Unit 19

Electromagnetic Induction

Teaching Periods 16 **Weightage %** 11

The Zorlu Energy Power Project is a wind farm situated in Jhimpir, Thatta District, in the Sindh province of Pakistan. This project, Pakistan's first wind farm, has gained global recognition. Wind power relies on electromagnetic induction to generate electricity.

In this unit student should be able to:

- Describe the production of electricity by magnetism.
- Explain that induced e.m.f can be generated in two ways.
  (i) by relative movement (the generator effect). (ii) by changing a magnetic field (the transformer effect).
- Infer the factors affecting the magnitude of the induced e.m.f.
- State Faraday's law of electromagnetic induction.
- Account for Lenz's law to predict the direction of an induced current and relate to the principle of conservation of energy.
- Apply Faraday's law of electromagnetic induction and Lenz's law to solve problems
- Explain the production of eddy currents and identify their magnetic and heating effects.
- Explain the need for laminated iron cores in electric motors, generators and transformers
- Define Self Induction and its unit
- How an inductor is used to store electric potential energy?
- Derive energy produced in Self Induction is $E = \frac{1}{2} LI^2$
- Explain Mutual Inductance (M) and its unit henry.
- Describe the construction of a transformer and explain how it works.
- Identify the relationship between the ratio of the number of turns in the primary and secondary coils and the ratio of primary to secondary voltages.
- Recall that how step up and step-down transformers can be used to ensure efficient transfer of electricity along cables.
- Describe the use of step-down and step-up transformers for the electric supply from power station to houses and electric appliances at home.
- Solve problems using $\frac{N_s}{N_p} = \frac{V_s}{V_p}$
- Define motional emf and Compute the potential difference across ends of a given rod or wire moving through a magnetic field
- Explain construction and working of an AC generator
- Identify the factors affecting induced EMF of an AC generator
- Solve problems using $\xi = \xi_0 \, Sin^2\pi ft$
- Describe the main features of an A.C motor and the role of each feature.
- Explain the production of back emf in electric motors.

Introduction:

Electromagnetic induction stands as a cornerstone in the realm of physics, serving as a fundamental principle that explains the dynamic relationship between electricity and magnetism. Discovered by the famous physicist Michael Faraday in the early 19th century, electromagnetic induction encompasses the phenomenon where the change in the magnetic fields induces the generation of an electromotive force (EMF) or voltage within a conductor. This revolutionary concept not only laid the groundwork for the understanding of essential electrical processes but also paved the way for the development of modern technologies such as electric generators and transformers. As we examine the intricacies of electromagnetic induction, we work out the interplay between magnetic flux, electric current, and the connection that binds these phenomena together. In this chapter, we understand the implications and applications of electromagnetic induction, from its beginning to its current prevailing influence on modern technology and industry.

19.1.2 Production of electricity by magnetism:

In order to demonstrate that moving electric charges (i-e an electric current) give rise to magnetic force, put a magnet compass near to current carrying wire the needle of compass will be deflected as shown in figure 19.1 This shows that moving charges produce magnetic field and in turn deflect magnetic compass. Such a demonstration for the first time was carried out in 1819 by Professor Hans Oersted of the University of Copenhagen

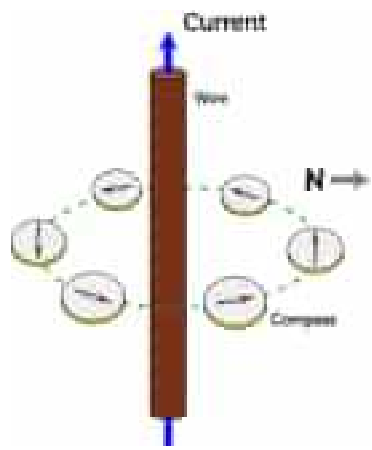


Figure 19.1 compass near to current carrying wire

The working of electric motor is based on this simple phenomenon, the current carrying coil produce magnetic field which interacts with the surrounding magnets causing the coil to rotate. In this case the electric energy is being converted into mechanical energy. The mechanical energy can be used to do variety of work, for example to pump water from ground level to a certain height.

On the other hand, the moving magnet produces electric force. To observe this phenomenon connect a coil with a sensitive galvanometer and a magnet move inside it. The relative motion of coil and motion will produce induced electric current. If the motion of magnet is stopped induced current ceases to exist.

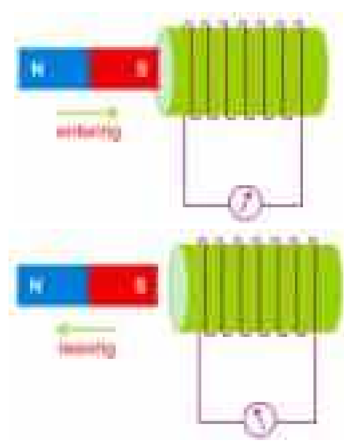


Figure 19.2 coil, Galvanometer and moving magnet

The simple experiment as shown in figure 19.2 is similar to the working of electric generator. In the electric generator the conductor coil is rotated within the field of permanent magnet. The changing magnetic field produces induced electric current. In 1831 Micheal Faraday demonstrated that copper coils exposed to changing magnetic field produces electric current in the coil. Michael Faraday demonstrated this phenomenon with the help of copper coil, a magnet and a galvanometer. If the magnet was brought near to the coil an induced emf was produced and galvanometer shown current in one way. When the magnet was moved from the coil away the direction of induced current was reversed and galvanometer needle swing other way.

The phenomenon in which an emf is induced in the coil due to the change in linking magnetic flux is called electromagnetic induction.

DO YOU KNOW?

An induction stove, also known as an induction cooktop, is a type of cooking appliance that uses electromagnetic induction to heat cookware directly. Not all cookware is compatible with induction stoves. Cookware must have a magnetic bottom or base to work effectively on an induction cooktop.

19.1.1 Induced Electromotive force EMF:

Induced electromotive force (emf) can be generated in two primary ways: by relative movement and by changing a magnetic field.

(i) By Relative Movement (The Generator Effect):

This method is based on Faraday's Law of Electromagnetic Induction, which states that an emf is induced in a conductor when it experiences a change in magnetic flux. The generator effect, also known as motional emf, occurs when there is a relative motion between a conductor and a magnetic field.

Example:

In a simple electrical generator, a coil of wire rotates within a magnetic field. This induced emf drives an electric current through an external circuit.

(ii) By Changing a Magnetic Field (The Transformer Effect):

This method also relies on Faraday's Law but involves changing the strength or orientation of a magnetic field around a stationary conductor.

Example:

In a transformer, an alternating current in the primary coil creates a changing magnetic field. This is the basis for how transformers transfer electrical energy between circuits at different voltages.

Generator Effect:

Induced emf due to relative motion between a conductor and a magnetic field.

Transformer Effect:

Induced emf due to a changing magnetic field around a stationary conductor.

Both effects are fundamental principles in electromagnetism and are widely utilized in various electrical devices and systems.

19.1.4 Faraday's law of electromagnetic induction:

Faraday's law of electromagnetic induction is a fundamental principle in electromagnetism that describes the relationship between a changing magnetic field and the induced electromotive force (emf) or voltage in a closed circuit as illustrated in figure 19.3. It can be stated as follows:

The electromotive force (emf) induced in a closed circuit is directly proportional to the rate of change of magnetic flux passing through the circuit.

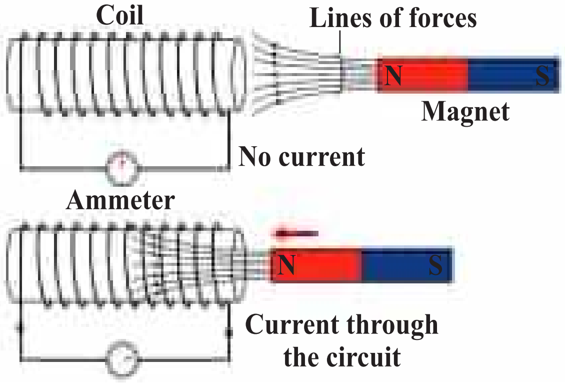


Figure 19.3 Electromagnetic induction

Mathematically, Faraday's law is often expressed as:

$$\varepsilon = -N\frac{\Delta\phi}{\Delta t} \quad ......(19.\ 1)$$

Where ε represents the induced electromotive force (emf) measured in volts (V).

$\frac{\Delta\phi}{\Delta t}$ Represents the rate of change of magnetic flux with respect to time, it is measured in weber per second (Wb/s or V), and N indicates number of turns of the coil: Negative sign is introduced because the induced emf opposes the change in flux. It will be explained in Lenz's law.

DO YOU KNOW?

Electromagnetic braking is a method of slowing down or stopping a moving object, such as a vehicle, using the principles of electromagnetic induction. Electromagnetic braking is used in electric and hybrid vehicles, where regenerative braking systems utilize this technology to transform kinetic energy into electrical energy. This generated electrical energy is then stored in batteries or capacitors for future use.

19.1.3 Factors affecting the magnitude of the induced emf:

The magnitude of the induced electromotive force (emf) in a circuit or coil is governed by several factors, which are primarily described by Faraday's law of electromagnetic induction. These factors include:

1. **Magnetic Flux Change:** If the rate of change of magnetic flux is higher, it will lead to a larger induced emf. Conversely, a slow change in the magnetic field will result in a smaller induced emf.
2. **Number of Turns in the Coil:** If a coil of wire has more turns, the greater will be the induced emf. Each turn of the coil contributes to the emf, so increasing the number of turns increases the overall emf.
3. **Area of the Coil:** The size of the coil or the area it encloses also affects the induced emf. A larger coil or a coil with a larger cross-sectional area will capture more magnetic flux lines, resulting in a larger induced emf.

4. **Angle between Magnetic Field and Coil:** The angle between the magnetic field lines and the plane of the coil affects the induced emf. When the magnetic field is perpendicular to the coil's plane (90°), the emf is maximized. When the field lines are parallel (0°), the emf is minimized.
5. **External Factors:** External factors, such as temperature, material property, pressure, and other environmental conditions, can also influence the induced emf, especially in situations where materials may exhibit nonlinear magnetic properties.

Self-Assessment Questions:

1. Explain Faraday's law of electromagnetic induction and its significance in electrical systems.
2. How does the rate of change of magnetic flux affect the induced electromotive force (EMF) in a coil?

19.1.4 Lenz's law and principle of conservation of energy:

After the introduction of Faraday's law of electromagnetic induction, Heinrich Friedrich Lenz formulated a rule for determining the direction of an induced current within a loop.

According to Lenz's law ***"The direction of induced emf in a circuit is always such that it opposes the cause which produces it"***

In Figure 19.4 (a) as the North Pole of the magnet approaches the surface of the coil, an induced current is generated within the coil in a anti clock wise direction. Consequently, the coil generates a North magnetic pole, resulting in a repulsive force experienced by the approaching magnet. In this manner, the coil resists the factor responsible for inducing the electromotive force (emf).

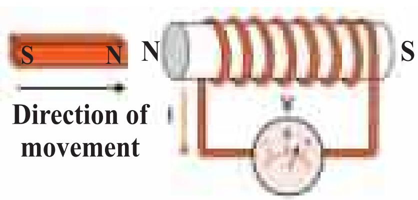


Figure 19.4 (a) Direction of induced emf

In Figure 19.3 (b), as the North Pole of the magnet moves away from the coil, an induced current is generated within the coil in a clockwise direction. Consequently, the coil generates a South magnetic pole, resulting in a attractive force experienced by the leaving magnet. Hence the law states that the induced current flows in a manner that oppose the change which is giving rise to it. That is why negative sign is introduced in equation 19.1.

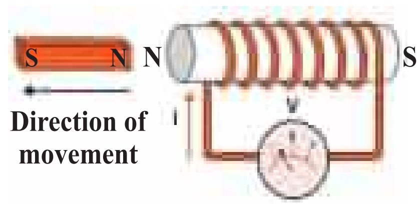


Figure 19.4 (b) Direction of induced emf

Lenz's law and Conservation of Energy:

The principle of conservation of energy states that energy cannot be created or destroyed; it can only change forms. When we apply this principle to electromagnetic induction, we see that the work done in changing the magnetic field is converted into electrical energy in the form of the induced current. Hence lenz's law is in accordance with the law of conservation of energy.

Self-Assessment Questions:

1. Provide an example from everyday life or technology where Lenz's law is applied.
2. Discuss the consequences of not following Lenz's law in electromagnetic systems.

Worked Example 19.1

A coil with 100 turns and an area of 0.02 square meters is placed in a changing magnetic field. The magnetic field changes from 0.2 Tesla to 0.5 Tesla in 0.1 seconds. Calculate the induced electromotive force (emf) in the coil, the direction of the induced current, and how this relates to Lenz's law.

Solution:

Step 1: Write the known quantities and point out quantities to be found

B changes from 0.2 Tesla to 0.5 Tesla
Time t = 0.1 seconds.
No of turns = 100
Area A = 0.02 m^2
Induce emf = ?

Step 2: Write the formula and rearrange if necessary

$$\varepsilon = -N\frac{\Delta\emptyset}{\Delta t}$$

Step 3: Now, substitute the values into the formula:

$$\varepsilon = -N\frac{\emptyset_2 - \emptyset_1}{\Delta t} = 100 \times \frac{0.01 - 0.004}{0.1}$$

$$\varepsilon = -6\,V$$

Result: The induced emf in the coil is *6 V*, and the induced current flows counterclockwise to oppose the increase in the external magnetic field, in accordance with Lenz's law.

Worked Example 19.1

A coil with 200 turns and an area of 0.03 square meters is placed in a uniform magnetic field of 0.4 Tesla. The coil is quickly pulled out of the magnetic field in 0.2 seconds. Calculate the induced electromotive force (emf) in the coil and determine the direction of the induced current.

Solution:

Step 1: Write the known quantities and point out quantities to be found

B = 0.4T
Radius of coil = *r* =0.1m
$A = 0.03\,m^2$
The coil is pulled out of the magnetic field in 0.2 seconds.
Induce and its direction =?

Step 2: Write the formula and rearrange if necessary

Calculate the initial and final flux:

So initial flux = $\emptyset_1$= 0.4 × 0.03 = 0.012 Weber

Calculate the final flux:

When the coil is completely out of the magnetic field, the flux becomes zero because there is no magnetic field passing through the coil. Final flux $\emptyset_2 = 0$

Step 3: Now, calculate the rate of change of flux: =

$$\frac{\Delta\emptyset}{\Delta t} = \frac{\emptyset_2 - \emptyset_1}{\Delta t} = \frac{0 - 0.012}{0.2} = -\,0.06\,Wb/s$$

$$\varepsilon = -N\frac{\Delta\emptyset}{\Delta t} = -1.2\,Volts$$

Result: The induced current flows counterclockwise to oppose the decrease in magnetic flux, in accordance with Lenz's law.

Eddy currents and their magnetic and heating effects:

Eddy currents are circulating currents induced in a conductor when it is exposed to a changing magnetic field. They are a common phenomenon in electromagnetic systems. These currents can have both magnetic and heating effects. Now let's discuss about the production of eddy currents and their effects:

19.2.1 Production of Eddy Currents:

Eddy currents are produced according to Faraday's law of electromagnetic induction, which state that a changing magnetic field induces an electromotive force (emf) in a conductor. When a conductor, such as a metal plate or a coil of wire, is subjected to a changing magnetic field, the magnetic flux through the conductor changes, leading to the induction of eddy currents. As shown in figure 19.5.

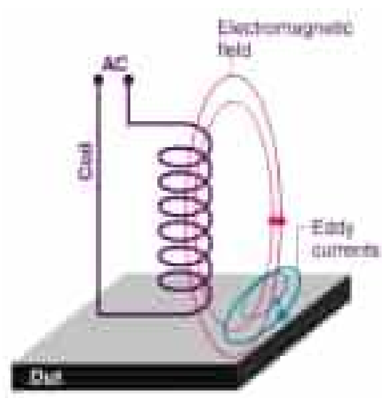


Figure 19.5
Production of Eddy Currents.

19.2.2 Magnetic Effects of Eddy Currents:

Counteracting Magnetic Field:

Eddy currents generate their own magnetic fields, and the direction of these fields opposes the original magnetic field that induced them as a result, eddy currents create a magnetic field that counteracts the original magnetic field's change, thereby reducing the net magnetic field.

Magnetic Damping:

In applications like electromagnetic brakes and magnetic dampers, eddy currents are intentionally induced to create a magnetic resistance that opposes motion. This magnetic damping effect is useful for controlling the movement of objects and slowing them down.

19.2.3 Heating Effects of Eddy Currents:

Joule Heating:

Eddy currents experience resistance as they flow through the conductor, and this resistance results in the conversion of electrical energy into heat, following Joule's law. Eddy currents can heat up the conductor. In some cases, such as induction heating for metal processing or cookware, this heating effect is used for practical applications.

19.2.4 Reduction of Eddy Currents:

In many electrical systems, eddy currents represent an undesirable source of energy loss, especially in transformers and electric motors. To minimize these losses, laminated cores are used in transformers to break up the conducting paths and reduce the formation of eddy currents.

The use of laminated iron cores in electric motors, generators, and transformers is essential for several important reasons:

In all three types of devices, the iron cores are exposed to alternating magnetic fields. When a solid iron core is used, it can create circular electrical currents within the core material called eddy currents. These eddy currents dissipate energy in the form of heat and can be highly inefficient. Laminated cores are constructed by stacking thin sheets or laminations of iron separated by insulating material. This design significantly reduces the formation of eddy currents because the laminations are electrically insulated from each other. Consequently, energy losses due to eddy currents are minimized.

Enhanced Efficiency:

By reducing the losses associated with eddy currents, laminated cores improve the overall efficiency of electric motors, generators, and transformers. Less energy is wasted as heat, allowing these devices to operate more efficiently and with less energy consumption.

Mitigation of Vibration and Noise:

Eddy currents generated in a solid iron core can lead to vibrations and noise, which can be undesirable in many applications. Laminated cores help reduce these vibrations and noise levels, making the devices quieter and more mechanically stable.

Better Cooling and Thermal Management:

Since laminated cores result in reduced heat generation due to decreased eddy current losses, they often allow for more efficient cooling and thermal management in these devices. This can lead to longer operational lifetimes and improved reliability.

Self-Assessment Questions:

1. When might the heating effects of eddy currents be undesirable?
2. How do the dimensions of a conductor impact the formation and magnitude of eddy currents?

19.3.1 Self Induction:

When an electric current pass through a coil, it creates a magnetic field around it. If the current in the coil changes, either increasing or decreasing, the magnetic flux within the coil also changes accordingly. As a result of the change in magnetic flux, an induced emf is generated in the same coil. This process, where a changing current in the coil induces an emf in the coil itself, is known as self-induction.

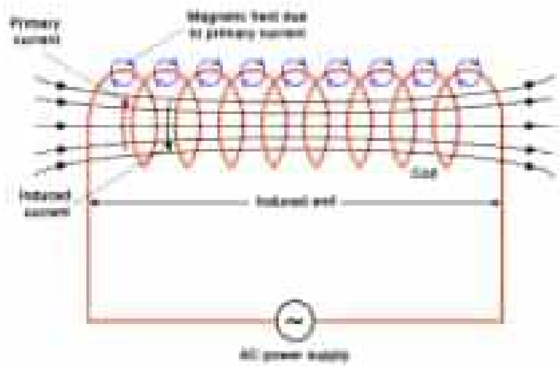


Figure 19.6 Self Inductions

Consider the circuit shown in Figure 19.6. which comprises a coil connected in series with a battery and a rheostat. When the rheostat is adjusted, it changes the current flowing through the circuit, leading to changes in the magnetic flux within the coil. These variations in magnetic flux result in the induction of an electromotive force (emf) within the coil.

If we denote the magnetic flux through a single loop of the coil as$\emptyset$, then the total magnetic flux passing through the N turns of the coil would be N$\emptyset$. This relationship holds true because the magnetic flux, directly proportional to the magnetic field, which, in turn, is proportionate to the current (I) flowing through the circuit

$$N\emptyset \propto I$$

$$N\emptyset = LI \ldots\ldots\ldots\ldots\ldots (19.2)$$

Where $L = \frac{N\emptyset}{I}$ is constant of proportionality called the self inductance of coil. It depends on factors such as the coil's number of turns, its cross-sectional area, and the material used for the core. Hence inductance of coil made up of soft iron is greater than the air core coil.

By the Faradays law of electromagnetic induction

$$\varepsilon = -N\frac{\Delta\emptyset}{\Delta t} \ldots\ldots\ldots\ldots\ldots\ldots (19.3)$$

Substitute equation (19.2) in Equation (19.3), we get

$$\varepsilon = -L\frac{\Delta I}{\Delta t} \ldots\ldots\ldots\ldots\ldots (19.4)$$

Equation (19.4) shows that the self-induced electromotive force (emf) within a coil is directly proportional to the rate of change of current within the coil. We can define the self-inductance, denoted as "L," as the ratio of this emf to the rate of change of current in the coil.

The negative sign in equation (19.4) signifies that the self-induced emf always opposes the cause that produces it. This is the reason why the self-induced emf is often referred to as the "back emf." Consequently, due to the phenomenon of self-inductance, coils of wire are commonly known as "inductors." In the field of electrical and electronics engineering, inductors find widespread use.

Unit of Inductance:

The unit of self-inductance is the Henry (H), named after the American physicist Joseph Henry.

One Henry (1 H) is defined as the amount of self-inductance in a circuit when a change in current of 1 ampere per second (1 A/s) induces an electromotive force (emf) of 1 volt (1 V) within the same circuit. Mathematically, this relationship can be expressed as:

$$1\ Henry = \frac{1 Volt}{1\ Ampere\ per\ Second}$$

19.3.2 Energy Stored in an Inductor:

An inductor is a passive electrical component that stores energy in the form of a magnetic field when an electric current flow through it. The ability of an inductor to store electric potential energy is based on the fundamental principle of electromagnetic induction. Here's a simple explanation of how an inductor stores electric potential energy:

Current Flow:

When an electric current flow through a coil of wire (the inductor), it creates a magnetic field around the coil.

Magnetic Field Buildup:

As the current increases, the strength of the magnetic field around the coil also increases. This process takes a short amount of time, as the magnetic field does not build up instantly; it grows with the rate of change of the current.

Energy Storage:

The energy is stored in the magnetic field. The inductor stores electric potential energy in this magnetic field. The more current that flows through the inductor or the faster the current changes, the stronger the magnetic field, and thus, the more energy is stored.

Magnetic Field Collapse:

When the current decreases or stops (like when you turn off the power), the magnetic field starts to collapse. As it collapses, it induces an electromotive force (EMF) or voltage in the coil.

Released Energy:

This induced voltage represents the stored energy being released. The inductor converts the stored magnetic energy back into electric energy. This energy can be used to sustain the current for a short period or can be transferred to other parts of the circuit.

Self-Assessment Questions:

1. When is the energy stored in an inductor released?
2. Provide examples of practical applications where the energy stored in inductors is crucial.

19.3.3 Energy produced in Self Induction:

An inductor stores energy in its magnetic field when it carries a direct current (DC). This energy remains stored as long as the inductor continues to carry the current. When the current in the inductor increases, the stored energy also increases, and conversely, it decreases when the current is reduced.

Consider an inductor connected to a DC power source through a switch, as depicted in Figure 19.7. When the switch is closed, the current in the inductor gradually rises until it reaches its maximum value, denoted as I. This changing current leads to a corresponding change in the magnetic flux within the coil, causing an induced electromotive force (emf) to establish itself in the coil. Consequently, an induced current is generated in the circuit, which works to minimize the current produced by the battery in accordance with Lenz's law.

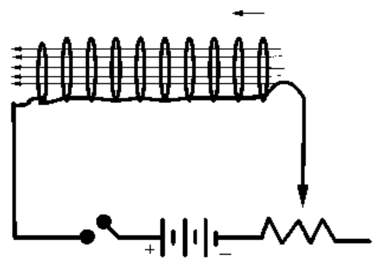


Figure 19.7 Energy produced in Self Induction

As a result, the battery must perform work on the charges to build up the current I. This work is mathematically expressed as follows:

$$W = \Delta V \Delta q \quad \ldots\ldots\ldots\ldots (19.5)$$

As the induced emf is produced in the inductor so $\Delta V = \varepsilon_L = L\frac{\Delta I}{\Delta t}$ and using work energy relation equation (19.5) can be written as

$$E = \frac{\Delta q}{\Delta t} L \Delta I \quad \ldots\ldots\ldots\ldots (19.6)$$

Since $\frac{\Delta q}{\Delta t} = \frac{0+I}{2} = \frac{I}{2}$

Equation (19.6) becomes $E = \frac{1}{2} L I^2$

Where:

- E is the energy stored in joules (J).
- L is the self-inductance of the inductor in Henries (H).
- I is the current flowing through the inductor in amperes (A).

This formula tells you that the energy stored in an inductor is directly proportional to the square of the current passing through it and is also dependent on the inductance of the inductor itself. As the current increases, the energy stored in the inductor increases, and as the current decreases, the stored energy decreases.

19.4.1 Mutual Inductance:

Imagine two closely positioned coils, as depicted in Figure 19.8. The first coil, known as the primary coil, is connected to a battery through a variable resistor 'R' and a switch 'S.' The second coil, known as the secondary coil, is connected to a galvanometer.

When the resistance is adjusted, it causes a change in the

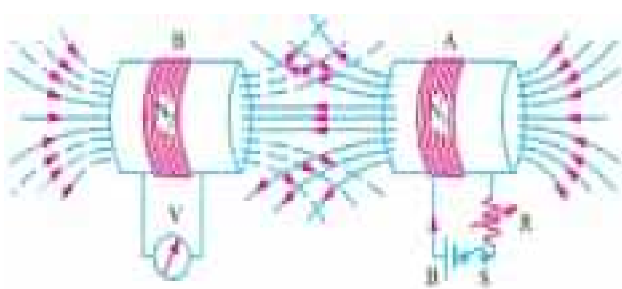


Figure 19.8 Mutual Inductance

electric current 'I' within the primary coil. This change results in the production of a varying magnetic field that interacts with the nearby secondary coil, effectively establishing a connection between them. Consequently, an electromotive force (EMF) is induced in the secondary coil in accordance with Faraday's law. **"A phenomenon where a changing current in one coil induces an electromotive force (EMF) in another coil is known as mutual induction".**

Consider the two closely wound coils of wire shown in Figure 19.8. The current I_1 in primary coil A, which has N_1 turns, creates a magnetic field. Some of the magnetic field lines pass through secondary coil B, which has N_2 turns. Let the flux passing through secondary coil having N turns be is $N_s\emptyset_s$. This magnetic flux depends on the primary coil current I_p

$$N_s\emptyset_s \propto I_p$$

$$N_s\emptyset_s = MI_p \text{............ (19.7)}$$

$$M = \frac{N_s\emptyset_s}{I_p}$$

Here, 'M' represents the proportionality constant known as the mutual inductance between the two coils. Mutual inductance depends on factors such as the number of turns in the coils, their geometrical characteristics, the materials used to construct the coils, and the separation between them. When the separation between the coils increases, the mutual inductance decreases as a result of the diminishing magnetic flux.

From faradays law of electromagnetic induction

$$\varepsilon_s = -N_s\frac{\Delta\emptyset_s}{\Delta t} \text{........ (19.8)}$$

Substitute Equation (19.7) in Equation (19.8), we get

$$\varepsilon_s = -M\frac{I_p}{\Delta t} \text{.............. (19.9)}$$

Equation (19.9) shows that induced emf produce in the secondary coil is equal to negative rate of change of current in the primary coil.

Equation (19.9) can be used to provide us a definition of mutual inductance which is Henry

$$M = -\frac{\varepsilon_s}{\left(\frac{I_p}{\Delta t}\right)}$$

One Henry (H) of mutual inductance can be defined as the mutual inductance between two coils when an EMF of one volt is induced in the secondary coil when the rate of change of current in the primary coil is one ampere per second.

Mutual inductance measures the ability of one coil to induce an electromotive force (EMF) in another coil when the current in the first coil changes.

Self-Assessment Questions:

1.Give an example of devices or systems where mutual induction is utilized.

2. What are the advantages of using mutual induction in practical applications.

19.5.1 Transformer:

A transformer is an electrical device used to transfer electrical energy between two or more coils of wire through electromagnetic induction. It can either step up (increase) or step down (decrease) the voltage of an alternating current while keeping the frequency of the alternating current unchanged. It works on the principle of mutual induction.

Construction of a Transformer:

The transformer consists of following main components as shown in figure 19.9.

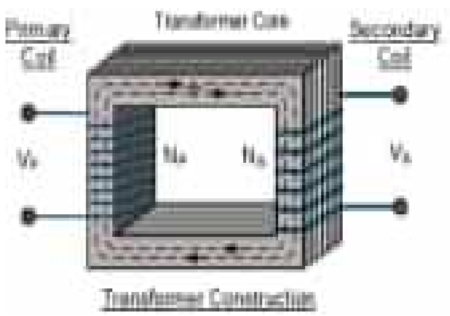


Figure 19.9 Transformer:

Core:

Transformers consist of two coils of wire, known as the primary coil and the secondary coil, wound around a common magnetic core. The core is typically made of materials with high magnetic permeability, such as laminated iron or ferrite, to enhance the efficiency of the transformer.

Primary Coil:

The primary coil is connected to the input voltage V_p source. It consists of a specific number of turns of wire wound around one section of the core denoted as N_p.

Secondary Coil:

The secondary coil is connected to the load or the device that needs the transformed voltage. It has a different number of turns of wire wound around another section of the core denoted by N_s.

Insulation:

Both the primary and secondary coils are insulated from each other to prevent electrical contact and ensure electrical isolation.

Working of a Transformer:

Imagine we have an alternating electromotive force (emf) applied to the primary coil. If, at a certain moment (t), the magnetic flux within the primary coil is changing at a rate of $\frac{\Delta\phi}{\Delta t}$ this change in flux will induce a counteracting electromotive force (emf) in the primary coil, opposing the applied voltage. We can express the instantaneous value of this self-induced emf as follows:

$$\text{Self-induced emf} = -N_p\frac{\Delta\phi}{\Delta t}$$

If the coil's resistance can be considered negligible, then the opposing emf in the primary coil is equal in magnitude but opposite in direction to the applied voltage. This relationship can be represented as:

$$V_p = -N_p\frac{\Delta\phi}{\Delta t} \quad \text{.......... (19.10)}$$

Here, N_p represents the number of turns in the primary coil.

Now, let's assume that the flux passing through the primary coil also flows through the secondary coil. In other words, these two coils are magnetically linked. Hence, the rate of change of magnetic flux in the secondary coil will also be $\frac{\Delta \phi}{\Delta t}$, and the magnitude of the induced emf across the secondary coil can be expressed as:

$$V_s = -N_s \frac{\Delta \phi}{\Delta t} \text{ .... (19.11)}$$

Where Ns is number of turns in secondary

When we divide equation (19.11) by equation (19.10), we obtain

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

Step-Up or Step-Down Transformers:

The ratio of the number of turns in the primary coil (Np) to the number of turns in the secondary coil (N_s) determines whether the transformer is a step-up or step-down transformer. If $N_s > N_p$ than it's a step-up transformer and it increases the voltage. Conversely, if $N_p > N_s$ it is a step-down transformer and it decreases the voltage.

19.5.2 Step up transformer:

Step-up transformers are designed to increase the voltage of electricity. They have more turns in the secondary coil than in the primary coil, resulting in a higher secondary voltage compared to the primary voltage.

Reduced Current:

Increasing the voltage through a step-up transformer reduces the current while maintaining the same power (P = VI). Lower current reduces the resistive losses in the transmission cables. The power lost as heat (I^2R losses) is proportional to the square of the current, so decreasing the current significantly reduces these losses.

Efficient Long-Distance Transmission:

High voltage is essential for efficient long-distance power transmission. Step-up transformers are used at power generation plants to raise the voltage, allowing electricity to be transported over extensive electrical grids with minimal energy loss. This is especially important for transmission lines covering large distances.

19.5.3 Step-Down Transformers:

Voltage Reduction:

Step-down transformers, on the other hand, lower the voltage from high levels to safer, more usable levels for homes and industries. They have fewer turns in the secondary coil, which decreases the secondary voltage.

Balanced Current:

While step-down transformers decrease voltage, they increase the current to maintain the same power. This is beneficial for local distribution because it ensures that the power can be delivered to homes, businesses, and industrial facilities while minimizing I^2R losses over shorter distances.

Self-Assessment Questions:

1. Differentiate between a step-up transformer and a step-down transformer, providing examples of each.
2. Name the fundamental principle behind the operation of a transformer

19.5.4 Transmission of Electricity:

Step-down and step-up transformers are used for the electric supply from power station to houses and electric appliances. Here's how they are used in the electric supply process a shown in figure 19.10:

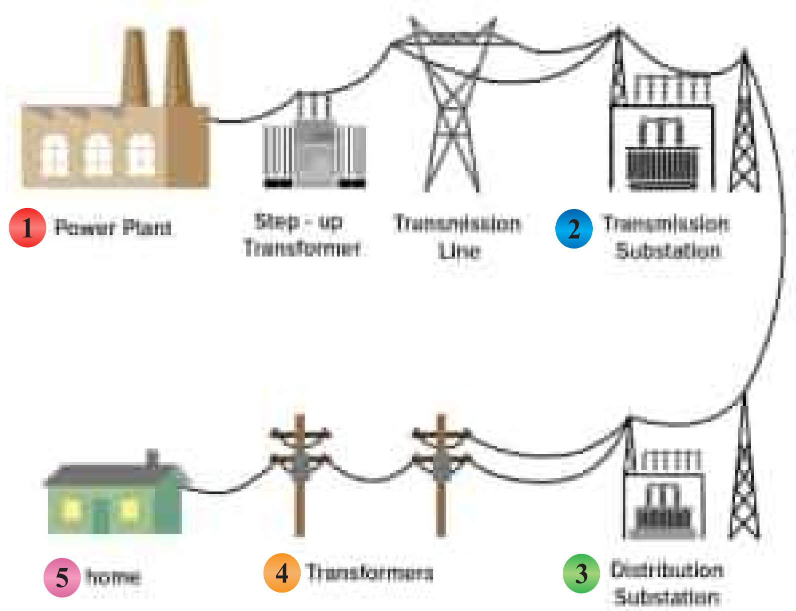


Figure 19.10 Transmission of Electricity

1. Power Generation at the Station:

Electricity is generated at power stations, often using generators powered by various sources such as hydel, coal, natural gas, nuclear energy, or renewable sources like wind and solar. The electricity generated is typically produced at a relatively low voltage level. For efficient generation and long-distance transmission, higher voltages are preferred to minimize energy losses.

2. Step-Up Transformers at the Power Station:

To raise the voltage to levels suitable for long-distance transmission, step-up transformers are employed at the power station. Step-up transformers increase the voltage and reduce the current, which lowers the I^2R losses, making electricity transmission more efficient. High-voltage transmission lines, such as overhead power lines or underground cables, carry the electricity over long distances to substations.

3. Transmission and Substations:

The high-voltage electricity is transmitted over transmission lines to substations located at various points in the electricity distribution network. At these substations, step-down transformers are used to lower the voltage to a more manageable level for further distribution.

4. Step-Down Transformers in Substations:

Step-down transformers reduce the high-voltage electricity to lower, safer voltage levels, suitable for local distribution. This lower voltage is then distributed to houses through distribution lines.

Worked Example 19.3

Suppose a step-up transformer have 200 turns in the primary coil and 800 turns in the secondary coil. If the voltage in the primary coils is 120 volts, calculate the voltage in the secondary coil.

Solution:

Step 1: Write down the known quantities and quantities to be found.

$N_p = 200$ $N_s = 800$ Vp = 120 volts Vs = ?

Step 2: Write down the formula and rearrange if necessary.

Using the turns ratio equation: $\frac{V_s}{V_p} = \frac{N_s}{N_p}$

Step 3: Substitute the known values:

Substitute the known values: $\frac{V_s}{120} = \frac{800}{200}$

Step 4: Solve for V_s,

We get: $V_s = 480\ Volts$

Result: The voltage in the secondary coil is 480 volts.

Worked Example 19.4

Let a step-down transformer have 600 turns in the primary coil and 150 turns in the secondary coil. The voltage in the primary coil is 240 volts. Calculate the voltage in the secondary coil.

Solution:

Step 1: Write down the known quantities and quantities to be found.

$N_p = 600$ $N_s = 150$ Vp= 240 Vs= ?

Step 2: Write down the formula and rearrange if necessary.

$\frac{V_s}{V_p} = \frac{N_s}{N_p}$

Step 3: Substitute the known values:

$$\frac{V_s}{240} = \frac{150}{600}$$

Step 4: Now, solve for V_s, we get:

$V_s = 60\ \text{Volts}$

Result: So, the voltage in the secondary coil is 60 volts.

19.6.1 Motional emf:

Motional electromotive force (emf) is a phenomenon that arises when a conductor moves through a magnetic field, inducing an electromotive force within the conductor. This concept is based on Faraday's law of electromagnetic induction and is a fundamental aspect of electromagnetism. Motional emf is commonly appears in various practical applications. For example, the generation of electricity by a generator. When a coil of wire rotates in a magnetic field, motional emf is induced, leading to the generation of electric current.

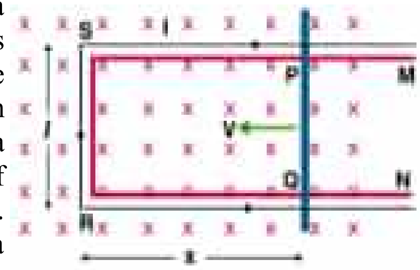


Figure 19.11 Motional emf

Understanding motional emf is crucial in designing and analyzing systems involving the motion of conductors in magnetic fields, and it plays an important role in the working of devices such as generators and certain types of sensors.

In summary, the Motional electromotive force (emf) is the voltage induced in a conductive rod as it moves through a magnetic field.

Consider a straight wire PQ having length l, as shown in figure 19.11. The conductor is in motion within a rectangular loop PQRS. This motion occurs within a uniform magnetic field B, perpendicular to the plane of the page. We assume that the rod moves uniformly at a constant velocity of v meters per second, and the surface it moves on is frictionless.

Each free electron of the conductor is moving with the conductor and thus experiences a force

$$F = -e\,(\vec{V}\times\vec{B}) \quad \textbf{or} \quad F = e\,(\vec{V}\times\vec{B})$$

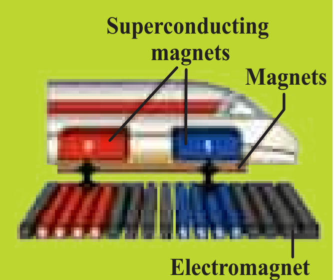
Electrons continue to accumulate at one end of the conductor, creating an excess of electrons, which results in a negative charge at that end. Conversely, the opposite end, with a deficiency of electrons, leads to the development of a positive charge. This process generates a potential difference within the wire, which is termed as motional electromotive force (emf). In order to derive an expression for the motional emf, we use the definition of potential difference.

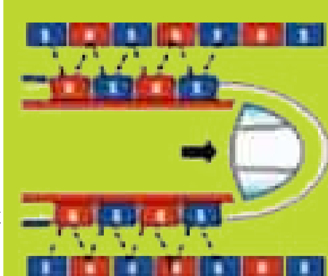
Since the potential difference is defined as work done per unit charge

$$V = \frac{w}{q} = \frac{Fl}{q} = \frac{qvB\sin\theta \times l}{q} = vBl\sin\theta$$

DO YOU KNOW?

Magnetic Levitation (Maglev) fastest trains in the world use the repelling force of magnets to stay in the air. So, they do not even have wheels and also do not touch the track. Maglev trains use superconducting magnets and motional emf to levitate and propel the train along the tracks.





If the conductor is moving right angle to the magnetic field then $\theta = 90^0$

$$V = vBl \text{..........} \quad 19.12$$

Where **V** is motional emf, v represents the velocity of conductor moving in a magnetic field and $\boldsymbol{l}$ is the length of conductor

Self-Assessment Questions:

1. Describe Fleming's right-hand rule and its application in the context of motional EMF.
2. How does the direction of motion, magnetic field, and current relate in Fleming's right-hand rule?

Worked Example 19.5

A straight conductor of length L = 0.5 meter move at a velocity of 2 m/s perpendicular to a magnetic field B = 0.1 Tesla. Calculate the motional emf induced in the conductor.

Solution:

Step 1: Write down the known quantities and quantities to be found.

Length of the conductor, L = 0.5 meter
Velocity of the conductor, v =2 m/s
Magnetic field strength, B = 0.1 Tesla

Step 2: Write down the formula and rearrange if necessary.

$V = vBl$

Step 3: Substitute the known values:

V = (0.1 T) · (0.5 m)·(2 m/s)
V = 0.1V

Step 4: Therefore, the motional emf induced in the conductor is 0.1 volts.

Result: This means that as the conductor moves through the magnetic field, an electromotive force of 0.10 volts is induced across its ends, creating the potential for an electric current if the circuit is closed.

19.6.2 AC Generator

An AC generator, also known as an alternator, is a device that converts mechanical energy into electrical energy in the form of alternating current (AC). It's based on the principle of electromagnetic induction, which was first described by Michael Faraday.

Construction of an AC Generator:

An AC generator typically consists of the following four components as shown in figure 19.12:

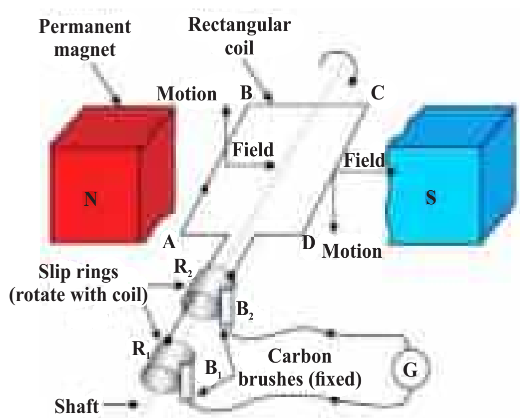


Figure 19.12 AC generator

(i) Armature
(ii) Field magnet
(iii) Slip-rings
(iv) Brushes

Armature:

The armature or rotor is a rectangular coil mounted on a rotating shaft. It is the component that spins within a magnetic field to induce electrical current.

Permanent magnet:

The permanent magnet or stator is a stationary part of the generator that produces a magnetic field. It is typically made up of a set of magnets or electromagnets arranged in a circular or cylindrical configuration around the rotor.

Slip Rings and Brushes:

The ends of the rotor coil are connected to slip rings, which are conductive rings that rotate with the rotor. Brushes, typically made of graphite, press against the slip rings to collect the generated electrical current.

Shaft and Bearings:

The rotor is mounted on a shaft that allows it to rotate freely. Bearings are used to reduce friction and enable smooth rotation.

Working of an AC Generator:

The working of an AC generator involves several steps:

Rotation of the Armature coil:

The coil or rotor is mechanically rotated using an external source of power, such as an engine, a turbine, or any other energy source.

Generation of a Changing Magnetic Field:

As the rotor spins within the stator's magnetic field, the magnetic field within the rotor coil changes. This changing magnetic field induces an electromotive force (emf) or voltage in the coil,

Generation of Alternating Current:

The induced voltage causes an electric current to flow through the coil, and since the magnetic field's direction is changing, the current produced is alternating in nature. This means the direction of the current constantly switches back and forth, resulting in an AC output.

Collection of Output:

The alternating current generated in the rotor coil is collected using slip rings and brushes. The brushes maintain contact with the slip rings as they rotate, allowing the generated AC to be drawn from the generator.

Induced EMF of an AC generator:

Suppose the armature coil AHCD rotates counterclockwise. As it rotates, the magnetic flux linked with it changes, inducing a current in the coil as shown in figure 19.13(a,b). The direction of the induced current follows Fleming’s right-hand rule.

When the armature is in the vertical position and rotates counterclockwise, wire AH moves downward, while DC moves upward. This causes the induced electromotive force (emf) to flow from H to A and from D to C, within the coil, forming a current path of DCHA.

In the external circuit, the current flows along B_1RB_2. This current direction remains consistent during the first half-turn of the armature.

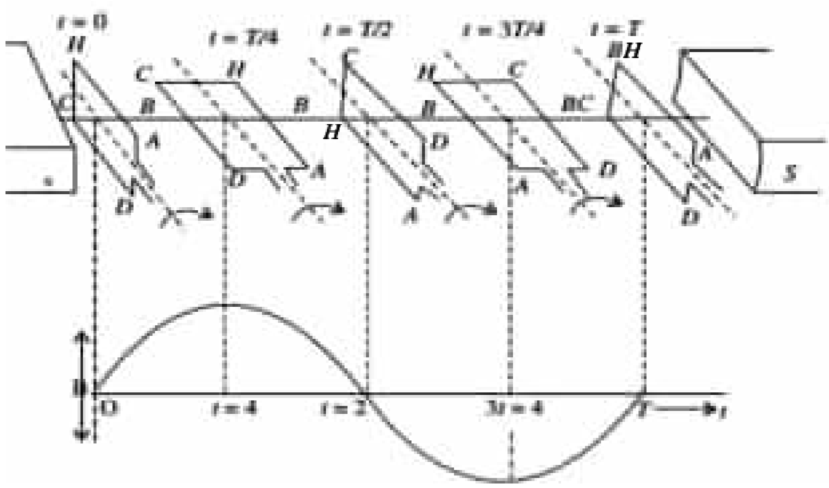


Figure 19.13(a) armature coil AHCD

However, during the second half-revolution, wire AH moves upward, and wires CD move downward, leading to a reversal in the direction of induced current within the coil to AHCD. In the external circuit, the direction changes to B_2RB_1. Therefore, the direction of the induced emf and the current alternates after every half revolution in the external circuit as well. Consequently, the current produced switches direction in each cycle.

When the coil is rotated, a motional electromotive force (emf) is generated in each of its sides, but these emfs have opposite directions because the two sides are moving in opposite directions relative to the magnetic field. However, the other two sides of the coil are moving in the same direction with respect to the field.

Consequently, emfs are induced in these sides in the same direction, leading to a mutual cancellation effect. As a result, the total emf induced in the coil is given by

$$\varepsilon = 2vBNlSin\omega t$$

Where v = linear velocity, B = magnetic field, N = Number of turns, L = length of coil and ω = angular velocity.

Since each particle of the sides AH and CD rotates in a circle of radius equal to the width of the coil b.

$$v = b/2\ \omega$$

$$\varepsilon = 2\ b/2\ \omega\ B\ \sin\omega\ t$$

$$\varepsilon = ANB\ \omega\ \sin\omega\ t$$

$$\varepsilon = \varepsilon_0\ \sin\omega\ t$$

Where ε_0 =ANB ω is the maximum or peak value of the emf which depends on the area and number of the coil, intensity of the field and speed of rotation.

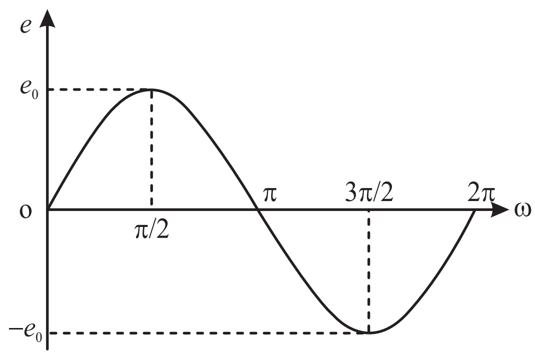


Figure 19.13(b) armature coil AHCD

The expression for the generated emf can also be expressed in terms of the frequency "f" i-e number of turns per second.

$$\varepsilon = \varepsilon_0 \text{Sin} 2\pi ft$$

Figure 19.13(b) shows the variation of emf versus (ω). It shows that direction of emf is reversed after every half revolution of the coil.

Self-Assessment Questions:

1. How does a rotating magnetic field contribute to the rotation of the motor's rotor?
2. Discuss common methods used for starting AC motors.
3. Provide examples of applications where AC motors are commonly used.

Worked Example 19.6

Find the frequency of an AC generator if the voltage output is given as $\xi_0 = 200$ V,

Solution:

Step 1: Write down the known quantities and quantities to be found.

$\xi = 100$ V, $t = 0.005$ seconds.

Step 2: Write down the formula and rearrange if necessary.

$$\varepsilon = \varepsilon_0 \text{Sin} 2\pi ft$$

Step 3: Substitute the known values:

$100 = 200 \sin(2\pi f \times 0.005)$

or

$\sin(2\pi f \times 0.005) = 0.5$

Step 4: To find the frequency, you need to find the value of f that makes the sine function equal to 0.5. This occurs when $\sin(\pi/6) = 0.5$, which is equivalent to $\pi/6$ radians.

So, $2\pi f \times 0.005 = \pi/6$

Solve for f:

$f = \pi / (2 \times 0.005 \times 6)$

$f = 52.36$ Hz

Result: The frequency of the AC generator is approximately 52.36 Hz.

19.7.1 A.C Motor:

An AC (Alternating Current) motor is a device designed to convert electrical energy into mechanical energy by using alternating current. There are various types of AC motors, but the main features and components are generally consistent across different designs. The primary components as shown in figure and their roles in an AC motor are as follows:

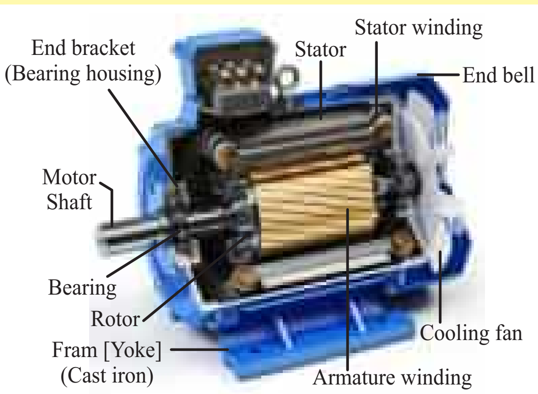


Figure 19.14 AC motor

Stator:

The stator is the stationary part of the motor and contains the primary windings. Its main role is to produce a rotating magnetic field when AC voltage is applied. The rotating magnetic field interacts with the rotor to induce motion.

Rotor:

The rotor is the rotating part of the motor. It can be of different types, such as squirrel-cage or wound rotor, depending on the motor design. When the stator produces a rotating magnetic field, the rotor experiences a torque due to the interaction with the field. This torque causes the rotor to rotate and generate mechanical output.

Bearings:

Bearings are essential components that support and allow the rotor to rotate within the stator. They reduce friction, enabling smooth and efficient operation of the motor.

Shaft:

The shaft is connected to the rotor and extends beyond the motor housing. It transfers mechanical energy to the outside world, allowing the motor to perform useful work when connected to a load.

Cooling System:

Many AC motors incorporate cooling systems, such as fans or fins, to dissipate heat generated during operation. Efficient cooling is important to prevent overheating and prolong the motor's lifespan.

The main features and components work together to enable the AC motor to function. When AC voltage is applied to the stator windings, a rotating magnetic field is created, which exerts a torque on the rotor. The rotor's rotation results in mechanical work being performed by the motor, and the motor can be used to drive various mechanical devices, such as fans, pumps, conveyor belts, and more.

The efficiency and performance of an AC motor depend on the design and quality of its components, the load it drives, and its operating conditions. Proper maintenance and control mechanisms, such as speed control, are often used to optimize the motor's performance in different applications.

19.6.2 The production of back emf in electric motors:

The concept of back electromotive force (back EMF) in electric motors is fundamental to understanding motor operation and efficiency. Back EMF is a self-generated electromotive force that opposes the applied voltage in a motor. It plays a crucial role in motor behavior, especially in limiting current and regulating speed. Here's a detailed explanation of the concept of back EMF in electric motors:

Electromagnetic Induction:

Back EMF is a consequence of Faraday's law of electromagnetic induction, which states that a change in magnetic flux through a coil of wire induces an electromotive force (EMF) in that coil. In an electric motor, the coil of wire is typically part of the rotor or armature.

Rotating Magnetic Field:

When an electric motor is powered, the stator (the stationary part of the motor) generates a rotating magnetic field by applying an alternating current (AC) voltage to its windings. In a direct current (DC) motor, the commutator and brushes create a changing magnetic field.

Rotor or Armature Interaction:

The rotor (or armature) in the motor is mounted within the magnetic field created by the stator. As the rotor rotates, it cuts through the magnetic field lines, causing a change in magnetic flux within the coils of wire on the rotor.

Back EMF Generation:

The change in magnetic flux through the rotor windings induces a voltage, which is referred to as back EMF. The direction of the induced voltage is in opposition to the applied voltage. In other words, it generates a voltage that resists the flow of current through the motor windings.

Current Regulation:

Back EMF has a critical function in motor operation. As the motor speeds up, the back EMF increases. This increase in back EMF results in a decrease in the net voltage across the motor windings. Consequently, the current flowing through the motor decreases. This self-regulation mechanism is essential for preventing the motor from drawing excessive current, overheating, and potentially damaging itself.

Effect on Motor Speed:

The relationship between back EMF and motor speed is inverse. When the motor operates at a higher speed, the back EMF is greater, and the current is reduced, helping maintain a consistent speed. Conversely, at lower speeds or when subjected to a higher mechanical load, the back EMF decreases, allowing more current to flow and providing the necessary torque to overcome the load.

In summary, the concept of back EMF in electric motors is the self-induced voltage that opposes the applied voltage and helps regulate the current and speed of the motor. It is a critical factor in ensuring the safe and efficient operation of electric motors, and understanding it is essential for motor design, control, and performance analysis.

Self-Assessment Questions:

1. Discuss how the production of back EMF aligns with the principle of energy conservation.
2. What is the primary purpose of the back EMF in electric motors?

SUMMARY

- ✓ When a current flows through the conductor magnetic field is produced around it.
- ✓ The relative motion of coil or magnet will produce induced emf. If the motion of magnet and coil is stopped induced current ceases to exist.
- ✓ The magnitude of the induced emf depends on the change of magnetic flux, number of turns in the coil, area of the coil, angle between magnetic field and coil.
- ✓ When the magnetic flux $\Phi_B$passing through a closed conducting loop changes over time, it results in the generation of a current and an electromotive force (emf) within the loop.
- ✓ Lenz's law states that ***"The direction of induced emf in a circuit is always such that it opposes the cause which produces it"***.
- ✓ Lenz's law is in accordance with the law of conservation of energy.
- ✓ If a current I in a coil changes with time, an emf is induced in the coil.This self-induced emf is given by $\varepsilon = -L\ \Delta I/\Delta t$
- ✓ An inductor stores energy in the form of a magnetic field when current flows through it, and this stored energy is proportional to the square of the current and the inductance of the inductor.
- ✓ If primary and secondary coils are near each other, a changing current in either coil can induce an emf in the other is known as mutual inductance.
- ✓ A transformer is an electrical device that transfers energy between two or more circuits using electromagnetic induction. It changes voltage levels while keeping power conservation and efficiency intact. The transformer has two or more coils, called windings, connected by a magnetic core, which allows it to increase (step-up) or decrease (step-down) voltage.
- ✓ Motional emf is the electromotive force induced in a conductor moving through a magnetic field, resulting from the relative motion between the conductor and the magnetic field lines.
- ✓ An AC generator converts mechanical energy into electrical energy in the form of alternating current.
- ✓ An AC motor converts electrical energy into mechanical energy.

CONCEPT MAP

Production of electricity by magnetism

- Faraday's Law of electromagnetic induction
- Lenz's Law predicting direction of induced current

Induced EMF generation (Generator effect) (Transformer effect) factor affecting magnitude of induced EMF

↓

Eddy currents production and effects (Magnetic and heating effects)

↓

Laminated iron cores purpose in motors, generators and transformers

↓

Self induction - energy storagein inductor

↓

Mutual inductance - definition and unit (Henry)

↓

Construction of transformer - working principle - step up and step down transformers

↓

Motional EMF

↓

AC generator - factor affecting induced EMF

↓

AC motor - main features and roles - back EMF production

EXERCISE

Section (A): **Multiple Choice Questions (MCQs)**
Choose the correct answer:

1. Electricity production by magnetism involves
   (a) the conversion of chemical energy to electrical energy.
   (b) the use of static electricity for power generation.
   (c) the movement of conductors within magnetic fields.
   (d) the absorption of solar energy by photovoltaic cells.
2. Induced e.m.f can be generated by relative movement, known as the generator effect, and by changing magnetic fields, known as the transformer effect.
   (a) True in transformers only.
   (b) False in all cases.
   (c) Applicable to both cases.
   (d) True only for static magnetic fields.
3. The magnitude of induced e.m.f. increases with
   (a) the decrease in the speed of the conductor's motion.
   (b) the decrease in the strength of the magnetic field.
   (c) the increase in the number of turns in the coil.
   (d) the reduction in the area of the coil.
4. Faraday's law of electromagnetic induction states
   (a) that current in a circuit always opposes the change in magnetic flux.
   (b) that the induced e.m.f. is directly proportional to the rate of change of magnetic flux.
   (c) that a changing electric field produces a magnetic field.
   (d) that magnetic fields can only be produced by electric currents.
5. Lenz's law predicts the direction of an induced current
   (a) to conserve electric charge.
   (b) by stating that the induced current will oppose the change causing it.
   (c) by following the direction of the applied magnetic field.
   (d) based on the magnitude of the electric field.
6. Eddy currents produce:
   (a) static electricity in conductive materials.
   (b) alternating magnetic fields with no heating effects.
   (c) magnetic fields that oppose the inducing field and cause heating in conductors.
   (d) uniform electric fields that have no impact on power generation.
7. Laminated iron cores are used in electric motors and transformers to
   (a) reduce the weight of the device.
   (b) enhance the mechanical strength.
   (c) minimize eddy current losses and reduce heating.
   (d) increase the magnetic permeability of the core.

8. Self-induction is the phenomenon where
   (a) a changing electric field induces a magnetic field.
   (b) a changing magnetic field within a coil induces an emf in the same coil.
   (c) a constant magnetic field induces a constant emf.
   (d) two coils induce emf in each other through mutual induction.
9. An inductor stores electric potential energy in:
   (a) the electric field around it.
   (b) the magnetic field within its coil.
   (c) the capacitance of its windings.
   (d) the heat generated by its resistance.
10. Transformers work on the principle of
   (a) converting direct current (DC) to alternating current (AC).
   (b) electromagnetic induction between primary and secondary coils.
   (c) generating electricity through chemical reactions.
   (d) using permanent magnets to maintain a constant voltage.

Section (B): CRQs (Short Answered Questions):

1. Explain Faraday's law of electromagnetic induction.
2. State Lenz's law and discuss its significance in the context of electromagnetic induction.
3. How does a step-up transformer differ from a step-down transformer?
4. Describe the principle of operation of an AC generator.
5. Define self-induction and explain how it occurs in a coil.
6. Define mutual induction and provide an example of a system exhibiting mutual induction.
7. How does the arrangement of coils influence the degree of mutual induction between them?
8. Define motional electromotive force (emf)
9. Differentiate between motional emf and electromagnetic induction in terms of their fundamental principles.
10. Differentiate between AC (alternating current) and DC (direct current) in the context of long-distance power transmission.

Section (C): ERQs (Long Answered Questions):

1. How does the strength of the magnetic field affect the induced electromotive force (emf) in a coil according to Faraday's law? b. Explain the relationship between the magnetic field strength and the magnitude of the induced emf.
2. In Faraday's law, why is the area of the coil an important factor in determining the induced emf?
3. How does changing the orientation of a coil with respect to the magnetic field influence the induced emf? Also describe the role of the number of turns in a coil in the context of induced emf. How does increasing the number of turns in a coil affect the induced emf, and why?
4. According to Faraday's law, why is the rate of change of magnetic flux crucial for inducing emf? Discuss how the speed of motion or change in magnetic field influences the induced emf.

5. How does the resistance of the conductor impact the flow of induced current in a circuit? In what situations might the resistance of the conductor become a significant factor in induced emf?
6. Explain the relationship between the frequency of the changing magnetic field and the induced emf. How does the frequency of the AC source affect the generation of induced emf in a coil?
7. Discuss how the material properties of a coil, such as its conductivity, can influence induced emf. In what ways might the type of material used in a coil affect its response to changing magnetic fields?
8. Why is the presence of a core material significant in transformers concerning induced emf? Explain how the type and properties of the core material can impact the efficiency of a transformer.
9. Why are slip rings used in AC generators, and how do they differ from commutator used in DC generators.
10. Why a commutator is necessary in DC motors, and how does it facilitate the continuous rotation of the motor?
11. What are the common applications of DC motors in everyday devices?

Section (D): Numerical:

1. Two coils are placed adjacent to each other, and a change in current in the first coil induces an emf of 0.5 V in the second coil. If the mutual inductance is 0.2 H, calculate the rate of change of current in the first coil. **(2.5A/s)**
2. A coil with an inductance of 0.5 H experiences a rate of change of current of 2 A/s. Calculate the induced EMF in the coil. **(-1V)**
3. Two coils are placed close to each other. If a change in current of 3 A/s in the first coil induces an EMF of 4 V in the second coil, calculate the mutual inductance. **(1.33H)**
4. A transformer has 200 turns in the primary coil and 400 turns in the secondary coil. If the primary voltage is 120 V, calculate the secondary voltage for a step-up transformer. **(240V)**
5. An inductor with an inductance of 0.02H has a current flowing through it of 2 A. Calculate the energy stored in the inductor. **(0.04J)**
6. A coil stores energy in form of electric potential energy of 0.2J when it carries a current of 2A. Calculate the inductance of coil. **(0.1H)**
7. An AC generator produces an alternating current with a maximum voltage of 240 V. If the frequency of the generated AC is 50 Hz, calculate the peak value of the voltage. **(339V)**
8. A transformer has 1000 turns in its primary coil and 200 turns in its secondary coil. If the primary voltage is 120 V, calculate the secondary voltage for a step-down transformer. **(24V)**
9. A conductor of length 0.4 m moves at a velocity of 5 m/s perpendicular to a magnetic field of 0.3 T. Calculate the motional EMF induced in the conductor. **(0.6V)**