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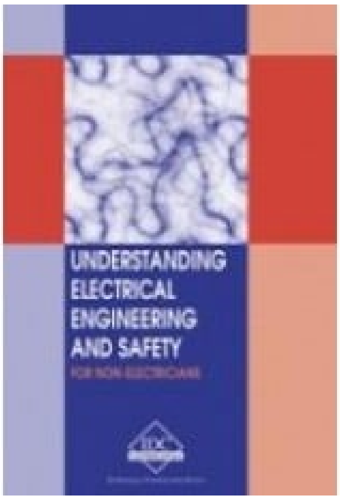
UE-E - Understanding Electrical Engineering and Safety for Non-Electricians



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Short Description

Electrical engineering is often considered to be a mysterious science, because electricity cannot be seen. However, we are all aware of its existence and usefulness in our daily lives. While many of us work on electrical systems, we do not fully appreciate the dangers, which we get exposed to when doing so. All it takes is a few simple precautions to avoid getting hurt. This manual teaches you about the dangers of careless handling of electrical appliances and prevention of electrical accidents.

Description

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This manual is not meant for electrical engineers and other qualified technicians. It is for those who are not formally trained as electricians but often have to handle and maintain electrical appliances in the course of their work. Readers will have an opportunity to understand how the appliances they see everyday actually function.

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First Chapter
Electricity

1 Electricity

Electricity plays a very important role in our daily life .It is a form of energy that helps us in many ways .It is used to light up our homes, also powers all electrical home appliances such as refrigerator, ovens, televisions, washing machines, etc. It also illuminates our streets, runs elevators, operates trains and machinery in industries and computers .Thus most of modern life would not exist if there was no electricity. But if not used safely, it can lead to fire hazards and/or fatal injuries.

Learning objectives

- Basic facts about Electricity
- Static electricity
- Electrical cells and DC
- Electricity as a form of energy
- Voltage and current relationship - Ohm's law
- Power and energy relationship
- A simple circuit using DC (battery) source
- Electromagnetic generators (AC) - relationship between magnetism and electricity
- Speed of rotation and frequency
- Single phase and 3-phase AC systems - basic facts
- Phase sequence

1.1 Basic facts about electricity

1.1.1 Types of sources

Sources are divided into two groups: primary sources and secondary sources.

Primary sources

- Renewable Sources – An energy source that are replenished naturally in a short period of time. Examples: Wind energy, Solar Energy, Water Energy, Biomass, Geothermal Energy.
- Non-renewable Sources – An energy source that we are using up and cannot recreate in a short period of time. Examples: Nuclear Energy, Natural Gas, Coal, Oil

Secondary Sources

Examples of secondary sources are electricity and hydrogen.

1.1.2 Electrical energy

Electricity or electrical energy is a form of energy that is converted into other forms of energy like:

- In an electrical heater, electrical energy gets converted into heat energy.
- With an electrical bell, electrical energy gets converted into sound energy.
- In Electrical Heating ovens and furnaces used in industries, electrical energy gets converted into heat energy.
- In Illumination, electrical energy gets converted into light energy.

This electrical energy can be generated in many ways in commercial power plants. The most common sources of power plants are:

- Fuel energy – Thermal Power plants
- Hydro-potential energy- Hydro power plants
- Nuclear energy- Nuclear power plants

For a simplified explanation of electric current, see Figure 1.1. An electric current is a movement or flow of charge similarly like the flow of water moving through the tube (wire).Electricity is a flow of current that is used to power lights, motors, tools, and many other devices.

Flow of charges in wire
Figure 1.1

1.2 Static electricity

Electricity is widely used and an extremely versatile form of energy. Every day we use electricity at least for 5 hours for our home needs. Transportation has also become much faster and easier with the use of electricity. Thus it is a powerful friend but dangerous because if electricity is used unsafely it can create a fire hazard or a fatal injury. It is most efficient in transmitting power from source to destination.

Static electricity or electrostatics is the branch of electricity which deals with the study of the properties and production of electric charges that remain at rest on a body.

The following examples show the existence of static electricity:

- A plastic comb run through dry, grease-free hair attracts bits of paper.
- A crackling sound is heard when we remove or put on nylon socks or synthetic clothes.
- When we walk across the rug, and reach for the doorknob and..........ZAP!!! It’s a static shock.

This property of attraction is due to the electric charge they possess. On rubbing, these objects acquire electric charges .These charges are called frictional charges (see Figure 1.2).

Figure 1.2

Static electricity

1.2.1 Atomic structure

To understand the theory of electrification by friction, knowledge of the atomic structure is necessary which is shown in Figure 1.3.

Everything we see is made up of tiny little parts called atoms. The atoms are made of even smaller parts. These are called protons, electrons and neutrons. They are very different from each other in many ways. One way they are different is their ‘charge’. Protons have a positive (+) charge. Electrons have a negative (-) charge. Neutrons have no charge, they are neutral. Protons and neutrons exist in the nucleus and electrons move around the nucleus in circular orbit. Under normal circumstances atoms have the same number of electrons and protons. Then the atom has no charge, it is ‘neutral’. Atoms of different elements contain different number of electrons, protons, neutrons. The electrons in an atom revolve around the nucleus in certain fixed orbits.

When a body is electrified or charged with electricity, charges are not produced or created, there is only transfer of charges from one body to another. It is always the negatively charged electrons that detach themselves from one body, leaving it positively charged, and attached themselves to another body, making it negatively charged. But charges are neither destroyed nor new charges are created during the process. The total amount of charge on the two bodies remains the same.

Figure 1.3

Structure of atom

1.1.3 Flow of charge

An amount of energy is needed to move these charges from one place to another against various types of forces to produce current. The pressure that pushes electrons in an electrical circuit is called voltage. Voltage can be thought off as similar to water pressure and electric current the water flowing through a pipe due to the water pressure.

Using a water analogy, if a tank of water was suspended one meter above the ground with a one-centimeter pipe coming out of the bottom, the water pressure would be similar to the force of a shower. If the same water tank was suspended 10 meters above the ground, the force of the water would be much greater, possibly enough to hurt you, as shown in Figure 1.4.

Figure 1.4

Flow of water

Analogy between electric and hydraulic characteristics

Let’s look at an analogy of a hose pipe and hydraulic characteristics with equivalent electric wiring characteristics:

1. Water pressure results from the head of water, e.g. a dam, and is regulated to customer in the same way that electricity comes from a power station, regulated along the way.
2. Different pressures and capacities necessitate different sized hose pipes at different sections of the route similarly differing voltages and current carrying requirements require varying size conductors and cable insulation.
3. With water, as the diameter of the pipe increases, so does the amount of water that can flow through it. Electricity is similar: a conducting wire is the pipe. As the cross-sectional area of the wire increases, so the amount of electric current (number of electrons) that can flow through it increases for any given applied voltage.
4. Water flow is measured as liters per second while electric current is measured in Amperes.
5. The water cycle takes place via evaporation and rain while electrons flow in a closed loop either via ‘Earth’ or conductor.
6. Resistance is a property that slows the flow of electrons – the current. Using the water analogy, resistance is an impediment to water flow. It could be a smaller pipe or fins on the inside of a pipe as shown in Figure 1.5. Resistance causes an opposition to the flow of electricity in a circuit.
7. There is a pressure drop while overcoming the resistance, thus reducing the flow of water. Similarly, there is voltage drop in electric circuit while overcoming the resistance, thus reducing the electric current. Thus equipment requires a minimum pressure to work efficiently.

Figure 1.5

Resistance to flow of water

Pressure difference and Potential difference

Consider two vessels connected together with water filled up to different levels. Water flows until the water levels, and hence the water pressure, are the same in the two vessels as in Figure 1.6a. To make the water flow continuously, you need to connect a water pump to the second vessel, which constantly pumps up the water to the first vessel. In this way, the level and hence the pressure of water in the first is always higher and the flow of water is continuous as in Figure 1.6b. Water flows continuously because of the ‘pressure difference’ in the two vessels, maintained by the pump.

Figure 1.6a Figure 1.6 b

Flow of water Flow of water using pump

Similarly, for electric charge to move we need some device that can constantly ‘pump’ charges in the same manner to create a ‘charge difference’. In electricity this is known as electric force or Potential Difference**.** And flow of charge is known as Electric Current. Thus, more the potential difference more is the current flow as shown in Figure 1.7.

Figure 1.7

Flow of charge in electric circuit

Thus now we know that electrons flow from a body that has an excess of electrons to one that has a deficit of electrons, i.e. from a body that is negatively charged, to a body that is positively charged. Earlier scientists thought that electric current was the flow of positive charge from a positively charged body to a negatively charged body. They therefore took this as the direction of flow of current. Today we consider the flow of conventional current to be from positive to negative and the flow of electronic current to be from negative to positive as shown in Figure 1.8.

Figure 1.8

Direction of conventional current

Thus, if conventional current flows from point A to point B in a wire we say that A is at a higher potential than B, or that there is a potential difference between A and B. The conventional current and not electronic current is said to flow from high to low potential. And electronic current flows from low to high potential.

The SI unit of current (I) is the Ampere (A) which means the flow of 1 Coulomb charge (Q) past any point in the conductor in one second time (t). **I = Q/t**

The SI unit of potential difference is the Volts (V). The potential difference (V) between two points is 1 Volt if 1 joule of work (W) is done in moving 1 coulomb of electric charge (Q) from one point to another. **V = W/Q**

1.3 Electric cells and DC (dry cell)

A device that can make charges move continuously in a wire by creating a potential difference is known as an electric cell.

1.3.1 Types of cells

Cells are of two types: primary cells and secondary cells

Primary cell: A primary can supply electric current until the electrolyte is exhausted or the negative electrode is completely dissolved. Then it has to be discarded. Even when stored, without being used, it discharges of its own accord. The shelf life of a primary cell is about one year. Example: Dry Cell.

Secondary Cell: A secondary cell can be recharged by passing a current in an opposite direction to the current that normally flows from the cell. During the process of recharging, the electrode surface is reformed and the electrolyte returns to its original state. Example: Lead acid cell.

The terms cell and battery are used interchangeably but incorrectly. A battery means a group of interconnected cells. A cell is one unit of battery.

1.3.2 Simple voltage cell

A simple voltage cell consists of copper and zinc electrodes immersed in an electrolyte (generally dilute sulphuric acid). When the electrodes are immersed in sulphuric acid, the acid decomposes into H_2^+ and SO_4^- ions. The surface of the zinc electrode dissolves in the sulphuric acid, the zinc atoms combining with sulphate ions to form zinc sulphate. In this process zinc atoms leave electrons on the zinc electrode which acquires a negative charge. The positively charged hydrogen ions travel to the copper electrode from which they acquire electrons. In giving up electrons the copper electrode becomes positively charged. Thus the potential difference is created between the copper and zinc electrodes. Now if the copper and zinc electrodes are connected externally, electrons flow from the zinc electrode to the copper electrode through the external path and the chemical action continues. Current flows from the copper electrode to the zinc electrode as in Figure 1.9.

If the copper and zinc electrodes are not connected externally, the chemical action ceases because zinc electrode becomes so negative that it repels the negatively charged sulphate ions and copper electrode repels hydrogen ions. The potential difference between the electrodes is typically 1.1 volts.

Figure 1.9

Simple voltage cell

1.3.3 Dry cell

The dry cell is a primary cell and is widely used in torches, portable music systems, etc. A dry cell consists of zinc container, which also serves as a negative terminal. The electrode is a paste of ammonium chloride. A carbon rod with a brass cap serves as the positive electrode. It is surrounded by a paste of powdered manganese dioxide and carbon particles as shown in Figure 1.10. In the dry cell, hydrogen is also formed in the chemical reactions that take place in the cell. The manganese dioxide reacts with the hydrogen formed and prevents it from collecting on the zinc terminal. A seal at the top prevents the chemicals from drying out. The cell is dry from outside but the chemicals must be kept moist, otherwise it will not work. The electrons flow in a wire connecting the two terminals from the zinc to the carbon electrode the carbon electrode. The dry cell, being compact, light and portable, is very convenient to use. The output voltage does not depend on the size of the cell. However the maximum current that can be drawn from the cell very much depends on the physical size of the cell.

Figure 1.10

Dry cell

1.3.4 Nickel cadmium cells

The nickel-cadmium cell is a rechargeable cell. This sealed cell is a small convenient package of high energy output and can be recharged for hundreds of cycles giving a long active life. Its main application is in portable electrical and electronic equipments such as movie cameras, electronic calculators and mobile phones. It is an alkaline cell. There are three types: button cells, cylindrical cells, rectangular cells.

1.3.5 Lead acid batteries

A lead acid battery is a device for storing chemical energy. During the process of charging, electrical energy is supplied to the battery and this energy is stored as chemical energy. When discharging, the stored chemical energy is converted into electrical energy which is supplied to the load connected to the battery terminals. Lead acid battery is a secondary cell and is very commonly used in power stations, substations, laboratories, etc.

1.4 A simple circuit using DC source

The arrangement for obtaining electric current by connecting it to a source of electric current is known as an electric circuit. An electric circuit is a continuous conducting path for electric current consisting of circuit elements such as lamps and conducting wires and a source of current such as a battery. Usually a key or switch is introduced in a circuit to complete it or break it. Figure 1.11a shows a simple electric circuit in which the circuit allows the flow of current so it is said to be complete or closed. In Figure 1.11b, one wire is disconnected from the circuit hence there is no flow of current so it is said to be incomplete or open. Figure 1.11c shows a circuit with a switch. The switch is an important part of an electric circuit. It is present in all circuits.

Figure 1.11

Simple electric circuit

An important element of a circuit is a resistor which offers some resistance to the flow of current. This resistance to the movement of current comes about because of the collision of the free electrons in a conducting wire with other electrons, atoms and ions in the wire.

On the basis of the resistance, substances can be divided into three groups:

- **Conductors**: Substances which offer very low resistance to the flow of current,
  g. copper, silver, aluminium, zinc.
- **Resistors**: Substances which allow high resistance to the flow of current, g. nichrome, tungsten.
- **Insulators:** Substances which offer infinite resistance to the flow of current, i.e. they do not allow current to flow through them, e.g. rubber, bakelite, plastics.

1.5 Electricity as a form of energy

Energy is the ability of a body to do work .So energy is measured by the amount of work that can be done by the object. Energy cannot be created or destroyed but can be converted from one form to another. Once work has been done, energy must have been expended (or transformed) from one type of energy to another. All forms of energy are stored in different ways, in the energy sources that we use every day, e.g. we burn coal to get heat energy.

1.6 Voltage and current relationship - Ohm’s law

EMF (electromotive force) is the name usually given to the total source voltage (voltage of a battery). Usually there is some voltage drop in the source itself. The voltage available at the terminals of the source is called as output voltage or terminal voltage or simply voltage. The SI unit of voltage is Volts.

The German physicist Dr. George Ohm experimentally determined the relation between voltage and current in conductors. That relation is known as Ohm’s law. Ohm’s law states that:

The potential difference (V) between the ends of a conductor is equal to the product of its resistance(R) and current (I). **V=IR**

Alternatively, the current in a path is a linear function of the potential difference across the path. **I=V/R**

A resistor which obeys Ohm’s law is called a linear resistor. A circuit which contains only linear components is called a linear circuit. But particularly in the electronics field, the volt ampere graph shows not a straight line but a curve. Such elements are called as nonlinear elements. The resistance of a nonlinear element is still defined as the ratio of potential difference to current but this resistance is not independent of the current and does not obey Ohm’s law. Figure 1.12 shows the relationship between volt and Ampere for linear and nonlinear resistors. The straight line in the figure shows the ideal straight line graph.

Figure 1.12

Graph for volt and Ampere

The SI unit of resistance is the Ohm. The ohm is defined as the resistance which permits a flow of 1 ampere when potential difference of 1 volt is applied to the resistance. The reciprocal of resistance is conductance (G). The SI unit of conductance is siemens. A siemens is also known as mho.

Ohm’s law is valid if the physical conditions like temperature are kept constant. This law is also valid for time varying voltages and current.

1.7 Power and energy relationship

1.7.1 Power

Power is the rate of doing work

Power = work/time

The SI unit of power is watt (W) which is defined as the power developed when 1 joule of work is done in 1 second.

Consider the motion of a charged particle in an electric field between two metal plates to which a voltage is applied as shown in Figure 1.13.

Figure 1.13

Motion of particle in an electric field

From Figure 1.13, the force acting on the particle is only in one direction towards positive plate and electric intensity or electric field strength is given by force per unit charge.

Force = electric intensity x charge (1)

Work done is given by

$$Work = force \times distance$$

$$= electric\ intensity \times Charge \times distance \quad (2)$$

But the voltage between the two plates is the product of electric intensity and the distance between the plates

$$V = Electric\ intensity \times distance \quad (3)$$

Thus from (2) and (3

$$Work = V \times Q \quad (4)$$

$$Power = work / time$$

$$= VQ / t$$

But Current $I = Q / t$ (5)

Thus Power = VI = Voltage x Current (6)

By using Ohm's law

$$Power = VI = (IR) \times I = I^2 \times R$$

When current flows through electrical equipment, a certain amount of power is consumed because of the resistance of the equipment. This power loss appears as heat which raises too much, the insulation on the equipment or even the equipment may be damaged. The maximum temperature rise depends on the power loss ($I^2 \times R$) and the ability of the equipment to dissipate heat into the surrounding air. The larger the surface area of the equipment and freer the circulation of air around this surface area, the more readily the equipment can dissipate heat. Depending on the amount of power loss in the equipment and its ability to dissipate heat, all equipments have a power rating which is the amount of power the equipment can safely handle without an excessive temperature rise.

1.7.2 Energy and its relationship with power

Energy is the capacity to do work. Once the work is done, energy must have been expended or transformed from one type of energy to another.

Energy = work = Voltage x charge from (4)

= V x I x t from (5)

= power x time from (6)

When 1 watt of power is delivered to an electrical appliance for 1 second, the energy consumed is 1 watt-second or 1 joule. As watt-second being a very very small unit, a practical unit of electrical energy is kilo watt-hour (KWh) is in use. It is also called commercial unit of electrical energy as electrical supply authorities charge the consumers for the kilowatt-hours of energy consumed.

1.8 Electromagnetic generators

Before studying electromagnetic generators, we should know first the concept of magnetic induction and electromagnetic induction.

1.8.1 Magnet and properties of magnets

Any material that has the property of attracting iron is called a magnet. Magnetite or loadstone is a natural magnet. The property of attraction is termed as magnetism. But as it occurs in odd shape it is not convenient to use. Thus mostly manmade magnets are in use. They are known as artificial magnets. The force that the magnet exerts on iron is called magnetic force.

Types of magnets

On the basis of retention of magnetism, magnets can be broadly classified into two types:

- Temporary magnets: These magnets are usually made of soft iron. They retain their magnetism only for a short duration. They lose their magnetizing power when the magnetizing force is removed.
- Permanent magnets: These magnets are made of steel, cobalt or nickel and retain their magnetism for a long time even when the magnetizing force is removed.

Shapes of magnets

Artificial magnets are of various shapes and sizes:

- Bar magnet
- Horse shoe magnet
- U-shaped magnet
- Cylindrical magnet
- Magnetic Needle
- Magnetic Compass

Parts of bar magnet

Figure 1.14 shows the parts of the bar magnet.

- Magnetic poles: The points (N *and*S) at the two ends of a magnet are called the poles of magnets.
    - The point N at the end of a freely suspended bar magnet pointing towards the north is the Magnetic North Pole.
    - The point S at the end of a freely suspended bar magnet pointing towards the South is the Magnetic South Pole.
- Magnetic axis: It is an imaginary line (XY) passing through the north and south poles of a magnet.
- Magnetic equator: It is an imaginary vertical line (PQ) dividing the magnet into two poles.
- Effective length: It is the distance between the magnetic north pole and magnetic South Pole.
- Length of magnet: It is the distance (N or S) between the centre of magnet and one pole.

Figure 1.14

Parts of bar magnet

Properties of magnets

- A magnet always points in the north-south direction when hung freely.
- A magnet attracts magnetic substances like steel, nickel and iron.
- Like poles repel and unlike poles attract each other.

1.8.2 Magnetic field

A bar magnet, suspended freely by thread, tends to align itself in the north-south direction. When the north pole of the magnet is brought near the north pole of another magnet, a force of repulsion is experienced. The force of repulsion is also experienced when South Pole of magnet is brought near the south pole of another magnet. However when N and S poles are brought near to each other, the magnets are attracted to each other.

The fact that repulsion or attraction occurs when two magnets are brought nearer is a force field exists around the magnets and that the field tends to be concentrated at the magnet's poles. This force around a magnet is known as magnetic field. The region around a magnet in which its magnetic influence can be felt is called as its magnetic field. It is strongest near the magnet and decreases with distance. It is assumed that magnetic lines of force exit from the north pole of a magnet and enter the magnet at its south pole. The direction of lines of force is defined as the direction in which an isolated north pole would move if it is placed in the magnetic field. These magnetic lines of are known as magnetic flux. Figure 1.15 shows magnetic field between poles.

Figure 1.15

Magnetic field

1.8.3 Magnetic induction

A magnet can induce magnetism in an object made of magnetic even without actual contact. If the north pole of a magnet is brought near an unmagnetized piece of iron, the latter becomes magnetized by induction with South Pole at the nearer end and North Pole at the far end. Thus, magnetic induction is a process by which a piece of magnetic material becomes a magnet when it is placed near or touching a permanent magnet. Magnetic induction is temporary. If the magnet is removed, the induced magnetism disappeared.

1.8.4 Electromagnetism

When an electric current is passed through a conductor, a magnetic field is set up around the conductor. This can be shown by simple experiment. Take one cardboard with hole in the centre. Pass a conductor through the hole by placing cardboard horizontally. Then sprinkle some iron fillings on cardboard. When the current in the conductor is zero, the iron fillings lie scattered in a haphazard manner. Now if a current is passed through the conductor and cardboard is tapped, the iron fillings settle in concentric rings around the conductor. This shows there is a magnetic field around the conductor. The direction of the magnetic field can be found by using right hand screw rule.

The right hand rule states that: Grasp the wire in the right hand, with the thumb pointing in the direction of the current. The fingers will curl around the wire in the direction of the magnetic field. It is illustrated in Figure 1.16.

Figure 1.16

Right hand thumb rule

Since a current carrying conductor has a magnetic field around it, when two current carrying conductors are brought close together, there will be interaction between the fields. When the currents in the two conductors are in opposite direction, the fields are in repulsion. Conclusively we can say that, the strength of the magnetic field is proportional to the direction of current. If current is doubled, the magnetic field is doubled. If the current is reduced to zero, the magnetic field is also reduces to zero. If the direction of current is reversed, the magnetic field also reverses its direction.

Electromagnetism is used both in the conversion of mechanical energy to electrical energy (in generators) and the converse in the case of electric motors.

1.8.5 Electromagnets

The magnet made by using electric current is called an electromagnet. An electromagnet made by passing electric current through a wire coiled around an iron bar. A coil of wire with an electric current flowing through it becomes a magnet. Putting iron inside a current-carrying coil increases the strength of the electromagnet. A changing magnetic field induces an electric current in a conductor.

For making electromagnet a long coil of insulated copper wire is taken and wound around an iron rod as shown in Figure 1.17. The two ends of the coil of copper wire are connected to a battery through switch. The current is switched on and it flows through the copper wire and produces a magnetic effect on the iron rod. Thus the iron rod gets magnetized. Now if the current is switched off, all the magnetism of the iron rod disappears.

Figure 1.17

Electromagnet

Uses of Electromagnets

Electromagnets are used in:

- Electric motors which are used in fans, washing machines and other electrical appliances.
- In making electric bells.
- To separate iron and steel objects from the heap of metal scrap.
- For carrying heavy steel and cast iron articles.

1.8.6 Electromagnetic induction

Now we know that a current flowing in the conductor produces a magnetic field. Similarly the converse is also possible that means a magnetic field can also able to produce a current in a conductor. This phenomenon is known as electromagnetic induction.

Faraday's Law of electromagnetic induction

Whenever a conductor lies in a changing magnetic field, there is an induced emf in it. If the conducting path is a closed circuit, a current will flow. The magnitude of the current depends on the emf (voltage) and resistance of the circuit (remember Ohm's Law). The direction of the current is the same as the direction of the induced emf. A conducting loop which has an ammeter attached to it will register a current if the magnetic flux through the loop changes in time. The change may arise from motion. Or the change in flux may be due to the changing current in a circuit. In Figure 1.18a there is no induced emf in loop 2 but when the battery is connected, the increasing current in loop 1 produces a changing magnetic field and hence induces an emf in loop 2 as in Figure 1.18b.

+

Figure 1.18

Electromagnetic induction

Faraday noted that the emf induced in a loop is proportional to the rate of change of magnetic flux though it.

$E = N * d\hat{I} /dt$

Where E is the electromotive force induced (measured in volts)

N is the number of turns of the coil.

Î is the flux derivative.

The negative sign the above equation is given by Lenz's Law. This states that the induced emf (and current) will be in a direction such that the induced magnetic field opposes the original magnetic flux change.

1.8.7 Electromagnetic generators and motors

An electric motor is an electromagnetic device that transforms electrical energy into mechanical energy. An electric generator is an electromagnetic device that transforms mechanical energy into electrical energy. Finally, a transformer is an electromagnetic device makes it possible to convert electrical power.

There are three requirements for an emf to be induced in conductor: presence of a conductor, presence of magnetic field and linking or cutting of the lines of force by the conductor. There are three methods by which a conductor can link/cut lines of force of a magnetic field. They are as follows:

- Stationary permanent magnet or direct current electromagnet and moving conductor. This arrangement is used in all DC generators and motors.
- Stationary conductor, moving permanent magnet or direct current electromagnet. This arrangement is used in all AC generators and motors.
- Stationary electromagnet, stationary conductor and a variation of magnetic flux by supplying alternating current to the electromagnet. This arrangement is used in transformers.

The emf induced by relative motion between the conductor and the field in methods 1 and 2 is termed as ‘dynamically induced emf’. The emf induced in method 3 is known as ‘Statically induced emf’.

1.9 Direct current and alternating current

There are two different ways that electricity is produced, and they are used in most cases for very different purposes. They can also be converted from one form to another.

The first and simpler type of electricity is called direct current, abbreviated 'DC'**.** This is the type of electricity that is produced by batteries, static and lightning. A voltage is created, and possibly stored, until a circuit is completed. Then the current flows directly, in one direction. In the circuit, the current flows at a specific, constant voltage. When you use a flashlight, pocket radio, portable CD player or virtually any other type of portable or battery-powered device, you are using direct current. Most DC circuits are relatively low in voltage; for example, your car's battery is approximately 12 V, and that's about as high a DC voltage as most people ever use. A representation of a direct current's voltage over time is shown in Figure 1.19.

Figure 1.19

DC circuit graph

The other type of electricity is called alternating current, or 'AC' and that we use to power most of our electrical appliances. Alternating current is harder to explain than direct current. The electricity is not provided as a single, constant voltage, but rather as a sinusoidal (sine) wave that over time starts at zero, increases to a maximum value, then decreases to a minimum value, and repeats. A representation of an alternating current's voltage over time is shown in Figure 1.20.

Figure 1.20

AC circuit graph

1.9.1 Speed rotation and frequency

While simple direct current circuits are generally described only by their voltage, alternating current circuits require more detail. First of all, if the voltage goes from a positive value to a negative value and back again, what do we say is the voltage? Is it zero, because it averages out to zero? That would seem to imply that there is no energy there at all. But imagine, if you will, a wave of water flowing across the surface of the sea. The peaks and troughs of the wave seem to 'cancel each other out', but the wave clearly exists and has energy. The same is true of alternating current.

The way to measure the energy in an AC signal is to compute what is called the root mean square (RMS) average of the voltage. In simple terms, the RMS value of an electrical current is the number which represents the same energy that a DC current at that voltage would produce; it is in essence an average of the alternating current waveform.

The other key characteristic of AC is its frequency, measured in cycles per second (cps) or, more commonly, Hertz (Hz). This number describes how many times in a second the voltage alternates from positive to negative and back again, completing one cycle.

1 Hz means that an event repeats once per second, 2 Hz is twice per second, and so on. To calculate the frequency of the event, the number of occurrences of the event within a fixed time interval are counted, and then divided by the length of the time interval.

An alternative method to calculate frequency is to measure the time between two consecutive occurrences of the event (the period) and then compute the frequency f as the reciprocal of this time:

$f = 1/T$ Where T is the period.

A more accurate measurement takes many cycles into account and averages the period between each cycle.

Why does standard electricity come only in the form of alternating current? There are a number of reasons, but one of the most important is that a characteristic of AC is that it is relatively easy to change voltages from one level to another using a transformer, while transformers do not work for DC. This capability allows the companies that generate and distribute electricity to do it in a more efficient manner, by transmitting it at high voltage for long lengths, which reduces energy loss due to the resistance in the transmission wires. Another reason is that it may be easier to mechanically generate alternating current electricity than direct current.

1.10 Single phase and three phase AC systems

1.10.1 Voltage in AC systems

Now we know that an alternating voltage is one which acts in alternate positive and negative directions. Its magnitude undergoes definite series of changes in definite intervals of time. The generation of an alternating voltage is shown in Figure 1.21.

Figure 1.21

Principle of generation of AC

When a conductor is rotated in a magnetic field a voltage is induced in the conductor. Even when the speed of rotation is constant, the rate and the direction of cutting of the field depend on the position of the conductor. Voltage follows the path as shown in Figure 1.18 completing the one rotation. The variation in emf has exactly the same relation as the variation of sine of an angle between zero and 360°.Therefore this is called a sinusoidal or sine wave.

1.10.2 Single phase AC systems

Phase is the term given to the timing of the magnets passing over the coils at different times during power generation. In AC systems we'll talk a lot about the phase of the current relative to the voltage. The current and voltage are in phase with each other, which means that the peak voltage is reached at the same instant as peak current as shown in Figure 1.17. Such a system in which only one circuit is used similar to 2 wire DC circuit is known as single phase AC systems or we can say a single-phase system is one where there is only one AC voltage source (one source voltage waveform) as shown in Figure 1.22.

Figure 1.22

Single phase AC circuit graph

Single-phase electric power refers to the distribution of electric power using a system in which all the voltages of the supply vary in unison. Single-phase distribution is used when loads are mostly lighting and heating, with few large electric motors.

1.10.3 Three phase AC systems

In AC systems it is possible to use two, three or more individual circuits in the same device. These circuits operate at the same frequency. However their voltages and current are out of phase from one another. Such systems are known as polyphase systems.

The system with three circuits is known as three phase AC system. Figure 1.23 shows the pattern of waveform of typical three phase system. In which three colors are three different phases working simultaneously. The generation of AC electric power is commonly three phase. In Three phase AC systems, the waveforms of three supply conductors are offset from one another by 120°. Standard frequency is 50 Hz.

Advantages of three phase systems over single phase system are:

- A three phase transmission line requires less conductor material than a single phase line for transmitting the same amount of power at the same voltage.
- For a given frame size a three phase machine gives a higher output than a single phase machine and also takes more load than Single Phase.
- Three phase motors are self starting and are more efficient. On the other hand single phase motors are not self starting and are less efficient. 3 phase power is typically 150% more efficient than single phase in the same power range.

Figure 1.23

Three phase AC circuit graph

1.11 Phase sequence

Phase rotation, or phase sequence, is the order in which the voltage waveforms of a three phase AC source reach their respective peaks.

For a three phase system, there are only two possible phase sequences: 1-2-3 and 3-2-1 corresponding to the two possible directions of alternator rotation as shown in Figure 1.24.

Figure 1.24

Phase sequence

1.12 Summary

In this chapter we studied basic concepts about electricity, the relationship between magnetic field and electricity, basic electric circuits and AC and DC waveforms. In following chapters we will study generation of electricity, distribution, transmission all in details along with AC motors, DC motors and transformers.