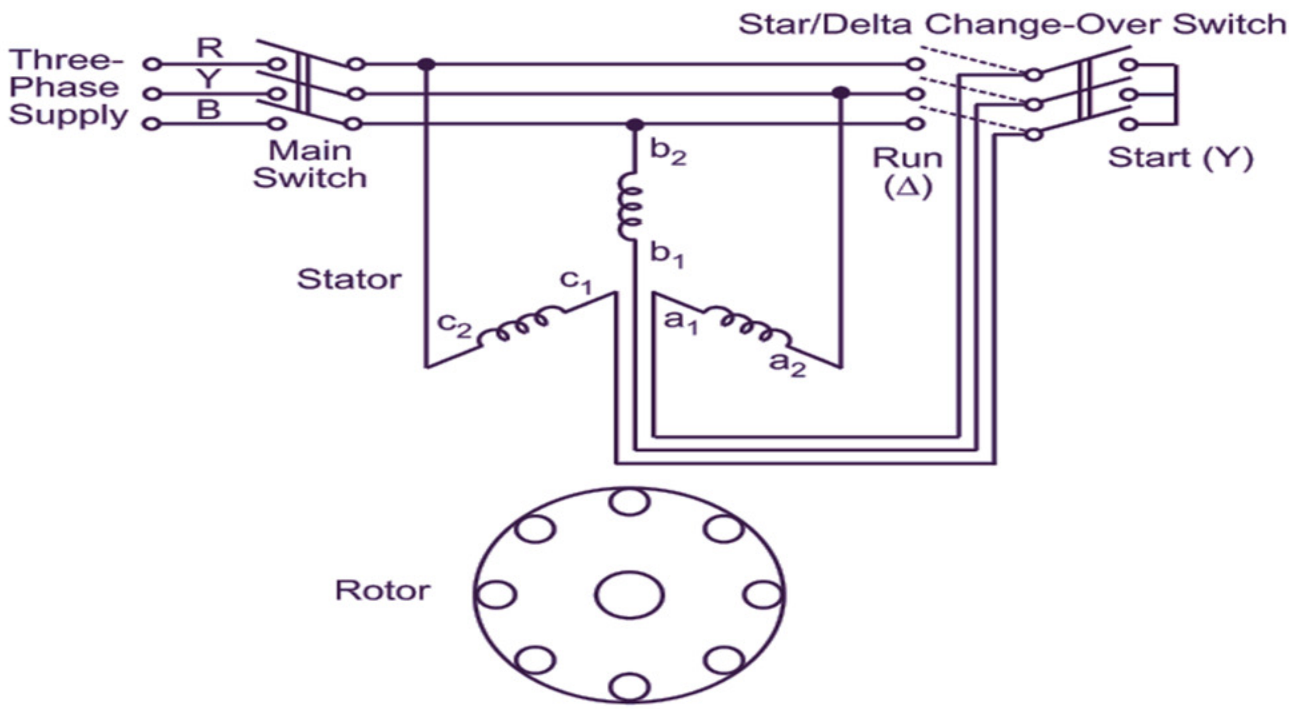

Figure 11.8: Diagram of Star Delta Starter

TheAdvantages of Star delta starter include:

i. It has a low surge current.
ii. It is inexpensive, and also does not need to be maintained.
iii. Large induction motors are started with it.
iv. It works best for accelerating for a long time.

TheDisadvantages of Star delta starter include:

i. There are additional wire connections, so it works on delta-connected motors.
ii. It has low starting torque that can't be kept up.
iii. Starting characteristics offer only a very limited amount of adaptability.
iv. When switching from star to delta, there is a mechanical jerk.

Soft Starter

The voltage reduction method is also used by the soft starter. The induction motor's voltage and starting current are controlled by means of semiconductor switches like TRIAC. Variable voltage is provided by using a phase-controlled TRIAC. The TRIAC's firing or conduction angles can be changed to change the voltage. To provide lower voltage, the conduction angle is kept as low as possible. Increasing the conduction angle gradually raises the voltage. The induction motor operates at its rated speed when the maximum conduction angle is reached. The full line voltage is applied to it.The torque, current, and starting voltage all rise gradually and smoothly as a result. As a result, there is no mechanical jerk and the machine runs smoothly, which extends its lifespan as shown in the given below Figure 11.9[7]–[10].

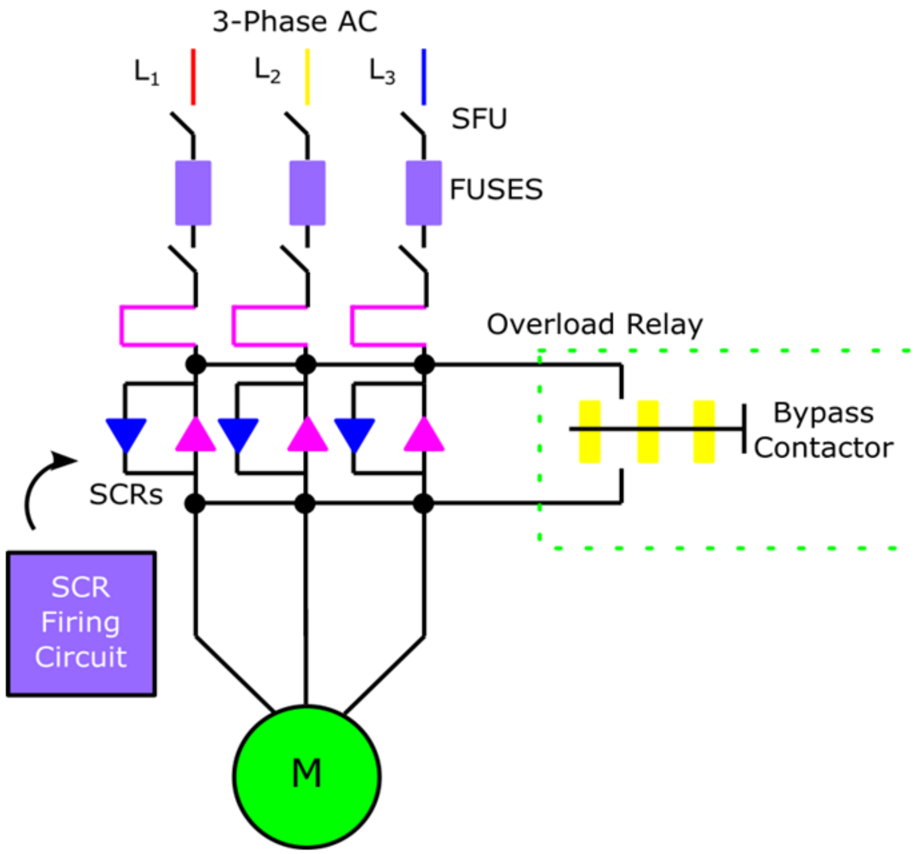

Figure 11.9: Diagram of Soft Starter

TheAdvantages of Soft starter include:

i. It provides smooth acceleration with no jerks and better control over the starting current and voltage.
ii. The system's power surges are reduced as a result.
iii. Increases the system's lifespan, improves efficiency, and eliminates the need for routine maintenance.
iv. It is small in size.

TheDisadvantages of Soft starter include:

i. It is more expensive than other starter
ii. The energy degenerate in the form of heat

Variable Frequency Drive (VFD)

A Variable frequency drive (VFD), like a soft starter, can change the voltage and frequency of the supplying current. Because it depends on the frequency of the supply, it is mostly used to control the speed of the induction motor. Using rectifiers, the AC from the supply line is transformed into DC. Using the pulse width modulation technique and power transistors like IGBTs, pure DC is transformed into AC with variable frequency and voltage. From 0 to the rated speed, it gives you complete control over the motor's speed. The variable voltage speed adjust option improves acceleration and starting current. In the figure given is showing the working and basic structure of VFD, as shown in Figure 11.10.

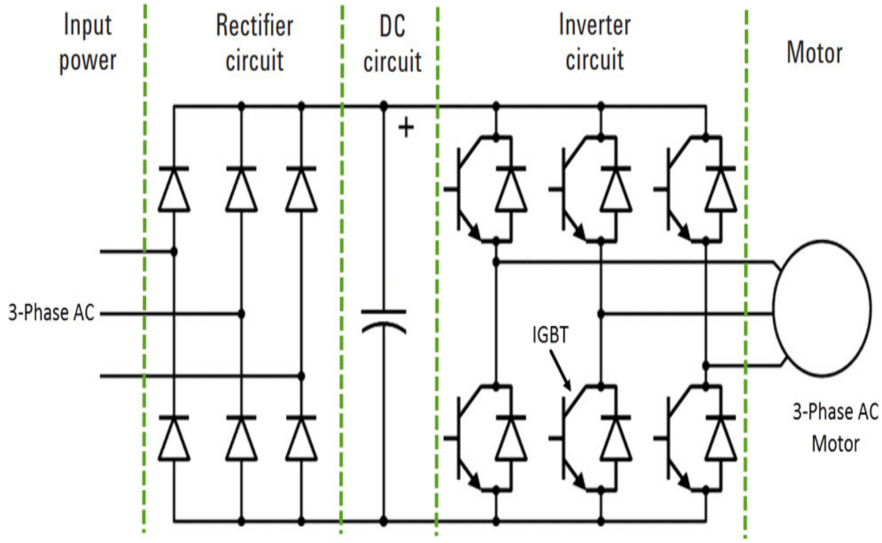

Figure 11.10: Variable Frequency Drive (VFD)

TheAdvantages of VFD starter include:

i. It offers full speed control with smooth acceleration and deceleration, making it ideal for large motors.
ii. Because there is no electrical or mechanical stress, it has a longer lifespan.
iii. It allows a motor to move forward and backward.
iv. It delivers an improved and regular acceleration for large motor

TheDisadvantages of VFD starter include:

i. Unless speed control is required, it costs a lot.
ii. VFDs dissipate heat, which can cause harmonics in electric lines to affect electronic equipment and power factor.

In this chapter we learn about the basic introduction about starters and how to start DC motors and why we need to start the motors. Later we focused on the types of starters and on what basis starters are classified. Starting of DC motors and we learn about the basic types of starters of DC motors. Starters are necessary and played an important role in today's starting of motors and technology, a DC motor is used for various purpose and it proves to be very useful for the electrical technology.

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CHAPTER 12

ELECTRICAL BRAKING OF DC MOTORS

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Electrical braking is typically used in situations where a motor-driven unit needs to be stopped precisely or its deceleration speed needs to be appropriately controlled. Applications requiring frequent, quick, accurate, or emergency stops call for electrical braking. Electrical braking makes it possible to stop smoothly without causing passengers any problems. Although ac motors are utilized the majority of the time, DC motors are utilized for a variety of purposes.A rotating magnetic field is created when the coils are turned on and off sequentially. This field interacts with the various fields of the stator's stationary magnets to produce torque, which causes the stator to rotate. DC motors are able to transform electrical energy from direct current into mechanical energy through rotation.Applications requiring frequent, quick, accurate, or emergency stops call for electrical braking. Electrical braking makes it possible to stop smoothly without causing passengers any problems.

Electric braking keeps the speed within safe limits as a loaded hoist is lowered. In any other case, the drive or machine's speed will reach dangerous levels. Electric braking is used to keep a train's speed within the safe limits when it descends a steep gradient. In situations where active loads are present, electrical braking is more frequently utilized. Mechanical brakes can provide the same amount of braking force as electric brakes do. Mechanical or electrical braking can quickly bring a motor that is running to a stop. Mechanical break shoes are used to apply the mechanical braking. As a result, the brakes' physical condition and surface influence mechanical braking's smoothness. Electric braking can be used to brake a motor smoothly[1]–[3].

Industrial fans, pumps, machine tools, household appliances, power tools, automobiles, and a wide range of drives all make use of electric motors. As you can see, electric watches also have tiny motors. As a generator, electric motors can also be used to recover energy lost through friction and heat. Both linear and continuous rotation are supported by the electric motor. The term ‘DC motor’ is used to refer to any rotary electrical machine that converts direct current electrical energy into mechanical energy. DC motors can vary in size and power from minor motors in toys and appliances to large mechanisms that power vehicles, pull elevtors and hosts, and drive steel rolling mills.

It may be necessary to quickly stop the motor or change its direction of rotation in some situations. Frictional braking can be used to bring the motor to a stop. The operation of frictional braking has the following disadvantages:

It is unable to be controlled, reliant on the braking surface, and far from smooth.

Electrical braking of DC Motor:

Electrical braking is typically used in situations where a motor-driven unit needs to be stopped precisely or its deceleration speed needs to be appropriately controlled. Applications requiring frequent, quick, accurate, or emergency stops call for electrical braking. Electrical braking makes it possible to stop smoothly without causing passengers any problems. Electric braking keeps the speed within safe limits as a loaded hoist is lowered. In any other case, the drive or machine's speed will reach dangerous levels. Electric braking is used to keep a train's speed within the safe limits when it descends a steep gradient. In situations where active loads are present, electrical braking is more frequently utilized. Mechanical brakes can provide the same amount of braking force as electric brakes do.

Types of electric braking:

A DC motor can use one of three forms of electric braking. They are plugging or reverse current braking, dynamic or rheostatic braking, and regenerative braking as shown in the given Figure 12.1.

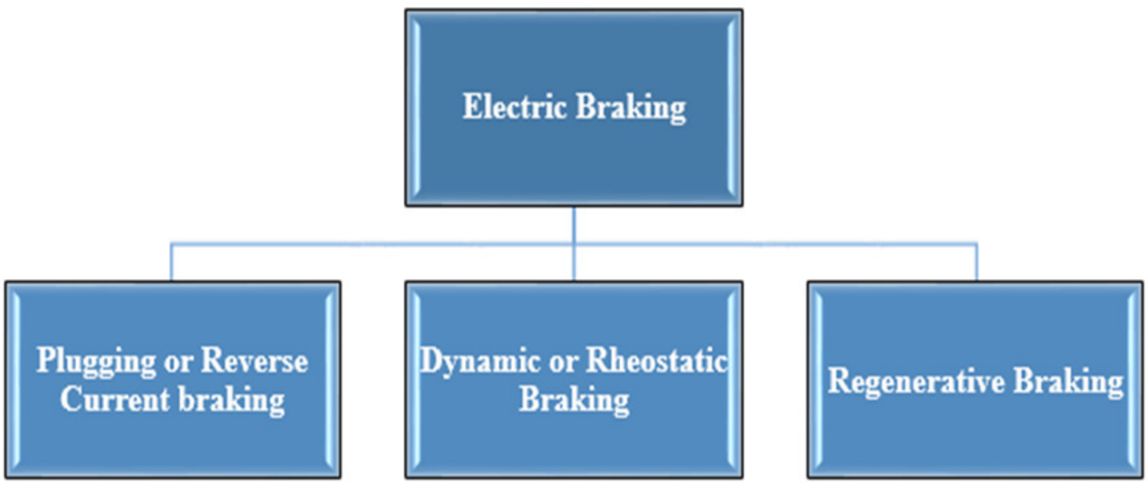

Figure 12.1: illustration the Types of electric braking

There are three types of electric braking for DC motors:

1. Plugging or reverse current braking
2. Dynamic or rheostatic braking, and
3. Regenerative braking

Plugging or Reverse Current Braking:

The armature terminals or supply polarity of a separately excited or shunt motor when running are reversed during Plugging or Reverse Current Braking. As a result, when the plug is plugged, the induced voltage Eb and the supply voltage V, also known as back EMF, will interact in the same manner. As a result, the effective voltage across the armature will be almost twice as high as the supply voltage when the plug is plugged in (V + Eb). High braking torque is produced as a result of the armature current being reversed. To maintain a safe operating current, the armature is connected in series to an external current limiting resistor. The motor tends to run in the opposite direction due to the armature connections being reversed in this method. The applied voltage V and the back EMF Eb begin to act in the same direction as a result of the armature terminals being reversed, which results in an increase in the total armature current.

A variable resistor is connected across the armature to limit this armature's current. This is the same for both shunt and series wound techniques. When compared to rheostatic braking, plugging produces more braking torque. Controlling elevators, machine tools, printing presses, and other devices typically entails using this approach. Changing the motor's polarity allows for the plugging operation. The polarities of the field or armature terminals are determined by the phase sequence of the starter winding and dc machines. The braking torque is generated by interchanging any two supply terminals, thereby reversing the motor's rotation and the magnetic field's direction of rotation. The rotor comes to a quick stop as a result of the developed electromagnetic torque. The machine is acting like a motor in each instance. Current braking and reverse current braking are two other names for this type of braking. The characteristics of the DC separately excited motor as well as the connection diagram for it are depicted in the Figure 12.2.

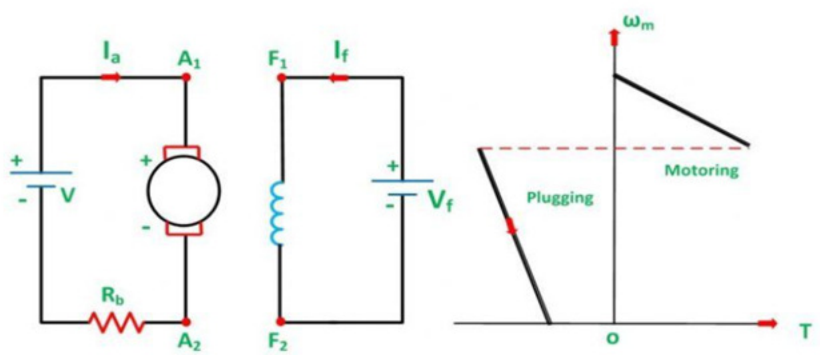

Figure 12.2: Plugging characteristics of the DC separately excited motor

Where,

V = It is the supply voltage

R_b is the external resistance

I_a is the armature current

I_f is the current of field.

In a similar vein, the following figure depicts the series motor's characteristic and connection diagram when it is in plugging mode as shown in the given below Figure 12.3.

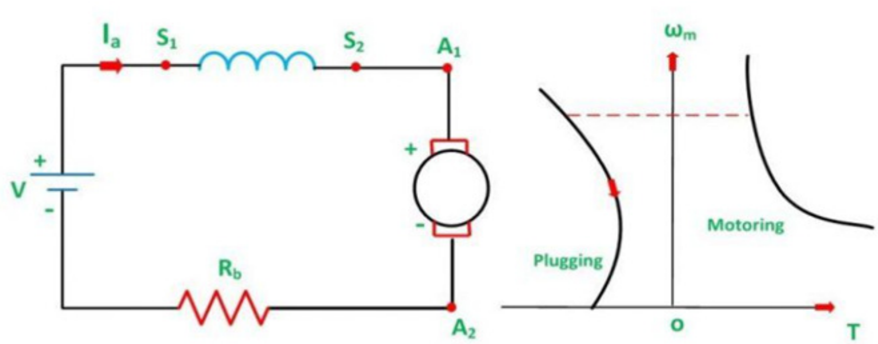

Figure 12.3: Plugging characteristics of the series DC excited motor

A series motor's armature or field terminals are flipped over for braking. However, field terminals and armatures cannot be reversed simultaneously. The reverse operation of both terminals will only result in normal operation. The braking torque is not zero at the zero speed. When the motor is used to stop a load, it must be disconnected from the supply and running at or close to zero speed. The motor will accelerate in the opposite direction if it is not disconnected from the supply mains. Centrifugal switches are used to disconnect the supply. Because both the power supplied by the source and the power supplied by the load are wasted in resistance, the method of braking known as "plugging" or "reverse current braking" is insufficient.

Applications of Plugging

The most commonly use of Plugging is for the following purposes listed below:

i. It is used for regulatoring the elevators
ii. It is used in Rolling Mills
iii. Used for Printing Presses
iv. Used for Machine tools work.

Dynamic or Rheostatic braking of DC Motor

When the DC motor is disconnected from the supply mains in Dynamic Braking, a braking resistor Rb is connected across the armature. The motor now generates the braking torque and functions as a generator. A kinetic energy is stored in the mass of an electric motor as it rotates. If the motor is disconnected from the power source, it will continue to rotate for some time until all of the kinetic energy is lost through rotational losses. The braking is more rapid the faster the kinetic energy is dissipated. The following is an illustration of the connection diagram for a separately excited DC motor, as shown in the Figure 12.4[4]–[6].

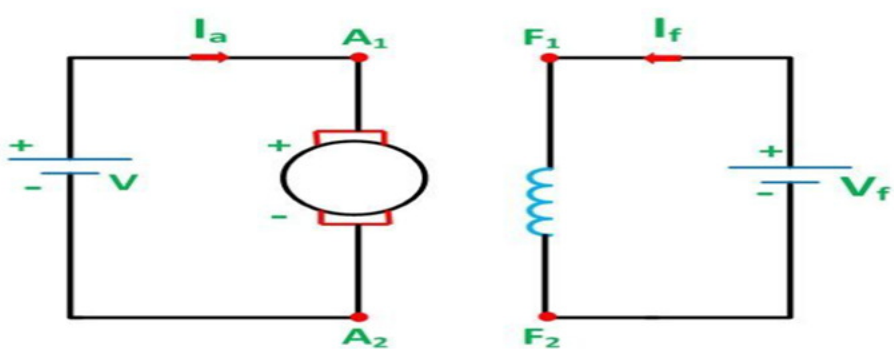

Figure 12.4: Dynamic characteristics of the DC separately excited motor

The motor is connected in two ways in Dynamic Braking for the purpose of braking. First, the separately excited or shunt motor can be connected as a flux-controlled separately excited generator. The second method involves connecting the field winding parallel to the armature to a self-excited shunt generator, when it is in the motoring mode of operation. The diagram is shown below shows the connection when braking with separate excitation is done, as shown in the Figure 12.5.

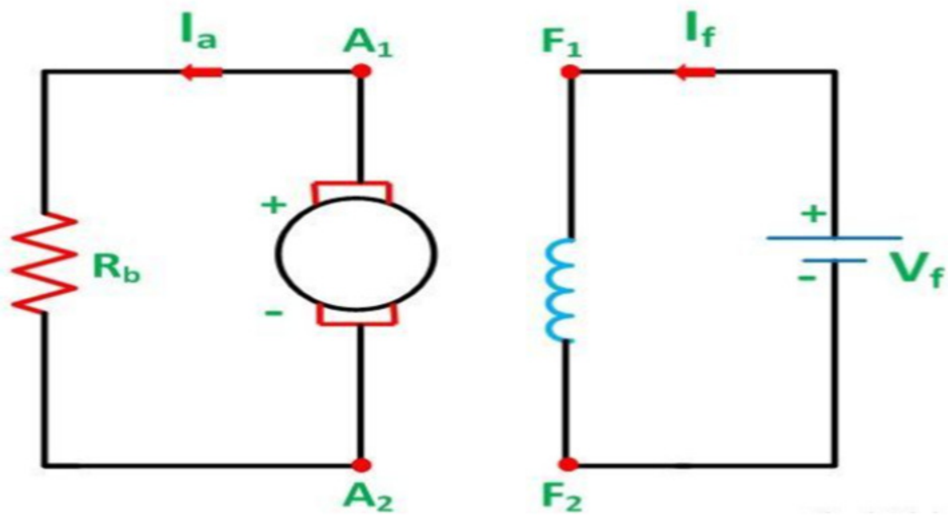

Figure 12.5: Braking with separate excitationof separately excited motor

The braking when it will be the self-excitation is designed, the diagram given below shows the relation in the Figure 12.6.

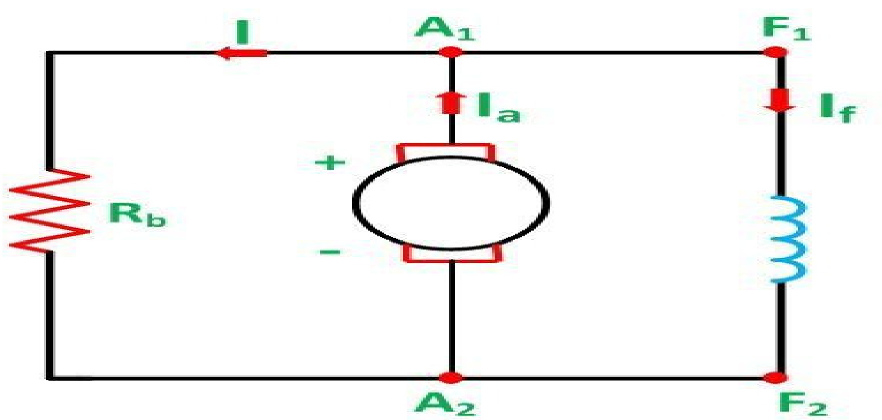

Figure 12.6: Braking with self-excitationof separately excited motor.

Because an external braking resistance Rb is connected across the armature terminals for electric braking, this method is also referred to as rheostatic braking. When the motor is acting as a generator, the kinetic energy stored in the machine's rotating parts and the connected load is converted into electric energy during electric braking. In the armature circuit resistance Ra and braking resistance Rb, the energy is lost as heat. A variable resistor called a rheostat is connected across the supply in DC shunt motors. The armature is disconnected from the supply. The supply is left connected across the field winding. Evidently, the machine begins to function as a generator as the armature is now driven by inertia. The braking effect is controlled by varying the resistance connected across the armature. As a result, the machine will now feed the current to the connected rheostat, and heat will dissipate at the rate of I^2R. The diagram of Dynamic Braking of DC Shunt Motor is shown below in given figure, when motoring mode is on, as shown in the Figure 12.7.

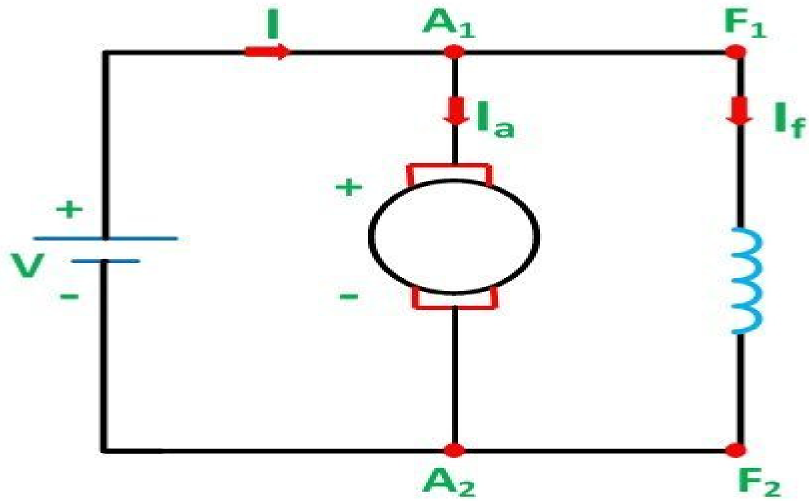

Figure 12.7: Dynamic Braking of DC Shunt Motor

The figure below depicts the connection diagram for shunt motor braking with self and separate excitation, shown in the Figure 12.8.

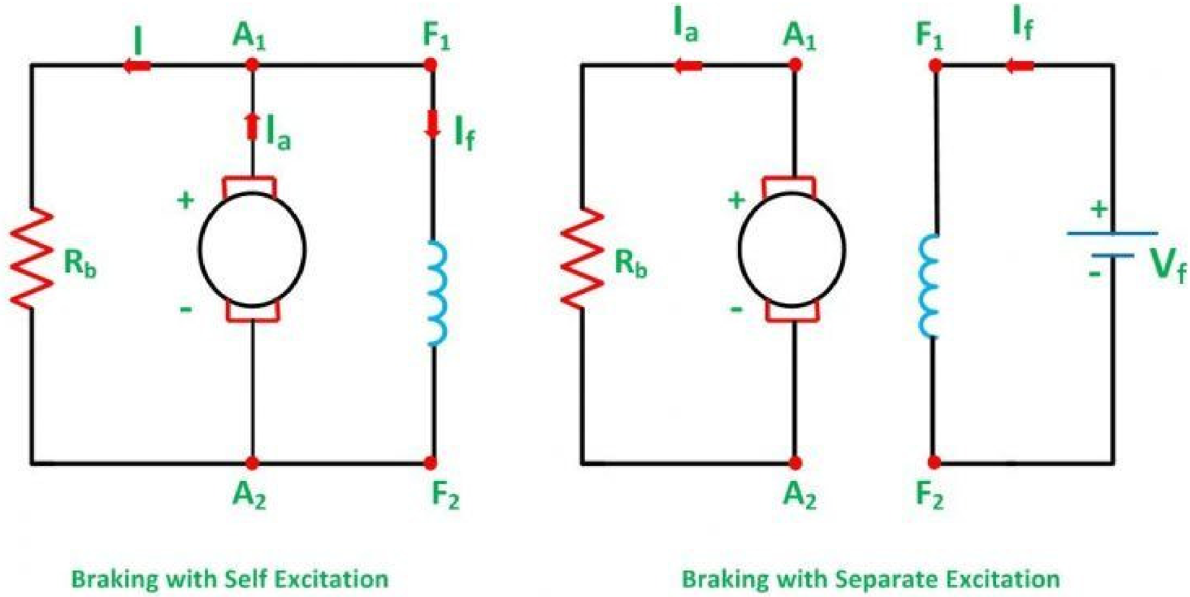

Figure 12.8: connection diagram for shunt motor braking with self and separate excitation

The series motor is disconnected from the supply for Dynamic Braking. The field windings' connections are reversed, and a variable resistance Rb is connected in series as depicted in the below Figure 12.9.

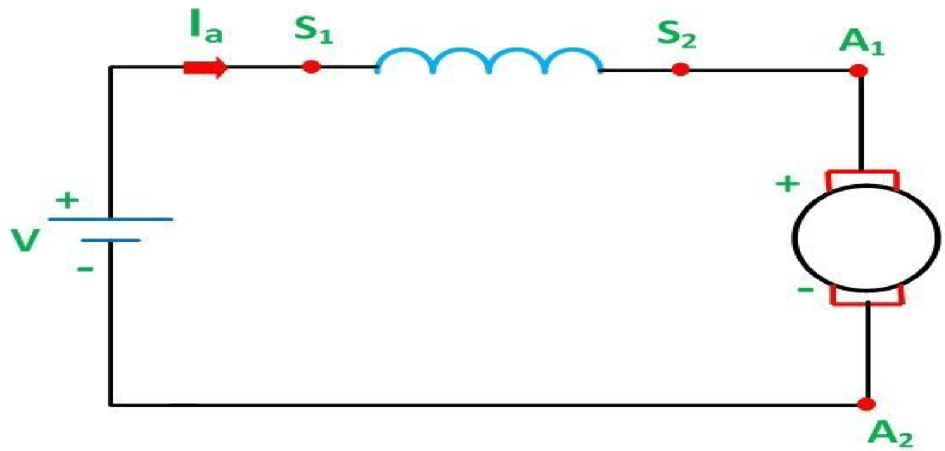

Figure 12.9: Motoring in DC series motor

Also, we have discussed about the braking with self-excitation as shown in the figure below, and we elaborate how braking with self-excitation is worked in case DC series motors, as shown in the given Figure 12.10.

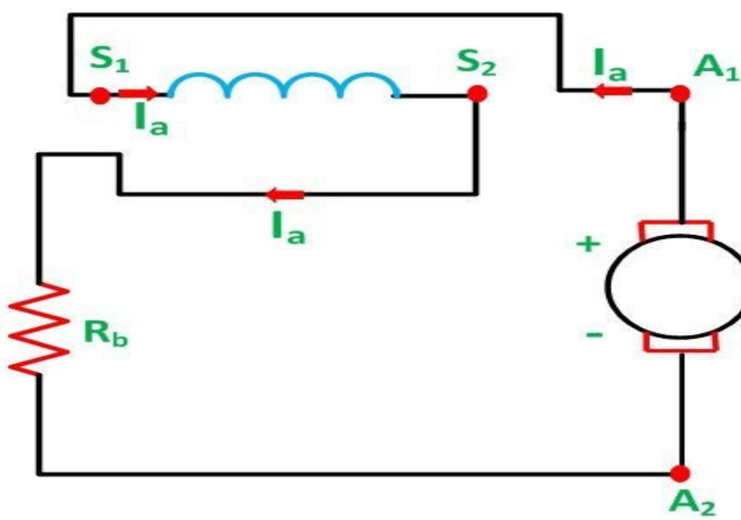

Figure 12.10: Braking with Self excitation in DC series motors

The braking process is sluggish when self-excitation is used. As a result, the machine is connected in self-excitation mode when quick braking is required. In order to keep the current at a safe level, the field and a suitable resistance are connected in series. Because all of the generated energy is lost as heat in the resistance, the Dynamic or Rheostatic Braking method is insufficient for braking.

Regenerative braking

In regenerative braking, the driven machinery's kinetic power or energy is returned to the mains power supply. When the load on the motor has a very high inertia, such as in electric trains, regenerative braking is used. It goes without saying that the armature current Ia, and consequently the armature torque, will be reversed when the applied voltage to the motor is decreased to less than the back EMF Eb. Thus, speed decreases. Regeneration is the process by which power is returned to the line when the generated EMF is greater than the applied voltage then the machine is acting as a DC generator. As speed continues to decrease, back EMF Eb also decreases until it falls below the applied voltage and the armature current again moves in the opposite direction of Eb. When the motor is continuously excited by a driven load or machinery, it can perform this type of braking at a speed higher than the no-load speed.The motor armature current moves in the opposite direction when the back EMF Eb of the motor exceeds the supply voltage V. The machine now begins to function as a generator, supplying the source with the generated energy. If the motor is connected as an independent excited generator, regenerative braking can also be performed at very low speeds. As the speed decreases, the motor's excitation increases, resulting in the satisfaction of the two equations presented below[7]–[10].

$$E_b = \frac{nP\varphi Z}{A} \quad \text{and} \quad V = E_b - I_a R_a$$

On increasing excitation, the motor does not reach saturation. The shunt and separately excited motors make it possible to perform regenerative braking. Braking is only possible in compound motors with weak series compounding**.**While still connected to the supply, the motor acts as a generator during the regenerative braking process. In this instance, the synchronous speed is lower than the motor speed. Electrical energy is produced when mechanical energy is converted into electrical energy. Some of this electrical energy is returned to the supply, while the remaining energy is stored neatly in the electrical machine's windings and bearings. When overdriven by the load, the majority of electrical machines move smoothly from the motoring region to the generating region as shown in the given below Figure 12.11.

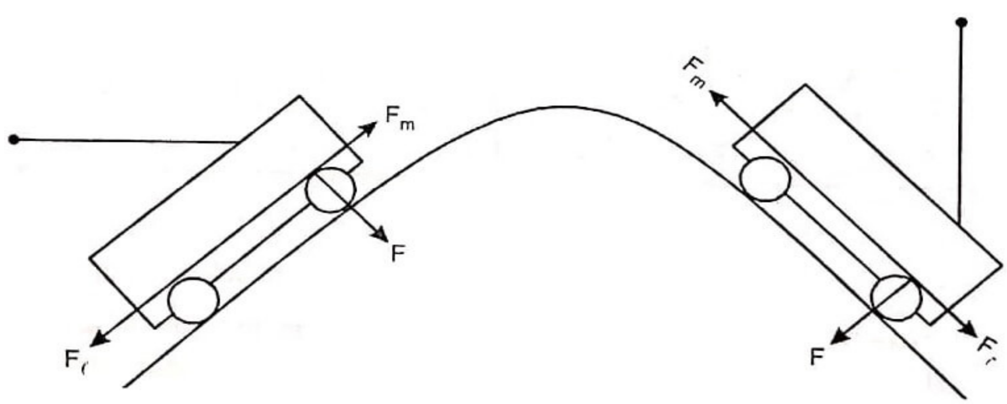

Figure 12.11: illustration of Regenerative braking

Regenerative braking in action, as depicted in the figure above. A trolley bus is being driven uphill and downhill here by an electric motor. In the upward direction, the gravity force can be divided into two components. One is parallel to the road surface Fl and the other is perpendicular to the load surface F. The parallel force pulls the motor down the hill. To propel the bus uphill, the motor must exert a force Fm opposite to Fl if we disregard the rotational losses. In the first quadrant of the figure, this operation is depicted. The load torque Tl is opposite the motor torque Tm in this instance, but the speed and motor torque are both moving in the same direction. The mechanical load receives power from the motor.

Speed-Torque Characteristics of Regenerative Braking:

When the motor's speed exceeds the synchronous speed, regenerative braking occurs. Regenerative braking is the name given to this baking technique because the supply receives power from the motors, which act as a generator. The primary requirement for regenerative braking is that the rotor must rotate at a speed greater than that of synchronous rotation; only then will the motor function as a generator, causing the direction of current flow in the circuit to reverse and braking to occur as shown in the graph between speed vs torque, as shown in the Figure 12.12.

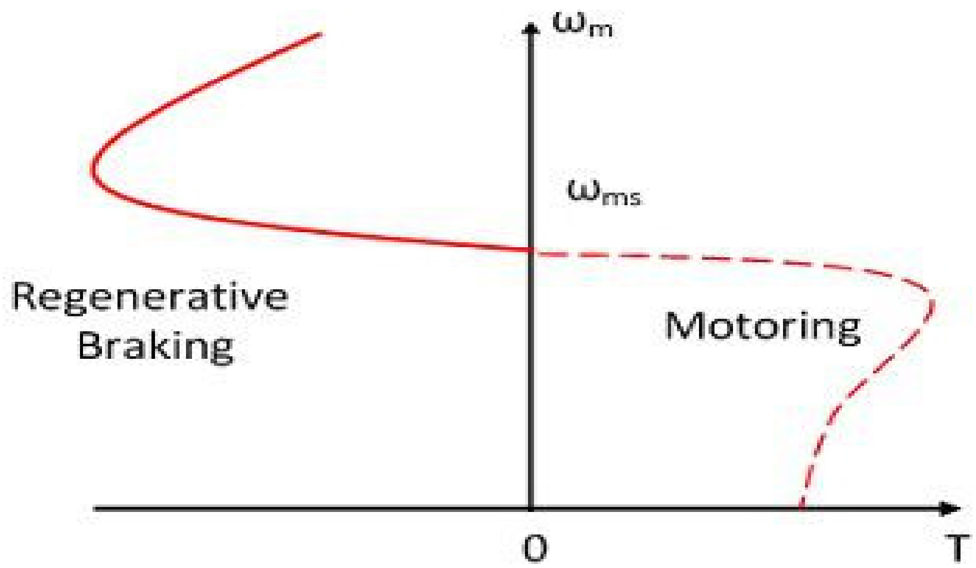

Figure 12.12: Speed-Torque Characteristics of Regenerative Braking

Applications of Regenerative braking

i. When frequent braking and driving at a slower speed are required, regenerative braking is often used.
ii. Holding a descending load of high potential energy at a constant speed is its greatest application.
iii. The speed of motors driving loads like electric locomotives, elevators, cranes, and hoists is controlled by regenerative braking.
iv. The motor cannot be stopped with regenerative braking. It is used to regulate motor driving speeds above the no-load speed.

Regeneration only works if the back EMF, Eb is higher than the supply voltage. If this happens, the armature current goes in the opposite direction and the mode of operation shifts from motoring to generating.

Regenerative Braking in DC Shunt Motors

Under the armature current at the normal operating condition is given by the equation shown below:

$$-I_a = \frac{V - E_b}{R_a}$$

The back EMF exceeds the supply voltage when the load is lowered by a crane, hoist, or lift, causing the motor speed to exceed the no-load speed. As a result, the armature current Ia turns negative. The equipment begins to function as a generator now.

Regenerative Braking in DC Series Motors

The armature current and field flux decrease when the speed of the DC Series Motor is increased. The supply voltage cannot be greater than the back EMF Eb. In a DC Series Motor, regeneration is possible because the field current cannot exceed the armature current. Where, DC Series Motors are frequently used, like in elevator hoists and traction, regeneration is required. For instance, an electro-locomotive moving down the gradient may require a constant speed. When the speed in hoist drives reaches dangerous levels, it must be reduced. Connecting a DC Series Motor as a shunt motor is one common method of regenerative braking. A series resistance is connected in the field circuit to keep the current within the safe range because the field winding has a low resistance.

Compare Electrical and Mechanical Braking

The speed of the driving motor gradually decreases until it reaches zero whenever an electric drive is disconnected from the supply. A set of operating conditions for electric drive systems is referred to as "braking," and it is a generic term. It includes quickly stopping the electric motor, holding the motor shaft in one place, keeping the speed at a desired level, and preventing the motor from going too fast. The energy can change its flow between the load and the source during the braking process. During this time, the machine acts as a generator, returning the energy to the power source. An electric drive system's entire operational cycle is highly dependent on its braking strategy. The productivity and quality of manufactured goods frequently depend on the speed and precision of braking techniques. There are typically two types of braking strategies:

1) Mechanical braking
2) Electrical braking

Mechanical braking:

If we talk about the construction and basic definition of mechanical braking, the necessary brake is produced by the frictional force between the rotating components and the brake drums. It is necessary to have mechanical devices such brake linings, brake shoes, and brake drums. This kind of brakes needs regular upkeep. The diagram shown below shows the construction of mechanical braking, as shown in the given Figure 12.13.

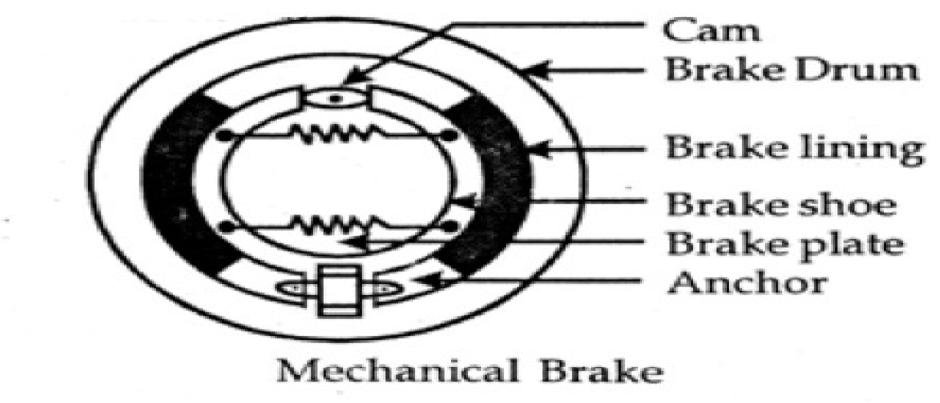

Figure 12.13: Mechanical braking in case of DC motors

Electrical braking:

The motor is made to function as a generator while using electric braking. A negative slip and torque are thus produced (braking torque). By appropriately altering the motor's electrical connections, this is accomplished. For safety reasons, the drive's braking system, whether it be mechanical or electric, electric braking should be designed to bring the motor to a complete stop at the designated time and place.

The following factors may necessitate electric braking:

i. The load torque will be the sole opposing torque in the event that a motor operating at a certain speed is disconnected from the input supply. After the kinetic energy stored in its inertia has been released, the motor will come to a stop. The motor takes a long time to come to a stop when either the load torque is low or the inertia is high. Using electric braking, additional opposing torque must be introduced to reduce stopping time in applications that necessitate frequent stops.
ii. In order to avoid accidents, quick emergency stops are necessary in some crucial applications like traction. The majority of the time, electric braking is used to make quick and very smooth stops.
iii. If the motor does not provide braking force, the drive speed will reach dangerous levels in some applications with active loads. For instance, when a loaded hoist is being lowered in a hoist application, the motor should exert braking force to maintain the safe speed. Similar to electric traction, a braking force is required to maintain a train's safe speed when traveling down a steep gradient.
iv. If the motor does not provide braking force, the drive speed will reach dangerous levels in some applications with active loads. For instance, when a loaded hoist is being lowered in a hoist application, the motor should exert braking force to maintain the safe speed. Similar to electric traction, a braking force is required to maintain a train's safe speed when traveling down a steep gradient.

Now we have to compare both the braking and find out which braking is more effective and applications of different according to the parameters in the given Table 12.1.

Table 12.1: Compare Electrical and Mechanical Braking

Mechanical Braking	Electrical Braking
It is Less effective.	It is highly effective method.
Friction wastes the energy of the rotating parts into heat.	The rotating parts' energy can be turned into electrical energy that can be used or returned to the mains.
It requires brake lining replacement and adjustment on a regular basis. They are easily damaged and worn.	It necessitates very less maintenance due to the absence of mechanical pieces of equipment.
The brakes may not be extremely smooth depending on the circumstances.	The brakes are very smooth and do not snag.
The system is held in place by applying this brake.	It is unable to generate holding torque. For it to work, electricity is needed.
In mechanical braking, we required a Brake drum, brake shoes, and brake linings, etc. for higher performance.	In some types of brakes, equipment with a higher rating than the motor rating may be required.

Electric braking is more effective and requires less upkeep than mechanical braking. However, electrical and mechanical transients can be stressful when braking. As a result, the braking system must be designed to operate safely and effectively. In this chapter we learn about the basic introduction of electric braking of DC motors and. Later we focused on the components or parts of braking and we learn about the basic types of braking and then distinguished the types into further parts.

Braking play a vital role in today's technology, and braking is used for various purpose and it proves to be very useful for the every types of vehicles as well instruments.

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Questionnaire

1. What is a magnet? Differentiate between permanent magnet and temporary magnet.
2. Discuss about the solar power plant with examples.
3. What are polyphase transformer?
4. Differentiate active and passive elements with examples.
5. Explain the methods of improving commutation?
6. What is DC generators? Explain working and construction of DC generators.
7. Explain the characteristics of series and compound DC generators.
8. What is DC motors? Discuss the working principle and construction of DC motors.
9. Explain the characteristics of series, shunt and compound DC motors.
10. Elaborate the Armature Resistance Control Method?

11. Why we need starter for DC motors?

12. Distinguished between electrical and mechanical braking.

Reference Books for Further Reading

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