Unit II: Key Topics

- Electromagnetic Induction
  - Faraday's Laws:
    - Lenz's Law: Induced EMF opposes the change producing it.
  - Types of Induced EMF:
    - Statically Induced EMF
      - Self-induced EMF: $e = -L \times \frac{di}{dt}$, $L = N \times \frac{d\phi}{di}$
      - Mutually induced EMF: $e_m = -N_2 \frac{d\phi_1}{dt}$ or $e_m = -M \frac{dI_1}{dt}$
    - Dynamically Induced EMF: EMF induced in a moving conductor in a magnetic field (generators).
- DC Machines
  - Principles:
    - DC Generator: Faraday's laws, converts mechanical to electrical energy.
    - DC Motor: Force on a current-carrying conductor in a magnetic field, converts electrical to mechanical energy.
  - Fleming's Rules:
    - Right-hand rule (generator): Direction of induced EMF.
    - Left-hand rule (motor): Direction of force on conductor.
  - Construction:
    - Key parts: Yoke, poles, armature, commutator, brushes.
  - DC Generator:
    - Working principle: Coil rotation in a magnetic field induces AC voltage, commutator converts it to DC.
      - EMF equation: $E_g = \frac{P\phi NZ}{60A}$

- DC Motor:
  - Working principle: Force on current-carrying conductors rotates the armature.
    - Back EMF (Counter EMF): $E_b = \frac{ZN\phi P}{60A}$
    - Torque:
      - Armature torque: $T_a = 0.159\phi Z I_a \frac{P}{A}$
      - Shaft torque: $T_{sh} = \frac{E_b I_a - P_i}{\frac{2\pi N}{60}}$
- Types of DC Motors:
  - Shunt: Field winding in parallel with armature.
  - Series: Field winding in series with armature.
  - Compound: Both shunt and series fields.
- Characteristics:
  - Shunt Motor: Torque vs. armature current, speed vs. armature current, speed vs. torque.
  - Series Motor: Torque vs. armature current, speed vs. armature current, speed vs. torque.
- Applications of DC Motors: Various industrial uses.
- Numericals on DC generators and motors.

- Transformers
  - Working principle: Mutual induction.
  - Construction: Primary and secondary windings on a core.
    - EMF equation: $E_1 = 4.44 f \phi_m N_1$, $E_2 = 4.44 f \phi_m N_2$
  - Transformer Losses

    - Numericals
- Induction Motors
    - Construction: Stator with 3-phase windings, rotor (squirrel cage or slip ring).
    - Rotating Magnetic Field: Production of rotating field by 3-phase supply.

State and explain Faraday's Laws of Electromagnetic Induction **(4 marks)**

- Faraday's First Law (2 marks):
    - "Whenever the magnetic flux linking with a conductor or coil changes, an emf is induced in it."
    - In simpler terms, this means that if a magnetic field interacts with a conductor in a way that the amount of magnetic field passing through the conductor changes, a voltage (EMF) is produced.
- Faraday's Second Law (2 marks):
    - "The magnitude of the emf induced in a conductor or coil is directly proportional to the rate of change of flux linkages."
    - This law quantifies the induced EMF. It states that the faster the magnetic flux changes, the greater the induced EMF.
    - Mathematically, this is expressed as $e = d(N\varphi)/dt$, where 'e' is the induced EMF, 'N' is the number of turns in the coil, and '$d\varphi/dt$' represents the rate of change of magnetic flux.

State and explain: 1)Self induced emf 2)Mutually induced emf 3)Lenz's law **6 MARKS**

1. Self-induced EMF (2 marks)

- Self-induced EMF is the electromotive force (EMF) produced in a coil when the current flowing through that same coil changes.
- This change in current causes a change in the magnetic flux linking with the coil, which, according to Faraday's law, induces an EMF.
- The induced EMF opposes the change in current, as described by Lenz's law.

- Mathematically, self-induced EMF is given by e = -L(di/dt), where L is the self-inductance of the coil, and di/dt is the rate of change of current.

2. Mutually Induced EMF (2 marks)

- Mutually induced EMF is the EMF induced in a coil due to the change in current in a neighboring coil.
- When the current changes in the first coil, the magnetic flux produced by it also changes.
- If this changing flux links with a second nearby coil, it induces an EMF in the second coil.
- The magnitude of the mutually induced EMF depends on the rate of change of current in the first coil, the number of turns in the second coil, and the mutual inductance (M) between the coils: e_m = -M(dI_1/dt).

3. Lenz's Law (2 marks)

- Lenz's Law states that the direction of the induced EMF and the current it produces always oppose the change that caused the induction.
- In simpler terms, the induced EMF tries to maintain the original state of the circuit.
- If the change is due to a moving magnet, the induced current will create a magnetic field that opposes the magnet's motion.
- If the change is due to a changing current in a nearby coil, the induced current will create a magnetic field that opposes this change.

With a neat diagram, explain the construction of DC Machine-**6 marks**

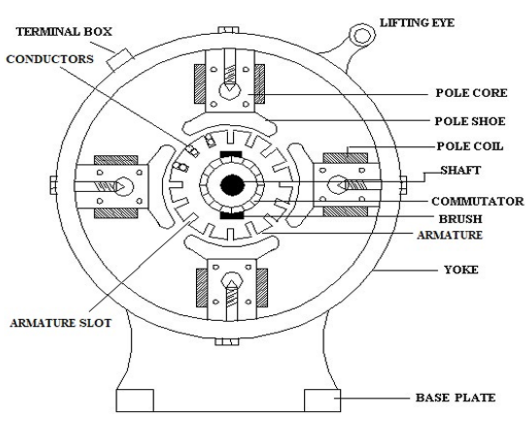

Figure 1.6: Construction diagram of a DC machine

A DC generator mainly consists of two parts:

1. Armature: the rotating part which converts mechanical energy into electrical energy.
2. Field: the stationary part which produces the magnetic flux. They are separated by a small air gap.

All DC machines have the following principal components:

Yoke or Magnetic Frame:

Usually made of cast iron or cast steel. Provides mechanical support to the poles and serves as a cover. It also provides the least reluctance path to the magnetic flux.

Poles:

The field magnets consist of pole cores and pole shoes. The pole shoes spread out the flux in the air gap, reduce the reluctance of the magnetic path, and support the exciting coils (field coils). The poles are made of alloy steel of high permeability. The pole core is laminated to reduce eddy current losses and supports the field coils. The function of field windings (or coils) is to provide the number of ampere-turns for ensuring the flow of required magnetic flux through the armature.

Armature:

Consists of the armature core and armature winding. The armature core is made of high-permeability silicon steel laminations, insulated from one another by varnish. It supports the armature conductor, causes the conductor to rotate between the magnetic field, and provides a low reluctance path for the magnetic field produced by the field coils. The conductors are placed in slots and insulated from one another and from the slots of the armature core. The armature conductors are connected together either as a lap winding or wave winding.

Armature windings:

Lap windings: the number of parallel paths is equal to the number of poles (A=P).

Wave windings: there are only two parallel paths irrespective of the number of poles (A=2).

Commutator:

Converts the alternating EMF generated in the armature winding into direct voltage in the external circuit. It is cylindrical in shape and built of wedge-shaped segments made of hard-drawn Copper, insulated from one another and from the shaft by mica strips. The segments are connected to the armature conductors.

Shaft and Bearings: The shaft of a DC generator is rotated by a prime mover, and since the armature is fixed to the shaft, the armature also rotates. The rotating armature is mounted inside the stationary frame with the aid of bearings.

Brushes: Made of carbon. They are fixed in brush holders and, with the help of springs, are made to contact the commutator segments. DC output voltage is taken out through these brushes.

Working of DC Generator

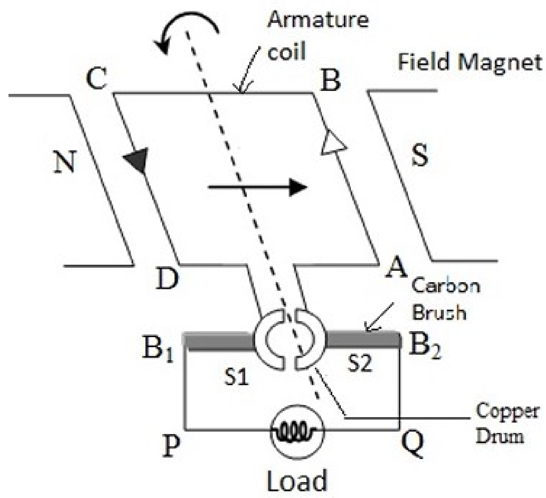

Figure 1.7: Working principle of a DC generator

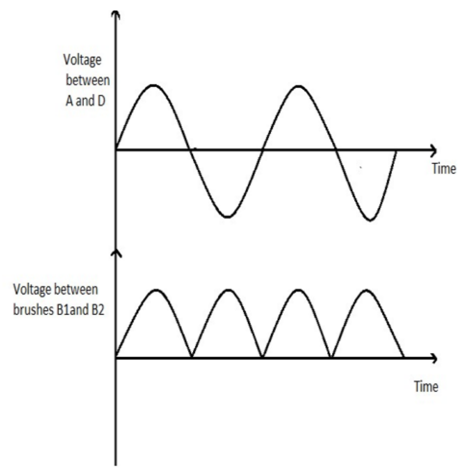

Figure 1.8: Voltage waveforms of a DC generator

- A DC generator works on the principle of Faraday's laws of electromagnetic induction.
- Consider a coil 'ABCD' being rotated in a magnetic field produced by a permanent magnet or an electromagnet.
- When the coil is at right angles to the direction of the lines of flux, the coil will be moving parallel to the lines of flux. Hence the coil does not cut any flux and the induced EMF is zero.
- When the coil is parallel to the lines of flux, flux cut is maximum and hence maximum EMF is induced in the coil.
- Since the coil sides alternately come under north and south poles, the direction of the induced voltage in the coil reverses at regular intervals, and thus we get an AC voltage across the terminals of the coil.
- To convert this AC voltage into unidirectional voltage, a copper drum is mounted on the same shaft as that of the coil.
- The drum is split into two halves (S1, S2), and insulation is placed between them. The two ends of the coil are connected to the two halves of the drum.
- Two fixed carbon brushes B1 and B2 make contact with the surface of the drum. The voltage between the brushes becomes unidirectional as brush B1 always makes contact with the coil side under the North Pole and brush B2 always makes contact with the coil side under the South Pole.

Derive the EMF equation of DC Generator-**4 marks**

Let

$$\phi = \text{Flux/pole in Wb}$$
$$Z = \text{Total number of armature conductors or coil sides on armature}$$
$$= \text{Number of slots} \times \text{number of conductors/slot.}$$
$$P = \text{Number of poles.}$$
$$A = \text{Number of parallel paths.}$$
$$N = \text{Speed of armature in r.p.m.}$$

The e.m.f. induced in a conductor when rotated in a magnetic field is directly proportional to the rate of change of flux.
The flux cut by a conductor in one revolution, $d\phi = P\phi$ Wb.
The time taken by the conductor to make one revolution $= dt = \frac{60}{N}$ second.
According to Faraday's laws of electromagnetic induction,

$$\text{the e.m.f. induced in one conductor} = \frac{d\phi}{dt} = \frac{P\phi}{\left(\frac{60}{N}\right)} = \frac{P\phi N}{60} \tag{1.6}$$

Generated e.m.f., E_g = e.m.f. generated/ parallel path.
= e.m.f. induced/conductor × number of conductors/parallel path

$$E_g = \frac{P\phi N}{60} \times \frac{Z}{A}$$

Working of DC Motor

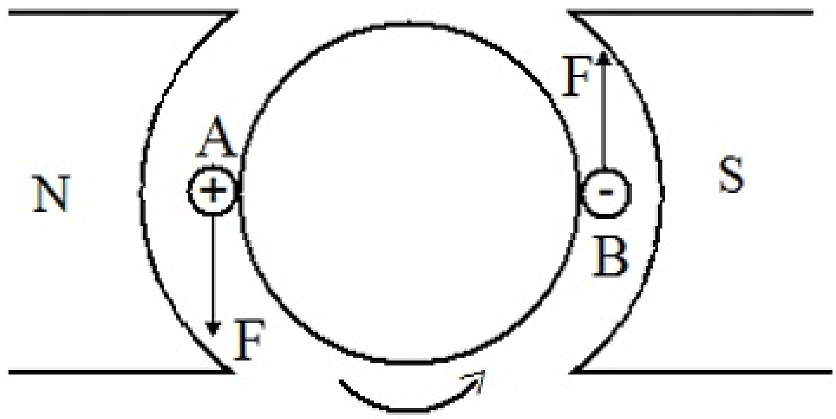

Figure 1.9: Working principle of a DC Motor

1. A DC motor is a machine that converts electrical energy into mechanical energy.
2. It is similar in construction to a DC generator. A DC machine can work both as a generator and a motor.
3. Any DC generator will run as a motor when its field and armature windings are connected to a source of direct current.
4. The field winding produces the necessary magnetic field, and the flow of current through the armature conductor produces a force that rotates the armature.
5. "Whenever a current-carrying conductor is placed in a magnetic field, it experiences a force whose direction is given by Fleming's Left Hand Rule".

Back EMF or Counter EMF:

- In a DC motor, when the armature rotates, the conductors on it cut the magnetic field in which they revolve, so that an EMF is induced in the armature.
- The induced EMF acts in opposition to the current in the machine and therefore, to the applied voltage, so that it is customary to refer to this EMF as the back EMF (as per Lenz's law).
- The magnitude of this back EMF, denoted by Eb, is calculated by using the formula for the induced EMF in a generator, and hence is proportional to the product of the flux and the speed

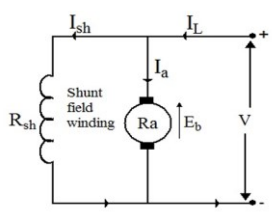

Figure 1.10: DC Shunt Motor

$$E_b = \frac{ZN\phi P}{60A} volts \tag{1.8}$$

The value of this e.m.f. is always lesser than the applied voltage. This difference actually drives current through armature circuit resistance R_a.
Thus, the voltage V applied across the motor armature has to:

1. overcome the back emf E_b and
2. supply the armature ohmic drop $I_a R_a$.

Therefore,

$$V = E_b + I_a R_a \tag{1.9}$$

This is known as the voltage equation of a motor.

$$\text{Hence, armature current } I_a = \frac{V - E_b}{R_a} \tag{1.10}$$

Multiplying both sides of (1.9) by I_a, one gets

$$VI_a = E_b I_a + I_a^2 R_a \tag{1.11}$$

Here, VI_a = Electrical power input to the motor, P_{in}
$E_b I_a$ = Electrical equivalent of mechanical power developed in the armature,
$I_a^2 R_a$ = Copper loss in the armature.

Armature Torque of a DC motor: **5-marks**

The torque means the turning moment or twisting moment of a force about an axis. Let Ta be the torque developed by the armature of a motor in Nm and N be its speed in r.p.m.,

$$\text{Then power developed} = T_a\omega$$

Here ω (omega) is the angular velocity in radian/second

$$\text{If } N \text{ is in rpm, } \omega = \frac{2\pi N}{60}\text{rad/sec}$$

$$\text{Then power developed} = \frac{2\pi N T_a}{60}\text{work done/sec}$$

But electrical power converted into mechanical power in the armature $= E_b I_a$ Watt. Comparing two expressions,

$$\frac{2\pi N T_a}{60} = E_b I_a$$

$$\text{Substituting back emf, } E_b = \frac{ZN\phi P}{60A}\text{in the above expression, one gets}$$

$$T_a = 0.159\phi Z I_a \frac{P}{A} Nm \tag{1.12}$$

Shaft torque of a DC motor:

- The armature torque is the gross torque, which is developed by the armature.
- A certain percentage of torque developed by the armature is lost in overcoming the iron and friction losses.
- Net torque (gross torque – torque lost in iron and friction losses) is known as shaft torque.
- The horsepower developed by the shaft torque is known as brake Horse Power.

1. If T_a is torque developed by armature in Nm,
2. T_i is torque lost in iron and friction losses (P_i), then
3. T_{sh} is the shaft torque or useful torque.
4. BHP is the Brake Horse Power.

$$T_a = \frac{E_b I_a}{\left(\frac{2\pi N}{60}\right)}$$

$$T_i = \frac{P_i}{\left(\frac{2\pi N}{60}\right)}$$

$$T_{sh} = \frac{E_b I_a - P_i}{\left(\frac{2\pi N}{60}\right)} Nm$$

$$T_{sh} = \frac{P_{out}}{\left(\frac{2\pi N}{60}\right)} = \frac{BHP \times 735.5}{\left(\frac{2\pi N}{60}\right)}$$

$$T_{sh} = \frac{BHP \times 735.5}{\left(\frac{2\pi N}{60}\right)} Nm$$

Draw and explain the characteristics of 1)DC Shunt motor 2)DC Series motor **-6 marks**

1. DC Shunt Motor (3 marks)

- Connection: In a shunt motor, the field winding is connected in parallel with the armature.
- Torque Characteristics:
  - The armature torque (Ta) is proportional to the armature current (Ia) since the field flux is practically constant.
- Therefore, the Ta/Ia graph is a straight line.

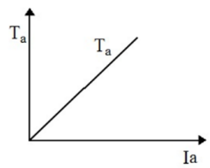

Figure 1.13: Torque v/s armature current characteristics of a DC shunt motor

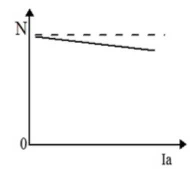

Figure 1.14: Speed v/s armature current characteristics of a DC shunt motor

- Speed Characteristics:
  - The speed (N) is inversely proportional to the field flux.
  - Since the flux is nearly constant, the speed is also nearly constant.
  - However, in reality, the speed slightly decreases with an increase in load.
  - Thus, the DC shunt motor is considered a constant speed motor.

2. DC Series Motor (3 marks)

- Connection: In a series motor, the field winding is connected in series with the armature.
- Torque Characteristics:
  - Armature torque (Ta) is proportional to the product of flux and armature current (Ia).
  - In a series motor, the field current is the same as the armature current, so the flux is proportional to Ia.
  - Therefore, Ta is proportional to Ia^2.
- This means the torque increases rapidly with the increase in armature current.

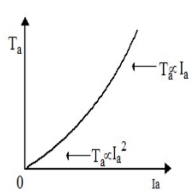

Figure 1.16: Speed v/s torque characteristics of a DC series motor

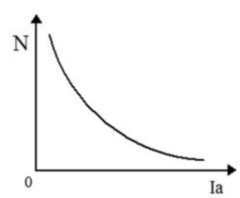

Figure 1.17: Speed v/s current characteristics of a DC series motor

- Speed Characteristics:
  - The speed is inversely proportional to the flux.
  - At low loads (and low armature current), the flux is low, and the speed is high.
  - As the load and armature current increase, the flux increases, and the speed decreases significantly.

1.6.3 Classification of Transformers based on construction

The types of transformers differ in the manner in which the primary and secondary coils are provided around the laminated steel core. According to the design, transformers can be classified into: (a) core type (b) shell type.

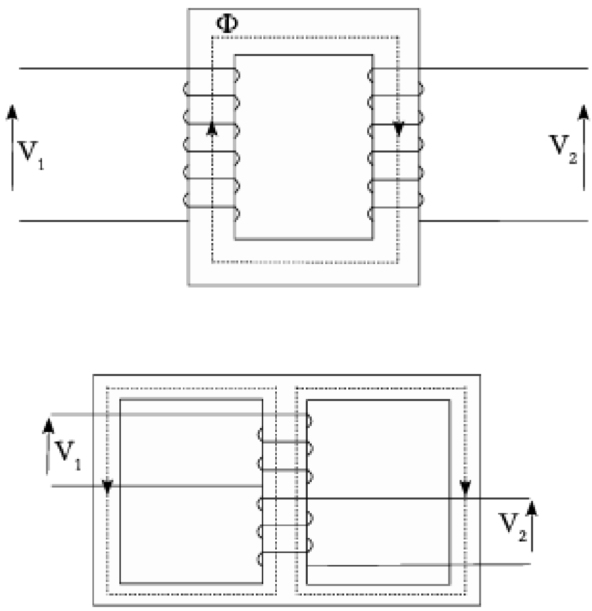

Figure 1.23: Types of Transformers:(a) Core-type (b) Shell-type

Core Type Transformer

If the windings are wound around the core in such a way that they surround the core ring on its outer edges, then the construction is known as the core type. In this type, half of each winding is wrapped around each limb of the core such that magnetic flux leakages can be minimized.

Shell Type Transformer

In shell type construction of the core, the windings pass through the inside of the core ring such that the core forms a shell outside the windings. This arrangement also prevents the flux leakages since both the windings are wrapped around the same center limb.

Explain the construction and working principle of single phase transformer

Construction

- The two main parts of the transformer are core and winding.
- A Silicon steel core C consists of laminated sheets, about 0.35- 0.7 mm thick, insulated from one another.
- The purpose of laminating the core is to reduce the eddy-current loss and use of silicon steel as material reduces the hysteresis losses.
- The vertical portions of the core are referred to as limbs and the top and bottom portions are the yokes. Coils P and S are wound on the limbs.
- Winding Coil P is connected to the supply and is therefore termed the primary; coil S is connected to the load and is termed the secondary.

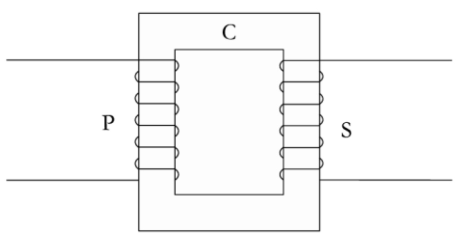

Figure 1.22: Schematic diagram of a transformer

Working principle

- An alternating voltage applied to primary winding P circulates an alternating current through the primary winding P.
- This alternating current produces an alternating current produces an alternating flux in the core, the mean path of flux is shown in dotted line D as indicated in Figure 1.24.
- This flux linking the primary coil produces a self-induced emf (E1).
- As the secondary winding is wound on the same core, entire flux produced by primary coil links the secondary and produces mutually induced emf (E2) across the secondary winding.

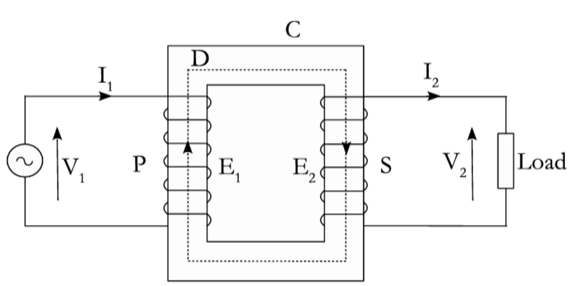

Figure 1.24: Working Principle of a transformer

When load is connected across the secondary terminals, the secondary current I2 starts flowing; which by Lenzs law produces a demagnetizing effect. Consequently, the net flux in the core reduces which inturn reduces primary induced emf. Therefore, there is a difference in primary supply voltage and primary induced emf. To compensate for the demagnetizing effect more current is drawn from the supply voltage and primary current varies in proportion to secondary line current.
Note: In an ideal transformer the induced emfs are same as the respective terminal voltages ie. E_1=V_1 and E_2 =V_2. where E_1 is induced emf in the primary coil P and E_2 is the induced emf in the secondary coil S.

$$\frac{V_2}{V_1} \simeq \frac{N_2}{N_1} \simeq \frac{E_2}{E_1} \tag{1.23}$$

In a transformer volt-ampere in primary and secondary are equal, thus

$$I_1V_1 \simeq I_2V_2$$

Or,

$$\frac{I_1}{I_2} \simeq \frac{V_2}{V_1} \tag{1.24}$$

Finally, from (1.23) and (1.24),

$$\frac{I_1}{I_2} \simeq \frac{N_2}{N_1} \simeq \frac{V_2}{V_1} \tag{1.25}$$

Thus in a transformer there exists a balance between primary and secondary ampere-turns.

Derive the EMF equation of a Transformer **-5marks**

Suppose the maximum value of the flux to be ϕ_m webers and the frequency to be f hertz. From figure 1.25 it is seen that the flux has to change from $+\phi_m$ to $-\phi_m$ in half a cycle, namely in $1/2f$ seconds.

$$\begin{aligned} \therefore \text{Average rate of change of flux} &= 2\phi_m \div (1/2f) \\ &= 4f\phi_m \text{ webers per second} \end{aligned}$$

and average e.m.f. induced per turn is $4f\phi_m$ volts

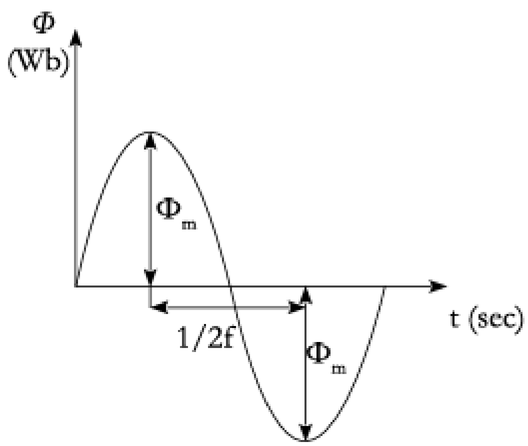

Figure 1.25: Waveform of flux variation

But for a sinusoidal wave the r.m.s. or effective value is 1.11 times the average value,

$\therefore$ r.m.s. value of e.m.f. induced per turn = $1.11 \times 4f\ \phi_m$

Hence, r.m.s. value of e.m.f. induced in primary is

$$E_1 = 4.44 f \phi_m N_1 \text{ volts} \tag{1.26}$$

and r.m.s. value of e.m.f. induced in secondary is

$$E_2 = 4.44 f \phi_m N_2 \text{ volts} \tag{1.27}$$

Write a note on 1) Loses in a single phase transformer

2)Autotransformer and its applications-**6 M**

1. Losses in a Single-Phase Transformer (3 marks)

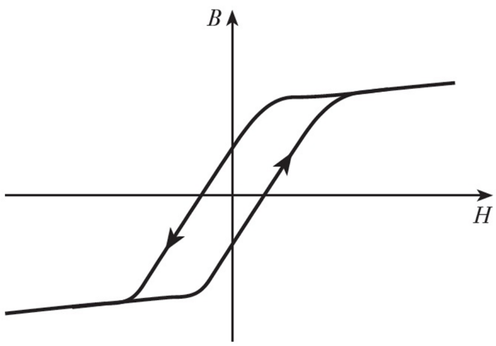

Figure 1.26: Hysteresis loop

- Transformers are subject to power losses that reduce their efficiency.
- These losses are mainly classified into two types: core losses and copper losses.
- Core Losses (Iron Losses):
    - These losses occur in the transformer's core and are independent of the load current.
    - They consist of hysteresis losses and eddy current losses.
    - Hysteresis loss is due to the repeated magnetization and demagnetization of the core as it is subjected to alternating magnetic fields.
    - Eddy current loss is caused by circulating currents induced in the core by the changing magnetic flux.
- Copper Losses (I^2R Losses):
    - These losses occur in the transformer windings (primary and secondary) due to the resistance of the copper wire.
    - They are proportional to the square of the current flowing through the windings (I^2R).
    - Copper losses vary with the load on the transformer, increasing as the load increases.

Autotransformer and Its Applications (3 marks)

A transformer in which part of the winding is common to both primary and secondary circuits, is known as an auto-transformer. The primary is both electrically and magnetically coupled to the secondary; thus, in figure 1.27 winding AB has a tapping at C, the load being connected across CB and the supply voltage applied across AB.

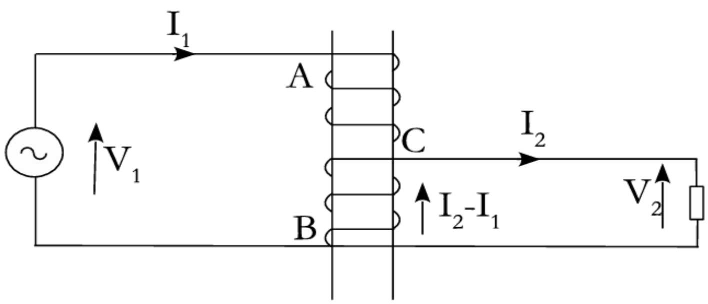

Figure 1.27: Schematic diagram of an auto-transformer

Let,

$$\begin{aligned} I_1 \text{ and } I_2 &= \text{primary and secondary currents respectively} \\ N_1 &= \text{number of turns between A and B} \\ N_2 &= \text{number of turns between C and B} \\ n &= \text{ratio of the smaller voltage to the larger voltage} \end{aligned}$$

Neglecting the losses, the leakage reactance and the magnetizing current, we have

$$n = \frac{V_2}{V_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1}$$

The nearer the ratio of transformation is to unity, the greater is the economy of conductor material. Also, for the same current density in the windings and the same peak values of the flux and of the flux density, the I^2R loss in the auto-transformer is lower and the efficiency higher than in the two- winding transformer.

Auto-transformers are mainly used for the following applications:

_1. As a regulating transformer

2. A continuously variable auto-transformer finds useful applications in electrical testing laboratory

3. Voltage adjustment for commercial and industrial machines

4. They are used in starting induction motors.

Construction of Induction motor

It mainly consists of two parts (i)Stator (ii) Rotor.

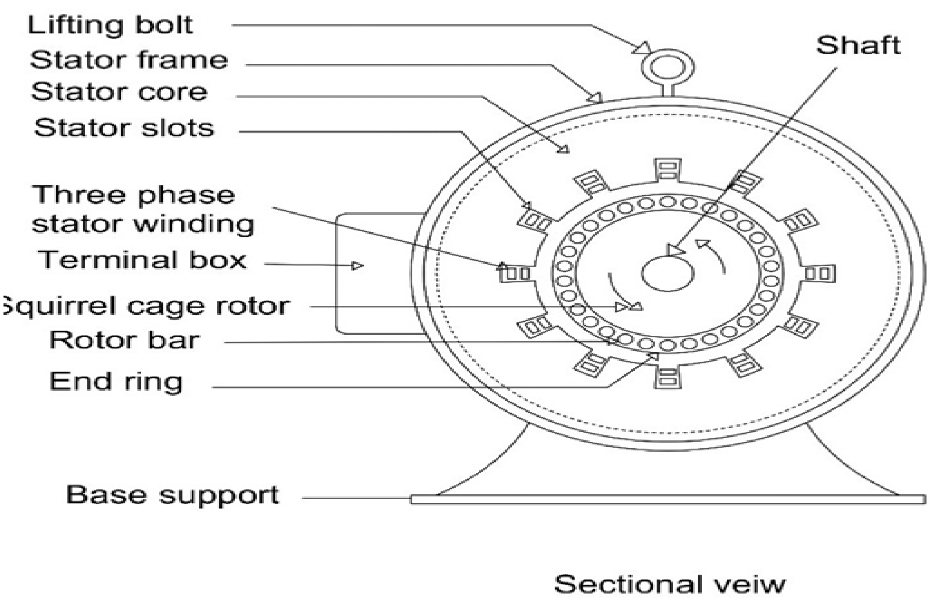

Figure 1.28: Three Phase Induction Motor

The rotor is the rotating part the induction motor. The stator is the stationary part. They are separated by a small air gap.

Stator

- Stator is a stationary part of induction motor.
- A stator winding is placed in the stator of induction motor and the three phase supply is given to it.
- It is a hollow and cylindrical core having slots in its inner surface to house windings.
- It consists of a set of silicon steel laminations attached to the yoke as shown in gure 2.27.
- In the slots of the laminations stator conductors are placed with proper insulation.
- These conductors are properly interconnected to form a balanced star or delta connected winding

Rotor

The rotor is the rotating part of induction motor.

The rotor is connected to the mechanical load through the shaft.

There are two types : (i) Squirrel cage rotor (ii) Phase wound rotor (Slip ring rotor)

Squirrel cage rotor

- The copper or aluminum heavy bars form the rotor conductors as shown in Figure 2.28.
- One bar is placed in each slot. Slots are made of steel laminations.
- All the bars are welded at both ends to two copper end rings thus short circuiting them at both ends.
- Since they are short circuited on both ends, no external resistance can be connected to it.
- This type of rotor has low starting torque.
- The motor with this type of rotor is named as squirrel cage induction motor

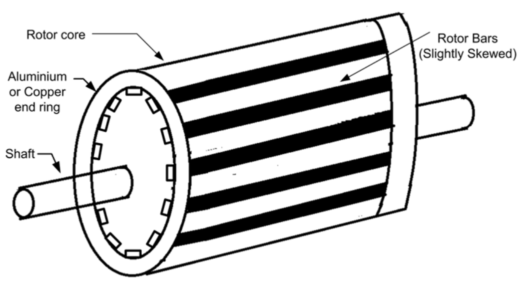

Figure 1.29: Squirrel Cage Rotor

Phase wound rotor (Slip Ring Rotor)

- The slip ring rotor forms laminated cylindrical core having uniform slots on its outer periphery as shown in figure 2.29.
- A three phase winding which is star connected is placed in these slots.
- The open ends of the star windings are brought out and connected to three insulated slip rings, mounted on the shaft of this rotor with carbon brushes resting on them.
- The rotor winding can be shorted through external variable resistance.
- The motor with this type of rotor is termed as slip ring induction motor.

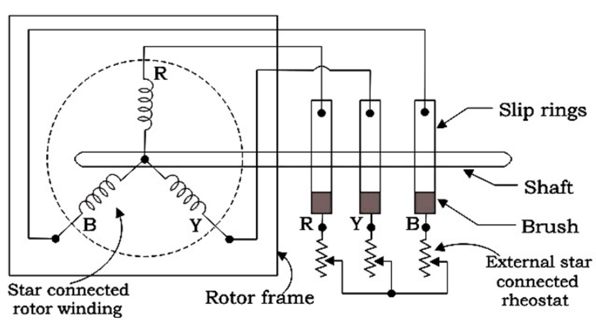

Figure 1.30: Slip Ring Rotor

Concept of rotating magnetic field

When a three phase supply is given to the three windings of the stator, three fluxes are produced in the three windings. The assumed positive directions of fluxes

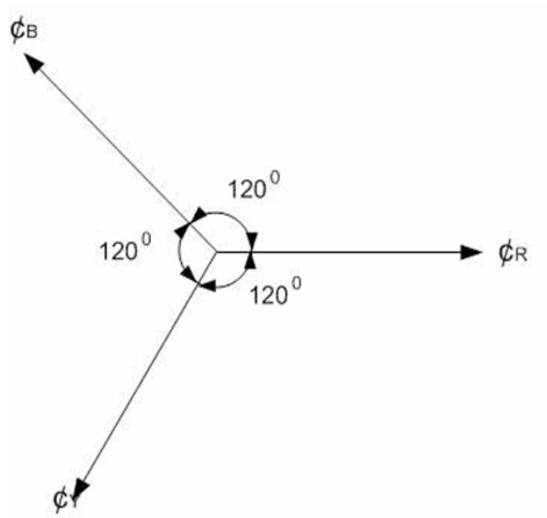

Figure 1.32: Assumed Positive directions

The equations for three fluxes are

$\phi_R = \phi_m \sin \omega t$

$\phi_Y = \phi_m \sin(\omega t - 120°)$

$\phi_B = \phi_m \sin(\omega t - 240°)$

The resultant flux ϕ_T of these three fluxes at any instant is given by the vector sum of the individual fluxes ϕ_R, ϕ_Y and ϕ_B

Case (i) : **At** $\omega t = 0$

$\phi_R = 0$

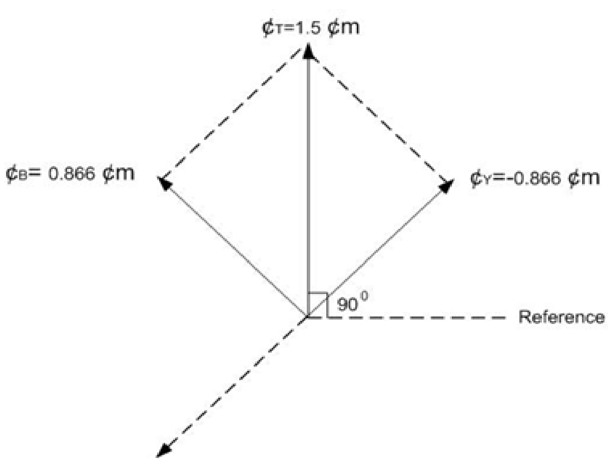

Figure 1.33: Resultant vector at $\omega t = 0$

$\phi_Y = \phi_m \sin(-120°) = -\frac{\sqrt{3}}{2}\phi_m$
$\phi_B = \phi_m \sin(-240°) = \frac{\sqrt{3}}{2}\phi_m$

$$\begin{aligned}
\phi_T &= \sqrt{\phi_B^2 + \phi_Y^2 + 2\phi_B\phi_Y \cos 60°} \\
&= \sqrt{[\frac{\sqrt{3}}{2}\phi_m]^2 + [\frac{\sqrt{3}}{2}\phi_m]^2 + \frac{\sqrt{3}}{2}\phi_m \frac{\sqrt{3}}{2}\phi_m \frac{1}{2} \times 2} \\
&= \sqrt{\frac{3}{4}\phi_m^2 + \frac{3}{4}\phi_m^2 + \frac{3}{4}\phi_m^2} \\
\phi_T &= \frac{3}{2}\phi_m = 1.5\phi_m
\end{aligned}$$

The resultant flux lies along Y axis.

Case (ii) : When $\omega t = 60°$

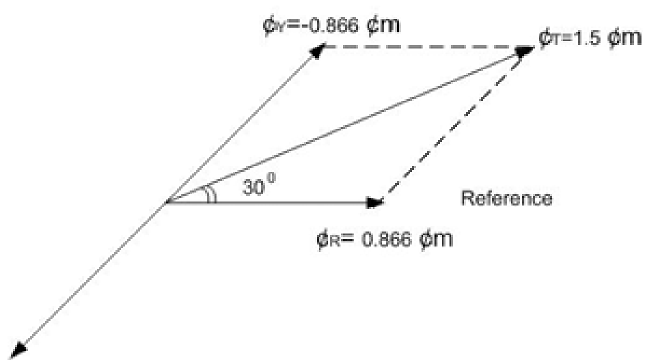

Figure 1.34: Resultant vector at $\omega t = 60^0$

$\phi_R = \frac{\sqrt{3}}{2}\phi_m$
$\phi_Y = -\frac{\sqrt{3}}{2}\phi_m$
$\phi_B = 0$
$\phi_T = \frac{3}{2}\phi_m = 1.5\phi_m$
The resultant flux has rotated by 60° in the clockwise direction.

Case (iii) : When $\omega t = 120^\circ$

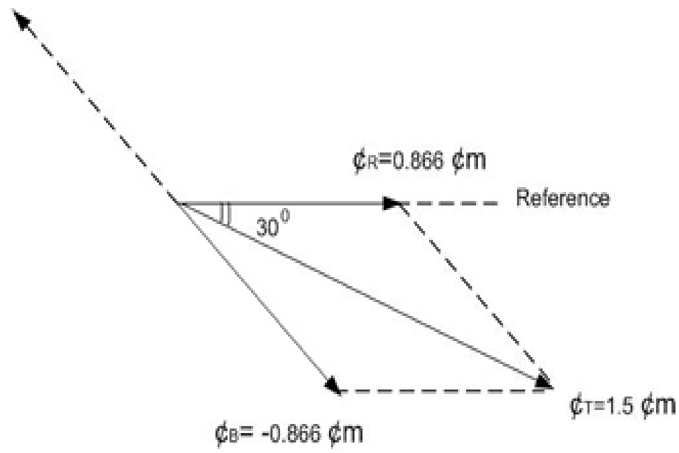

Figure 1.35: Resultant vector at $\omega t = 120^0$

$\phi_R = \frac{\sqrt{3}}{2}\phi_m$

$\phi_Y = 0$

$\phi_B = -\frac{\sqrt{3}}{2}\phi_m$

$\phi_T = \frac{3}{2}\phi_m = 1.5\phi_m$

The resultant flux is further moved by 60° in the clockwise direction where as the magnitude of the resultant flux remains the same.

Case (iv) : When $\omega t = 180°$

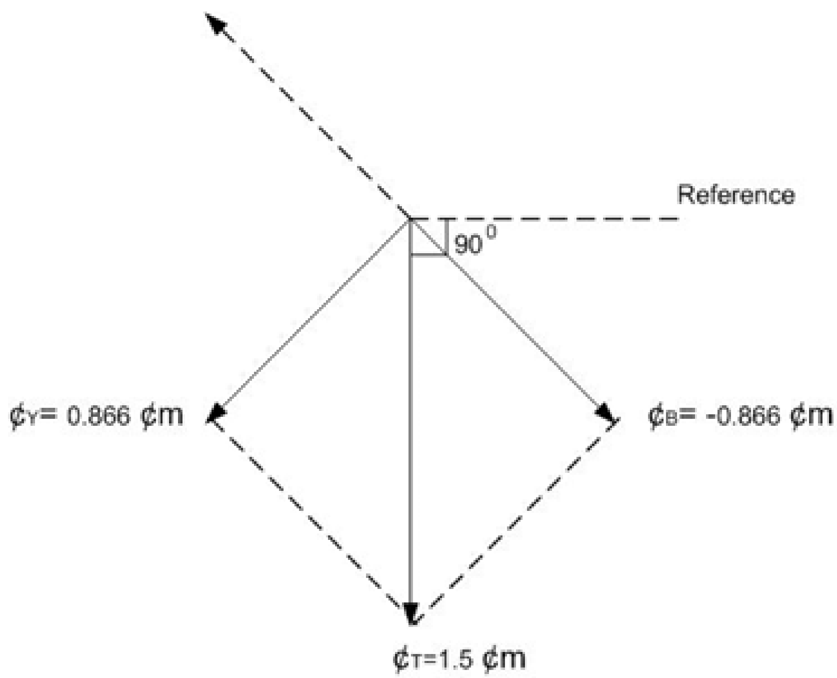

Figure 1.36: Resultant vector at $\omega t = 180^0$

$\phi_R = 0$

$\phi_Y = \frac{\sqrt{3}}{2}\phi_m$

$\phi_B = -\frac{\sqrt{3}}{2}\phi_m$

$\phi_T = \frac{3}{2}\phi_m = 1.5\phi_m$

Here resultant flux is rotated by 180 degree from its original position.

From above analysis we can conclude that as ωt varies from 0 to 360°, the resultant flux also rotates with the same angular velocity ω and having a constant magnitude of $1.5\phi_m$.

Thus when 3ϕ supply is given to the stator windings of 3ϕ induction motor, a rotating magnetic field of constant magnitude and rotating with synchronous speed is produced.

The synchronous speed is given by $N_s = \frac{120f}{P}$

Where f=supply frequency

P=number of poles.

FORMULAS

- **Self-induced EMF:**
  - $e = -L * (di/dt)$
  - $L = N * (d\phi/di)$
- **Mutually induced EMF:**
  - $e_m = -N_2 * (d\phi_1/dt)$
  - $e_m = -M * (dI_1/dt)$
- **Generated EMF of a DC generator:**
  - $Eg = (P \phi N Z) / (60 A)$
- **Armature torque of a DC motor:**
  - $Ta = 0.159 \phi Z Ia (P/A)$
- **Shaft torque of a DC motor:**
  - $Tsh = (Eb Ia - Pi) / (2\pi N/60)$
  - $Tsh = (Pout) / (2\pi N/60) = (BHP * 735.5) / (2\pi N/60)$
- **Transformer EMF equation:**
  - $E_1 = 4.44 f \Phi m N_1$
  - $E_2 = 4.44 f \Phi m N_2$

- **Transformer efficiency:**
  - η = (output power) / (input power) = (output power) / (output power + losses)
  - Various forms of the efficiency equation are given in the document.
- **Condition for maximum efficiency of a transformer:**
  - Variable losses = constant losses
- **Frequency of generated voltage:**
  - f = (P N) / 120

---

1. An 8-pole wave connected DC generator has 960 armature conductors and flux/pole 0.04Wb. At what speed must it be driven to generate 400 V?

   Solution:
   Given:
   Number of poles, $P = 8$
   Number of conductors, $Z = 960$
   Flux per pole, $\phi = 0.04\text{Wb}$
   Number of parallel paths, $A = 2$ (since the armature winding is wave-connected).
   E.m.f. required to be generated, $E_g = 400$ V

   Now, the expression for induced e.m.f. in a DC generator is:

$$E_g = \frac{ZN\phi}{60} \times \frac{P}{A}$$

$$\therefore 400 = \frac{960 \times N \times 0.04}{60} \times \frac{8}{2}$$

   Hence $N = 156.25$ rpm.

2. The power input to a 220 V D.C. shunt motor is 10 kW. The field resistance is 230 ohm and armature resistance is 0.28 ohm. Find the input current, armature current and back e.m.f.

Solution:

Given:

Motor terminal voltage $V = 220$ V,

Motor input power, $P_{in} = 10$ kW,

Field resistance, $R_{sh} = 230$ ohm,

Armature resistance, $R_a = 0.28$ ohm.

From Fig. 1.19, input line current,

$$\begin{aligned} I &= \frac{P_{in}}{V} \\ &= \frac{10000}{220} \\ &= 45.45 \text{ A} \end{aligned}$$

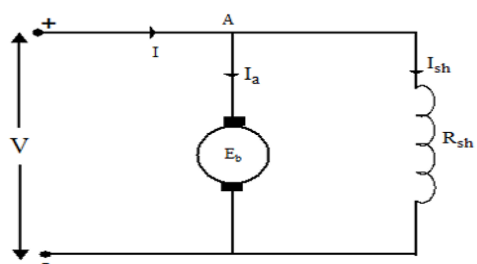

Figure 1.19: Connection diagram of a DC shunt Motor (Courtesy: www.electricaldiary.com)

Field current,

$$\begin{aligned} I_{sh} &= \frac{V}{R_{sh}} \\ &= \frac{220}{230} \\ &= 0.956 \text{ A} \end{aligned}$$

Therefore, armature current, $I_a = I - I_{sh} = 45.45 - 0.956 = 44.49$ A.

Hence back emf, $E_b = V - I_a R_a = 220 - 44.49 \times 0.28 = 207.54$ V.

3. A eight-pole lap-connected 230 V shunt motor has 576 armature conductors. It takes 40 A on full load. The flux per pole is 0.04 Weber. The armature and field resistances are 0.1 ohm and 110 ohm respectively. Contact drop per brush = 1 V. Determine the speed of the motor at full load.

   Solution:
   Given:
   Motor terminal voltage $V = 230$ V,
   Motor input current, $I = 40$ A,
   Number of armature conductors, $Z = 576$,
   Flux per pole, $\phi = 0.04$ Weber,
   Armature resistance, $R_a = 0.1$ ohm,
   Field resistance, $R_{sh} = 110$ ohm,
   Contact drop per brush = 1 V.

   From Fig. 1.20, field current, $I_{sh} = \frac{V}{R_{sh}} = \frac{230}{110} = 2.09$ A.
   Hence armature current, $I_a = I - I_{sh} = 40 - 2.09 = 37.9$ A.

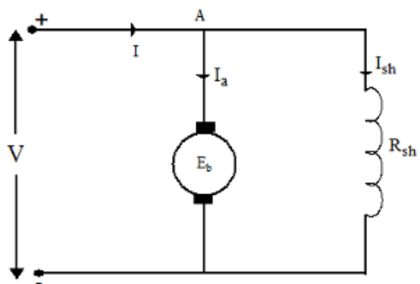

Figure 1.20: Connection diagram of a DC shunt Motor

Now, back emf,

$$\begin{aligned} E_b &= V - I_aR_a - 2(\text{contact drop per brush}) \\ &= 230 - 37.9 \times 0.1 - 2 \times 1 \\ &= 224.21\text{V}. \end{aligned}$$

Further,

$$\begin{aligned} E_b &= \frac{ZN\Phi}{60} \times \frac{P}{A} \\ 224.21 &= \frac{576 \times N \times 0.04}{60} \times \frac{8}{8} \end{aligned}$$

Hence $N = 583.59$ rpm.

NOTE: Since the machine is lap-wound, the number of parallel paths, A is equal to number of poles, P.

4. A six pole, lap-wound 400 V series motor has the following data: Number of armature conductors = 920, flux/pole = 0.045 Wb, total motor resistance = 0.6 ohm, iron and friction losses = 2 kW. If current taken by the motor is 90 A, find: (i) Total torque (ii) Useful torque at the shaft (iii) Power output.

Solution:

Given:

Number of poles of series motor, $P = 6$,

Terminal voltage, $V = 400$ V,

Number of armature conductors, $Z = 920$,

Flux/pole, $\phi = 0.045$ Wb,

Motor current, $I_a (= I_S e) = 90$ A,

Total motor resistance $= R_a + R_{Se} = 0.6$ ohm,

Iron and friction losses, $P_i = 2$ kW.

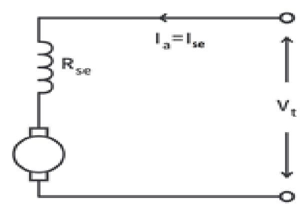

Figure 1.21: Connection diagram of a DC Series Motor (Courtesy: www.electricaldiary.com)

Now armature torque,

$$\begin{aligned} T_a &= 0.159 Z \phi I_a \left(\frac{P}{A}\right) \\ &= 0.159 \times 920 \times 0.045 \times 90 \times \left(\frac{6}{6}\right) \\ &= 592.434 \text{ Nm} \end{aligned}$$

Back e.m.f., $E_b = V - I_a(R_a + R_{Se}) = 400 - 90 \times 0.6 = 346$ V.

Now

$$\begin{aligned} E_b &= \frac{ZN\phi}{60} \times \left(\frac{P}{A}\right) \\ 346 &= \frac{920 \times N \times 0.045}{60} \times \left(\frac{6}{6}\right) \end{aligned}$$

Hence, motor speed, $N = 501.45$ rpm.

Now, torque corresponding to constant losses,

$T_i = \frac{P_i}{\left(\frac{2\pi N}{60}\right)} = \frac{2000}{\left(\frac{2\pi \times 501.45}{60}\right)} = 38.08$ Nm.

Useful torque at the shaft, $T_{sh} = T_a - T_i = 554.34$ Nm.

Power output $= T_{sh} \times \left(\frac{2\pi N}{60}\right) = 554.34 \times \left(\frac{2\pi \times 501.45}{60}\right) = 29416.88$ W $= 29.109$ kW.

1. A 200 kVA, 3300 V/230 V, 50 Hz single-phase transformer has 80 turns on the secondary. Calculate:
   (a) the approximate values of the primary and secondary currents;
   (b) the approximate number of primary turns;
   (c) the maximum value of the flux.

   Solution

   (a) Full-load primary current

$$\simeq 200 \times 1000/3300 = 60.60 \quad \text{A}$$

   and full-load secondary current

$$\simeq 200 \times 1000/230 = 869.56 \quad \text{A}$$

   (b) No. of primary turns

$$\simeq 80 \times 3300/230 = 1148$$

   (c) From (1.27),

$$\begin{aligned} E_2 &= 4.44 N_2 f \phi_m \\ 230 &= 4.44 \times 80 \times 50 \times \phi_m \\ \therefore \phi_m &= 12.9 \text{ mWb} \end{aligned}$$

2. A single phase 50 Hz transformer has 80 turns on the primary winding and 400 turns on the secondary winding. The net cross sectional area of the core is 200 cm^2. If the primary winding is connected to 230 V, 50Hz supply, determine:
(a) The e.m.f. induced in the secondary winding
(b) Maximum value of the flux density in the core

Solution

(a) Turns Ratio

$$(a)K = \frac{V_2}{V_1} = \frac{N_2}{N_1}$$
$$K = \frac{400}{80} = 5$$
$$V_2 = K \times V_1 = 5 \times 230 = 1150V$$

(b) From (1.27),

$$\begin{aligned} E_2 &= 4.44 N_2 f \phi_m \\ 1150 &= 4.44 \times 400 \times 50 \times \phi_m \\ \therefore \phi_m &= 12.9 \text{ mWb} \end{aligned}$$

$$B_m = \frac{\phi_m}{A} = \frac{12.9m}{200 * 10^{-4}}$$
$$B_m = 0.645T$$

3.The primary and secondary windings of a 200 kVA transformer have resistances of 0.25 and0.002 respectively. The primary and secondary voltages are 2000 V and 200 V respectively and the core loss is 2.1 kW. Calculate the efficiency of the transformer (a) full load and unity power factor; (b) half load and 0.8 power factor.

Solution

(a) Full-load secondary current,

$$\begin{aligned} I_2 &= \frac{VA}{V_2} \\ &= \frac{200 \times 1000}{200} \\ &= 1000 \text{ A} \end{aligned}$$

Full-load primary current,

$$\begin{aligned} I_1 &= \frac{VA}{V_1} \\ &= \frac{200 \times 1000}{2000} \\ &= 100 \text{ A} \end{aligned}$$

Therefore secondary I^2R loss on full load is: $= I_2^2 R_2 = (1000)^2 \times 0.002 = 2000$ W

and primary I^2R loss on full load is: $= I_1^2 R_1 = (100)^2 \times 0.25 = 2500$ W.

$\therefore$ Total I^2R loss on full load$= 2000 + 2500 = 4500W = 4.5$ kW.

and Total loss on full load $= 2.1 + 4.5 = 6.6$ kW.

Output power on full load $= 200 \times 1 = 200$ kW

$\therefore$ Input power on full load $= 200 + 6.6 = 206.6$ kW

Efficiency on full load is

$$\left(1 - \frac{6.6}{206.6}\right) = 0.9680 \text{per unit} = 96.80\%$$

(b) Since the I^2R loss varies as the square of the current, $\therefore$ Total I^2R loss on half load$= 4.5\times\ (0.5)^2 = 1.125$ kW

and Total loss on half load $= 1.125 + 2.1 = 3.225$ kW.

Output power on half load $= 0.5 \times 200 \times 0.8 = 80$ kW.

$\therefore$ Input power on half load $= 80 + 3.225 = 83.225$ kW.

$\therefore$ Efficiency on full load is

$$\left(1 - \frac{3.225}{83.225}\right) = 0.9612 \text{per unit} = 96.12\%$$

4. A 25kVA, 50Hz, 2000/200V transformer has iron and copper loss of 350W and 400W respectively. Find (a) the number of turns in each winding for a maximum core flux of 0.045 Wb, (b) efficiency at half rated kVA, and unity power factor, (c) the efficiency at full load, and 0.8 power factor lagging, and (d) the kVA load for maximum efficiency.

Solution

(a) Using the emf equation

$$E_2 = 4.44\ f N_2\ \Phi_m$$

$$N_2 = \frac{E_2}{4.44\ f\Phi_m} = \frac{200}{4.44 \times 50 \times 0.045} = 20.02\ \cong 20 \text{ turns}$$

$$N_1 = \frac{E_1}{E_2} N_2 = \frac{2000}{200} \times 20 = 200 \text{ turns}$$

(b) At half rated kVA, the current is half of the full load current, hence the output power too reduces by half.

Thus, output power $P_o = 0.5 \times\ kVA \times (\text{power factor}) = 0.5 \times 25 \times 1 = 12.5$ kW.

Since copper loss is proportional to the square of the current

Copper Loss $P_c = (0.5)^2 \times (\text{Full load Copper loss}) = (0.5)^2 \times 400 = 0.1$ kW.

Iron loss will be constant. $\therefore P_i = 350 \text{ W} = 0.350\ \text{ kW}$.

Therefore efficiency

$$\eta = \frac{P_o}{P_o + P_c + P_i} = \frac{12.5}{12.5 + 0.35 + 0.1} \times 100 = 96.52\%$$

(c) At full load and 0.8 power factor:

Output Power $P_o = kVA \times (\text{power factor}) = 25 \times 0.8 = 20\ \text{ kW}$

Copper Loss $P_c = 400 = 0.4\ \text{ kW}$

Iron loss $P_i = 350W = 0.35\ \text{ kW}$

Therefore efficiency

$$\eta = \frac{P_o}{P_o + P_c + P_i} = \frac{20}{20 + 0.4 + 0.35} \times 100 = 96.38\%$$

(d) Let x be the fraction of the full load kVA at which the efficiency becomes maximum, and at this kVA, variable copper loss is equal to the fixed iron loss.

Then $x^2 P_c = P_i$ or $x^2 \times 400 = 350$

$$x = \sqrt{\frac{350}{400}} = 0.935$$

The load kVA under the maximum efficiency condition is

Load kVA $= x \times (\text{Full load kVA}) = 0.935 \times 25 = 23.38$ kVA.

5. A 400kVA single phase transformer has an efficiency of 98.77% at full load 0.8 power factor and 99.13% at half full load unity power factor. Calculate iron loss and full load copper loss. Also determine its efficiency at 80% of full load and 0.8 power factor

At full load and 0.8 power factor

$$\eta = \frac{xVAcos\Phi}{xVAcos\Phi + x^2P_c + P_i}$$

$$0.9877 = \frac{1\times400\times1000\times1}{1\times400\times1000\times0.8+P_i+1^2\times P_c}$$

$$P_i + P_c = 3985.01Watts \ ..... \ (1)$$

At half full load and unity power factor

$$\eta = \frac{xVAcos\Phi}{xVAcos\Phi + x^2P_c + P_i}$$

$$0.9913 = \frac{0.5\times400\times1000\times1}{0.5\times400\times1000\times1+P_i+0.5^2\times P_c}$$

$$P_i + 0.25 \times P_c = 1755.27Watts \ ...... \ (2)$$

Solving equations (1) and (2), we get

$$P_c = 2972 \text{ W}$$

$$P_i = 1013.01\text{W}$$

Efficiency at 80% full load and 0.8 power factor

$$\eta = \frac{xVAcos\Phi}{xVAcos\Phi + x^2P_c + P_i}$$

$$\eta = \frac{0.8\times400\times0.8}{0.8\times400\times0.8+0.8^2\times2.972+1.013}$$

$$\eta = 98.46\%$$

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NMAM INSTITUTE OF TECHNOLOGY, NITTE

Off-Campus Centre of Nitte (Deemed to be University)

I Sem B.Tech. (CBCS) Mid Semester Examinations - II, November

ation: 1 Hour

EE1001-1 – BASIC ELECTRICAL ENGINEERING

Note: Answer any **One** *full question from* **each Unit.**

Unit – I

		Marks	BT
a)	State and explain (i) self induced emf (ii) mutually induced emf (iii) Lenz's Law.	06	L*
b)	A 250 kVA, 11000 V / 400 V, 50 Hz single-phase transformer has 80 turns on the secondary. Calculate: (i) The approximate values of the primary and secondary currents; (ii) The approximate number of primary turns; (iii) The maximum value of the flux.	04	L
a)	Derive the emf equation of single phase transformer.	04	L
b)	The primary and secondary windings of a 500 kVA transformer have resistances of 0.42 Ω and 0.0019 Ω respectively. The primary and secondary voltages are 11000 V and 400V respectively and the core loss is 2.9 kW, assuming the power factor of the load to be 0.8. Calculate the efficiency on (a) full load; (b) half load.	06	

Unit – II

a)	With neat diagram explain construction of DC machine.	06	
b)	Derive the emf equation of DC generator.	04	
a)	Prove that two wattmeter are sufficient to measure the three phase power in a balanced star connected system with the help of vector diagram.	06	
b)	A 4 pole lap wound DC generator has 672 conductors. It is driven at 1120 rpm. If the useful flux per pole is 21 mWb, Calculate the generated emf. Find the speed at which it is to be driven to generate the same emf with wave wound armature.	04	

* Bloom's Taxonomy, L* Level; CO* Course Outcome; PO* Program Outc

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NMAM INSTITUTE OF TECHNOLOGY, NITTE

Off-Campus Centre of Nitte (Deemed to be University)

II Sem B.Tech (CBCS) Mid Semester Examinations - II, April 20[illegible]

EE1001-2 – BASIC ELECTRICAL ENGINEERING

(For AD, AM, CB, CC, CS, IS, RI)

Duration: 1 Hour

M[illegible]

Note: Answer **One** full question from **each Unit.**

Unit – I

		Marks	BT[illegible]
1. a)	With a neat diagram, explain the construction of a DC machine.	6	L*2[illegible]
b)	A 8 pole lap wound 230 V shunt motor has 576 armature conductors. It takes 40 A on full load. The flux per pole is 0.04 Wb. The armature and field resistances are 0.1 Ω and 110 Ω respectively. Determine the speed of the motor at full load.	4	L3[illegible]
2. a)	Draw and explain the characteristics of (i) DC shunt motor and (ii) DC series motor.	6	L[illegible]
b)	An 8 pole wave wound DC generator has 960 armature conductors and flux/pole 0.04 Wb. At what speed must it be driven to generate 400 V?	4	L[illegible]

Unit – II

		Marks	BT[illegible]
3. a)	Write a note on (i) losses in a single phase transformer and (ii) autotransformer and its applications.	6	L[illegible]
b)	A 400 kVA single phase transformer has an efficiency of 98.77 % at full load 0.8 power factor and 99.13 % at half full load unity power factor. Calculate the iron loss and full load copper loss.	4	L[illegible]
4. a)	Derive the condition for maximum efficiency of a single phase transformer.	6	L[illegible]
b)	A 200 kVA, 3300 V/230 V, 50 Hz single phase transformer has 80 turns on the secondary. Calculate (i) the approximate values of the primary and secondary currents (ii) the approximate number of primary turns and (iii) the maximum value of the flux.	4	[illegible]

BT* Bloom's Taxonomy, L* Level; CO* Course Outcome; PO* Program Outcom[illegible]

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NMAM INSTITUTE OF TECHNOLOGY
Off-Campus Centre of Nitte(Deemed to be University), NITTE
II Sem B.Tech (CBCS) Mid Semester Examinations - II, April 2023
EE1001-1 – BASIC ELECTRICAL ENGINEERING

Duration: 1 Hour Max. Ma

Note: Answer any **One** *full question from* **each Unit.**

Unit – I

Q.		Question	Marks	BT*	CO*
1.	a)	State and explain Faradays laws of Electromagnetic Induction.	04	L*2	03
	b)	In a 50 KVA, 1100/220 V single phase transformer the iron and full load copper losses at full load are 350W & 425W respectively. Find (i) Efficiency at full load unity p.f (ii) The load at which maximum efficiency occurs iii) Max efficiency at unity power factor	04	L3	03
	c)	List the various losses in a transformer.	02	L1	03
2.	a)	What is an autotransformer? List its advantages and applications.	04	L1	03
	b)	Derive the emf equation of a single-phase transformer	04	L2	03
	c)	Define self and mutually induced emf.	02	L1	03

Unit – II

Q.		Question	Marks	BT*	CO*
3.	a)	With a suitable diagram explain the construction of synchronous machine.	05	L2	0
	b)	A six pole, lap-wound 230V series motor has the following data: Number of armature conductors = 800, flux/pole = 0.04Wb, total motor resistance = 0.5Ω, iron and friction losses = 1.5kW. If current taken by the motor is 60A, find: i. Total torque ii. Useful torque at the shaft iii. Power output.	05	L3	
4.	a)	Draw and explain the torque Vs armature current characteristics of DC shunt motor.	03	L2	
	b)	Derive the emf equation of the DC generator	04	L2	
	c)	A 12 pole 500 rpm star connected alternator has 48 slots, with 15 conductors/slot, the flux/pole is 0.02 Wb. Assume unity distribution factor and winding factor as 0.97. Calculate line EMF.	03	L3	

BT* Bloom's Taxonomy, L* Level; CO* Course Outcome; PO* Program Outcome

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... triangle. 5 L2

Unit – II

4. a) Derive the emf equation of a transformer. 4 L1

b) Derive the expression for the armature torque of a DC motor. 5 L3

c) A 16-pole star-connected alternator has 144 slots and 10 conductors per slot. The flux per pole is 30 mWb and the speed is 375 rpm. Find the frequency, the phase emf and line emf. Assume that the winding is concentrated and full-pitched ($K_d = K_p = 1$). 5 L3

5. a) Prove that the efficiency of a transformer is maximum when its Copper loss equals its iron loss. 6 L2

b) Discuss the three characteristics of a DC shunt motor. 6 L3

c) Describe the working principle of a 3-phase synchronous motor. 5 L2

6. a) Obtain the expression for the frequency of the induced emf of an alternator in terms of number of poles and rpm. 5 L2

b) A 4-pole DC generator has a lap-wound armature with 50 slots with 16 conductors per slot. The useful flux per pole is 30 mWb. Determine the speed at which the machine must be driven to generate an e.m.f. of 240 V. 4 L[illegible]

c) A 250-kVA, single-phase transformer has an efficiency of 96 % on full load at 0.8 power factor lagging and also on half load 0.8 power factor lagging. Find its iron loss and full-load copper loss. 6 [illegible]

6

ISE-(I)