UNIT 4 ELECTRICAL MACHINES

Structure

4.1 INTRODUCTION

For common terms electrical machine means any appliance, which converts mechanical energy to electrical energy (recollect generator) or electrical energy to mechanical energy (recollect motor).

It is always beneficial to utilize electrical energy – because it can be easily transmitted and distributed, easy to control and more efficient and cheaper.

The input mechanical energy to the generators is taken from prime movers like petrol engine for portable generators, diesel engines, water turbines at hydroelectric plant like Bhakara dam, steam turbine at thermal power plant like Belarpur etc. These turbines are coupled to the generators.

The conversion of electrical energy into mechanical energy is done through electric motors. In the industry, these motors are intensively used to drive electric locomotives, floor mills, machine tools, water boosters etc. Thus, the generating and motoring action is reversible.

Whole of electrical system is based on :

(a) Generation of electrical power through generators.

(b) Transmission and distribution of electrical power to consumers.

(c) Utilization of the electrical power at consumers' end.

The arrangement of fetching electric power from generating station to the various consumers is called Distribution System.

This power distribution system is finally classified into :

(a) (a) Primary Distribution or HT (High Tension) at 11 kV.

(b) Secondary Distribution or LT (Low Tension) at 400 V, 3-phase 4-wire system.

Objectives

After studying this unit, you should be able to

- explain the principle of DC machines,
- explain the working of transformers, and
- know the electrical distribution systems.

4.2 DC MACHINES

A DC machine is an electromechanical conversion device. The working of a DC machine as a generator or motor is as follows :

(i) (a) By Faraday's induction law when a conductor cuts a magnetic field then an emf is induced in conductor (i.e. when the armature of DC machine rotates with any prime mover, an emf is induced in it, so it works as a DC generator).

(ii) (b) If a current carrying conductor is placed in a magnetic field perpendicularly, then a force acts on conductor and direction of force is determined by Fleming's left hand rule (i.e. when we provide the supply across armature of a DC machine then the armature rotates in the direction of force, so it works as DC motor).

(c) For a DC machine, either DC generator or DC motor, there should be a magnetic field and the rotating conductors. In a DC machine, magnetic field is provided by permanent magnets for small machines and by electromagnets in large machines because the strength of permanent magnets gets reduced with time or long use. From construction point of view, DC generator and DC motor both are same.

4.2.1 DC Generator

The DC generator gets its name from the type of voltage it generates, which is DC voltage. It has two parts – a **stator** and a **rotor**. Stator is a cylindrical hollow part which always remains static and houses a rotating part, mounted on a bar through two bearings, called rotor. Although usually stator has magnetic poles, which can be of permanent magnet or electromagnets, and the rotor carries axially placed conductor wiring at its periphery called armature, but in principle either of them can serve as magnetic field producer and the other as armature. Usually, permanent magnet generators have armature on stator as no contact with rotating part is required for supply of electricity.

The generator works on the principle laid down by Faraday's Law. When the rotor is rotated at a particular speed, there is continuous change of magnetic flux linked with each conductor on armature. This rate of change of flux gives rise to an induced voltage in each conductor, which when joined in series through the coils in armature add up to give the rated generated voltage. When armature is on rotor, the output voltage is taken through contact brushes on rotor.

EMF Equation

Let us now derive the expression for generated voltage at armature terminals.

Let ϕ = flux per pole in Webers,

P = No. of poles in machine, and

Z = Total number of armature conductors.

Let a conductor move from A to B (which is one pole pitch), then the flux linked or flux is ϕ Webers.

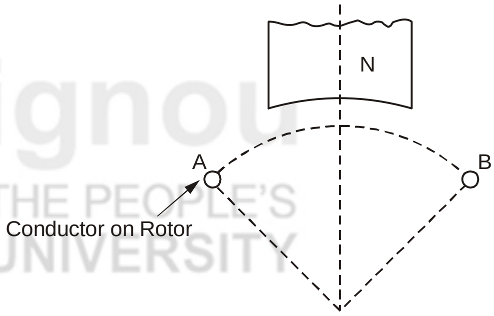

Figure 4.1 : A Portion of Machine

If t = time taken for the conductor to move from A to B, then emf induced in the conductor,

$$e = \text{Rate of change of flux} = \frac{\phi}{t} \text{ volts}$$

Let N = RPM of the rotor

i.e. Time for N revolutions = 1 minute = 60 seconds

Time for 1 revolution = $\frac{60}{N}$ seconds.

Time for 1 pole pitch = $\frac{60}{N} \times \frac{1}{P}$

(1 Pole Pitch is angular distance between two consecutive poles.)

or $t = \frac{60}{NP}$ seconds

Then emf is $e = \frac{\phi}{t} = \frac{\phi \times NP}{60}$ volts per conductor

The Calculation of emf Across Generator Terminals

Let A = No. of parallel paths and there are two types of windings – lap and wave.

For lap winding, $A = P$ and for wave winding $A = 2$.

The conductors in series per path = $\frac{Z}{A}$.

EMF induced per path across generator terminals

$$= \frac{\text{EMF}}{\text{Conductor}} \times \frac{Z}{A} = e \times \frac{Z}{A}.$$

$$= \frac{\phi\, NP}{60} \times \frac{Z}{A}$$

or $$E = \frac{\phi ZN}{60} \times \frac{P}{A} \text{ volts}$$

4.2.2 Types of DC Generator

The generators used for industrial applications have the magnetic field generated through current carrying coils wound onto poles. These coils connected in series with each other are collectively called field winding.

To provide the flux by Field system or Field coil, the field coils are excited by some external source or by the generator itself and thus there are two types of DC generator.

Separately Excited DC Generators

A DC generator whose field coils are energised by the external DC source, such as a battery etc., is called separately excited DC generator as shown in Figure 4.2.

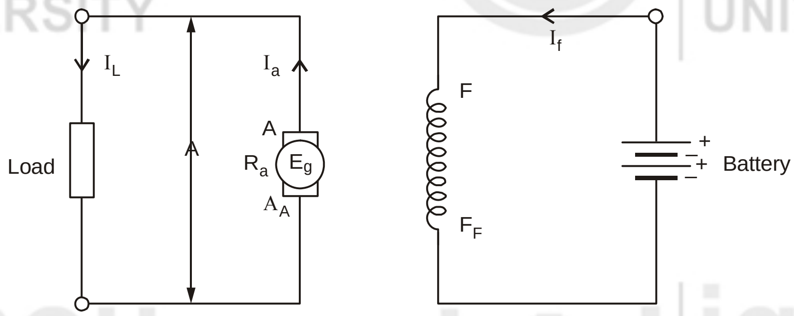

Figure 4.2 : Separately Excited DC Generator

Self Excited DC Generators

A DC generator whose field windings are excited by the current flowing from the generator itself is called self excited DC generator. The current flowing through field winding depends on the connections of field winding. There are three possible connections of field winding so that self excited DC generators are classified as follows :

(a) Series wound DC generator

(b) Shunt wound DC generator

(c) Compound wound DC generator

4.2.3 Working of DC Generators

Some magnetic flux is always present in iron core of field coils or field system of self excited DC generators due to residual magnetism. When the armature cuts this flux then an emf is induced in armature conductors.

To buildup the rated voltage in any self excited DC generator :

(a) There should be residual magnetism in pole cores.

(b) The direction of rotation of armature should be correct or forward. If direction is reversed, then the flux produced by field current opposes the residual magnetic flux rather than aiding it.

(c) The resistance of load for DC series generator or resistance of shunt field for DC shunt generator should not be more than a critical resistance.

In DC series generator, the voltage is built up at Rated Value when we connect the load across terminals because current flowing through armature is same as field current. Due to small induced emf, a field current flows through field coils so the magnetic flux rises. Due to this increased flux, the emf induced in armature is also increased so a large current flows through field coils due to this emf. This continues till iron core reaches saturation and rated voltage is reached.

For any magnetic material as per molecular theory of magnetism when we increase the field current gradually, then after some value of field current, saturation occurs. At that time rated emf is induced at the terminals of DC generator.

For DC shunt generator, if there is no load across terminals then the emf is induced because of field current in shunt winding, which is parallely connected across armature terminals who will induce emf across its terminals. Due to this emf, field current builds up through field coils.

If a curve is drawn between field current and armature open terminal voltage, then it is called open circuit or magnetic characteristics of DC generator. By drawing tangent on linear portion of OCC we find value of critical resistance as slope of this tangent.

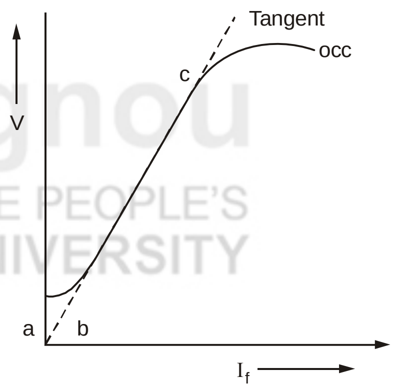

Figure 4.3 : Open Circuit Characteristics (OCC)

4.2.4 Operation of Different Types of Generator

Separately Excited DC Generator

Let R_a is armature resistance, E_g is induced emf in armature, and V is terminal voltage across armature. When a load is connected across terminals of generator then load current will be equal to armature current

So, $I_a = I_L$

By applying KVL in armature circuit, we get

$$E_g = V + I_a R_a$$

Here, V is voltage across load.

Power developed in armature $P_g = E_g I_a$ Watts

Power delivered to load $P_L = V I_L = V I_a$ watts

Power loss in the armature of machine, $P_a = P_g - P_L$ watts

The expression for E_g is as derived earlier

$$E_g = \frac{\phi\, N\, Z\, P}{60\ A} \text{ volts}$$

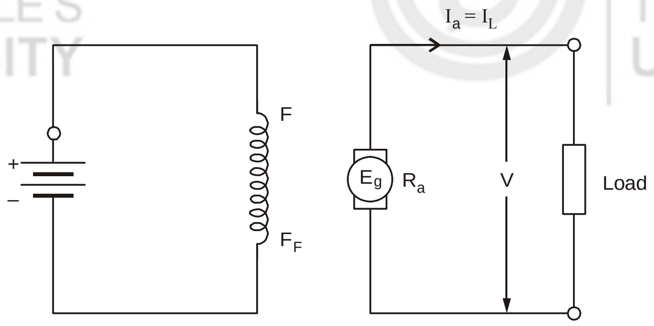

Figure 4.4 : Separately Excited DC Generator

DC Series Generator

Similarly we can derive equations for DC series generator.

$$I_a = I_{se} = I_L$$

$$E_g = V + I_a\ (R_a + R_{se})$$

$$P_g = E_g\, I_a \text{ watts}$$

$$P_L = V \cdot I_a \text{ watts}$$

$$P_a = P_g - P_L \text{ watts}$$

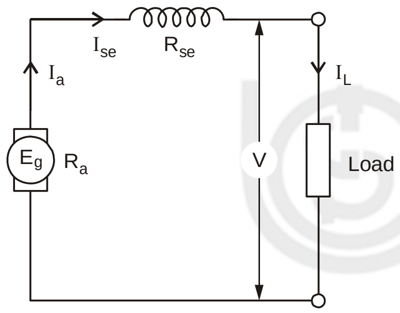

Figure 4.5 : DC Series Generator

DC Shunt Generator

In DC shunt generator, the shunt resistance R_{sh} is introduced across E_g.

$$I_a = I_{sh} + I_L$$

$$I_{sh} = \frac{V}{R_{sh}}$$

$$E_g = V + I_a\, R_a$$

$$P_g = E_g \cdot I_a \text{ Watts}$$

$$P_L = V \cdot I_L \text{ Watts}$$

$$P_a = P_g - P_L \text{ Watts}$$

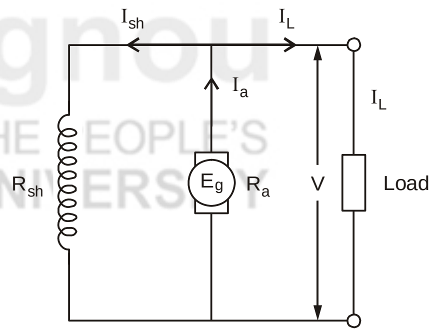

Figure 4.6 : DC Shunt Generator

DC Compound Generator

Long Shunt

There are of two types of compound generator :

(i) long shunt, and

(ii) short shunt.

The connections for long shunt compound generator is shown in Figure 4.7.

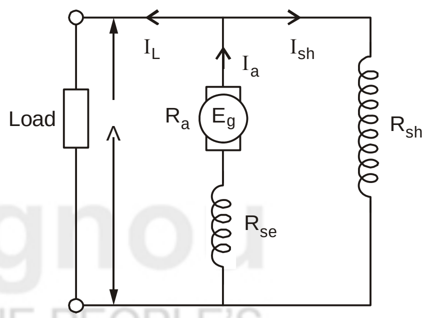

Figure 4.7 : Long Shunt

Equations of operation for long shunt are :

$$I_a = I_L + I_{sh}$$

$$I_a = I_{se}$$

$$I_{sh} = \frac{V}{R_{sh}}$$

$$E_g = V + I_a (R_a + R_{se})$$

$$P_g = E_g \cdot I_a \text{ Watts}$$

$$P_L = V \cdot I_L \text{ Watts}$$

$$P_a = P_g - P_L \text{ Watts}$$

Short Shunt

The connections for short shunt compound generator is shown in Figure 4.8.

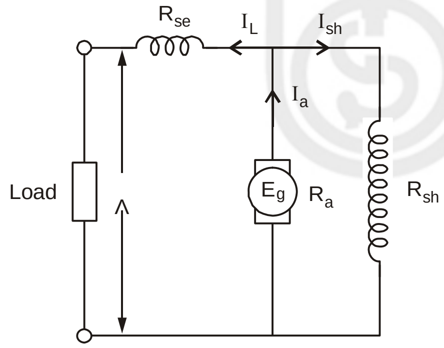

Figure 4.8 : Short Shunt

Equations of operation in short shunt compound generator are :

$$I_a = I_L + I_{sh}$$

$$E_g = V + I_a R_a + I_L R_{se}$$

$$I_{sh} = \frac{E_g - I_a R_a}{R_{sh}} = \frac{V + I_L R_{se}}{R_{sh}}$$

$$P_g = E_g I_a \text{ Watts}$$

$$P_L = V \cdot I_L \text{ Watts}$$

$$P_a = P_g - P_L \text{ Watts}$$

In all the above cases, if there is brush drop of V_b volts in the 2 brushes connected to armature, the voltage equation of generator has an additional drop term of 2 V_b added to $I_a R_a$ term. For example, the voltage equation for short shunt compound generator would be

$$E_g = V + I_L R_{se} + (I_a R_a + 2 V_b)$$

SAQ 1

(a) (i) Deduce the expression for EMF induced by operation of a DC Generator.

(ii) What EMF will be generated in a 8-pole lap wound DC generator if it is rotated at 200 RPM? The flux per pole is 0.05 Weber and the number of armature conductors is 960.

(b) A DC shunt generator has an induced voltage of 125 V on open circuit. When the machine is loaded the terminal voltage is 120 volts. The field resistance is 15 ohms and the armature resistance is 0.05 ohm. Determine the load current.

(c) A long shunt compound generator supplies a load current of 50 amperes at 220 volts. Shunt field resistance is 110 ohms. Series field resistance is 0.01 ohm and armature resistance is 0.02 ohm. Find the emf generated and power developed in the armature. Take contact drop per bush as 1.5 volts.

4.3 DC MOTOR

Construction and Working of DC Motors

Motor is a device which converts electrical energy into mechanical energy. When a current carrying conductor is placed in a magnetic field then a force acts on the conductor and conductor starts moving in the direction of force. The construction of DC motor is similar to that of DC generator. When the DC machine is connected to DC supply, a current passes through the armature winding. When a conductor of armature winding carries outward current under North pole and incoming current under South pole then it experiences a force in clockwise direction according to Fleming's left hand rule. Due to this force, the conductor moves clockwise. When the conductors which were under North pole will come under South pole, they would have experienced a force in anticlockwise direction, if the direction of current is unchanged. So, there is a requirement to reverse the direction of current to make the conductor still move in clockwise direction. The direction of current is reversed by commutators in contact with brushes and, thus, armature conductors always experience a force in clockwise direction and rotate in same direction continuously.

Types of DC Motor

DC motors are also classified on lines similar to DC generators.

4.3.1 Working of DC Motors

In a DC motor, as in case of a DC generator, when armature rotates then an emf is induced in armature conductors known as back emf which opposes the applied voltages. The expression for this voltage is same as that for DC generator, i.e.

$$E_b = \frac{\phi\, Z\, N\, P}{60\, A} \text{ Volts}$$

If R_a is armature resistance, then

$$V = E_b + I_a R_a$$

Here I_a is armature current and V is applied voltage.

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

Back emf makes a DC motor self regulating. When speed is low then back emf will be less as it is directly proportional to speed and armature current will be large because of above relation.

Power Equation

The voltage equation for separately excited or shunt motor is

$$V = E_b + I_a R_a$$

By multiplying I_a in this equation, we get

$$VI_a = E_b I_a + I_a^2 R_a$$

It is a power equation, where $V I_a$ is input power, $E_b I_a$ is power developed in armature and $I_a^2 R_a$ represents power losses in armature.

So mechanical power developed by motor is

$$P_m = E_b I_a = V I_a - I_a^2 R_a$$

or, P_m = Input Power – Losses

On differentiating this equation with respect to I_a, we get

$$\frac{d P_m}{d I_a} = V - 2 I_a R_a$$

For maximum power, put $\frac{d P_m}{d I_a} = 0$

so, $V - 2 I_a R_a = 0$

or, $V = 2 I_a R_a$

But $I_a R_a = V - E_b$

so, $V = 2 (V - E_b)$

or, $E_b = \frac{V}{2}$

Thus, in DC motor mechanical power developed in armature is maximum when back emf is half of applied voltage. This condition is avoided in practice due to large losses as efficiency in this case would be below 50%.

Speed Equation

The back emf in armature is

$$E_b = \frac{P \phi Z N}{60 \text{ A}}$$

so, $$N = \frac{E_b \, 60 \text{A}}{P \phi Z}$$

since P, Z and A are constant for a machine.

Then $$N \propto \frac{E_b}{\phi}$$

or, $$N \propto \frac{V - I_a R_a}{\phi}$$

For a shunt motor, field current and hence ϕ is constant, then

$$N \propto E_b \qquad \text{or } N \propto (V - I_a R_a)$$

For a series motor I_f and hence ϕ is proportional to I_a.

So, $$N \propto \frac{E_b}{I_a}$$

Percentage speed regulation = $\frac{N_0 - N_f}{N_f} \times 100$.

Here N_0 is speed at no load in RPM, i.e. at $I_a = 0$, and N_f is speed at full load in RPM, i.e. at $I_a = I_{FL}$.

Torque Equation of DC Motor

At a wheel of radius r metre if a force F acts on circumference, then

Torque $T = F \cdot r$

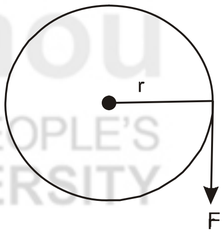

Figure 4.9

Work done per revolution = $F \cdot 2\pi\, r$

Work done per second = $F \cdot 2\pi\, r \cdot n$

Here, n is speed in revolutions per second, i.e. $n = \frac{N}{60}$ and N is speed of rotation in RPM.

So, power developed, P = Work done per second

or, $P = Fr \cdot 2\pi\, n$

or, $P = T \cdot \omega$

where, T = Torque, and ω = angular velocity.

Here, $\omega = 2\pi\, n = \frac{2\pi N}{60}$

But, power developed in armature = $E_b \cdot I_a$

So, $E_b\, I_a = T \cdot \omega$

or, $$T = \frac{E_b\, I_a}{\omega} = \frac{E_b\, I_a}{2\pi\, N} \times 60 = 9.55\, \frac{E_b\, I_a}{N} = \frac{9.55}{N}\, P_m$$

Also, $$T = \frac{E_a\, I_a}{\omega} = \frac{P\,\phi\, Z\, N}{60\,\text{A}}\, \frac{I_a}{\frac{2\pi N}{60}}$$

or, $$T = \frac{P\,\phi\, Z}{2\pi\, A} \cdot I_a = 0.159\, \phi\, ZP\, \frac{I_a}{A}$$

Shaft torque, $T_{sh} = \frac{9.55}{N}$ × Mechanical power of shaft and it is also called armature torque.

Since Z, P and A are constant

$\therefore \quad T \propto \phi\, I_a$

From this equation, it is clear that direction of DC motor can be reversed by reversing the direction of current either in armature or field winding. If current through both windings is reversed then direction of rotation will be same.

For DC shunt motor ϕ is constant

$\therefore \quad T \propto I_a$

And for DC series motor, $\phi \propto I_a$,

$\therefore \quad T \propto I_a^{\,2}$

4.3.2 Operation of Different Types of Motor

Separately Excited DC Motor

$$E_b = V - I_a R_a$$

$$I_a = I_L$$

Power drawn from supply

$$P = V I_L$$

Mechanical power developed

$$P_m = E_b I_a$$

$$= I_a (V - I_a R_a)$$

$$= V I_a - I_a^2 R_a$$

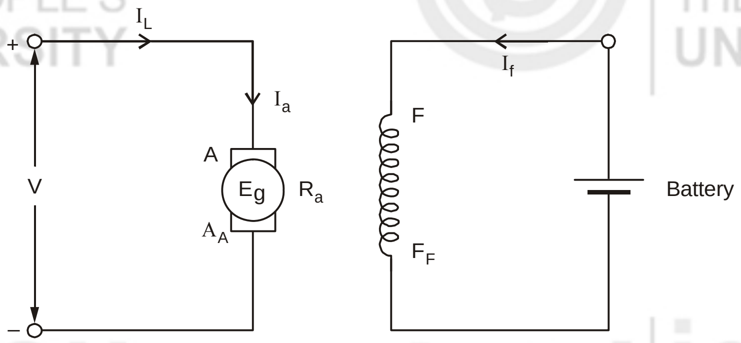

Figure 4.10

Series Wound DC Motor

$$I_a = I_{se} = I_L$$

$$E_b = V - I_a (R_a + R_{se})$$

Power drawn from supply

$$P = V I_a$$

$$P_m = E_b I_a = [V - I_a (R_a + R_{se})] \times I_a = V I_a - I^2_a R_a - I^2_a R_{se}$$

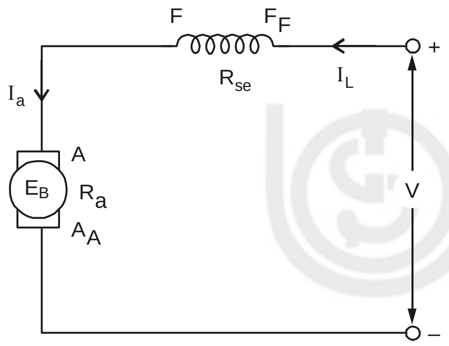

Figure 4.11

Shunt Wound DC Motor

$$I_L = I_a + I_{sh}$$

$$I_{sh} = V / R_{sh}$$

$$E_b = V - I_a R_a$$

$$P = V \cdot I_L$$

$$P_m = I_a E_b$$
$$= I_a (V - I_a R_a)$$
$$= V I_a - I_a^2 R_a$$

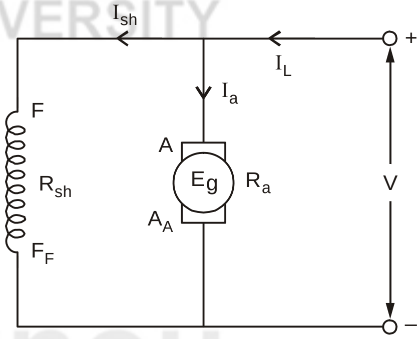

Figure 4.12

SAQ 2

(a) A 250 volts DC shunt motor takes a total current of 20 amperes.

Resistance of shunt field = 200 ohms

Resistance of armature = 0.30 ohm

Find :

(i) The current in the armature.

(ii) The back EMF.

(b) Determine the value of the torque established by the armature of a 4-Pole motor having 744 conductors, wave wound. The flux per pole is 2.4×10^{-2} Webers and the total armature current is 50 amperes.

(c) A 200 volts DC series motor runs on 500 rpm, when taking a current of 25 ampere. The resistance of the armature is 0.5 ohm and that of the field is 0.3 ohm. If the current remains constant, calculate the necessary additional resistance in series with armature to reduce the speed to 250 rpm.

(d) A 240 volts DC shunt motor has an armature resistance of 0.10 ohm and field resistance of 400 ohms. The normal speed is 1000 rpm and the armature current is 50 ampere. What additional resistance should be added in the field to increase the speed to 1200 rpm. Assume that the armature current remaining same and magnetisation curve is a straight line.

4.4 TRANSFORMER

Transformer is an AC machine without any rotating part, that

(a) transfers electric energy from one circuit to another without a conducting link.

(b) converts energy without the change in frequency.

(c) it is a combination of electrical circuits linked by common magnetic circuit.

(d) it links two circuits operating at two different voltages.

When the transformer raises the voltage it is called step up transformer and when it lowers, it is called step down transformer.

4.4.1 Working Principle and Construction of Transformer

Transformer consists of a soft iron or silicon steel core and two windings of copper placed on it. Windings are insulated from the core and also from each other. Core is built up of silicon steel laminations to provide a path of low reluctance to the magnetic flux. Winding connected to supply mains is called primary and winding connected to the load is called secondary. Constructional features of a transformer are depicted in Figure 4.13.

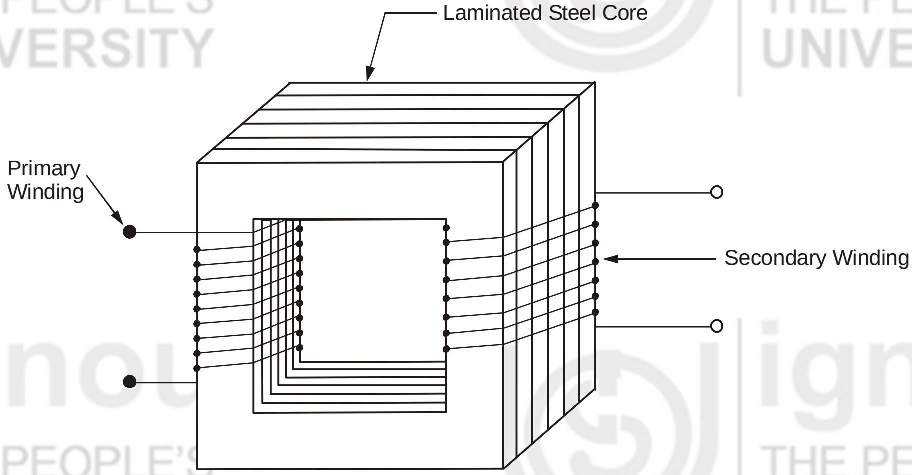

Figure 4.13

When the primary winding is connected to an AC supply mains, current flows through it, so current flowing through this winding produces an alternating flux. This flux linked with secondary winding mutually induces an emf in secondary winding. This flux is also linked with primary winding which induces an emf which opposes the applied voltage.

Emf Equation

Alternating flux which is produced by primary current is expressed by (as shown in Figure 4.14).

$$\phi = \phi_m \sin \omega t$$

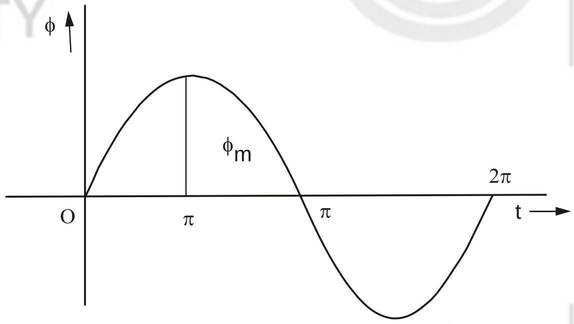

Figure 4.14

By Faraday's Law

$$\text{Induced emf} = -N \frac{d\phi}{dt}$$

$$\therefore \quad e = -N \frac{d}{dt} (\phi_m \sin \omega t)$$

Here, N is no. of turns in coil.

or, $e = -N \omega \phi_m \cos \omega t$

$\because$ $\sin (90 - \theta) = \cos \theta$

or, $$e = -N \omega \phi_m \sin \left(\frac{\pi}{2} - \omega t \right)$$

or, $$e = N \omega \phi_m \sin \left(\omega t - \frac{\pi}{2} \right)$$

or, $$e = E_m \sin \left(\omega t - \frac{\pi}{2} \right)$$

Here $E_m = N \cdot \omega \cdot \phi_m$

The rms value of emf will be

$$E_{\text{rms}} = \frac{E_m}{\sqrt{2}}$$

$$= \frac{N \omega \phi_m}{\sqrt{2}}$$

$\because$ $\omega = 2\pi f$

$$E = \frac{2\pi f N \phi_m}{\sqrt{2}} = 4.44 f N \phi_m$$

If N_1 is the number of turns in primary winding, then

$$E_1 = 4.44 f N_1 \phi_m$$

And if N_2 is number of turns in secondary winding, then

$$E_2 = 4.44 f N_2 \phi_m$$

Here $\phi_m = B_m \cdot A$

and B_m is maximum flux density in Tesla and A is effective cross-sectional area of iron core.

Voltage Transformation Ratio

Voltage Transformation Ratio is the ratio of secondary voltage to primary voltage.

$$\text{Voltage Transformation Ratio } (K) = \frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{N_2}{N_1}$$

For step up Transformer $K > 1$

For step down Transformer $K < 1$

Current Ratio

When losses are negligible then

$$\text{Input } VA = \text{Output } VA$$

$$V_1 I_1 = V_2 I_2$$

$$\therefore \qquad \frac{I_2}{I_1} = \frac{V_1}{V_2}$$

where, Current Ratio = $\frac{I_2}{I_1}$

So, Current Ratio $= \frac{I_2}{I_1} = \frac{V_1}{V_2} = \frac{1}{K}$

or, Current Ratio $= \frac{1}{\text{Voltage Transfomation Ratio}}$

SAQ 3

A 25 kVA transformer has 500 turns on the primary and 50 turns on the secondary winding. The primary is connected to 3300 V, 50 Hz supply. Find the full load primary and secondary currents, the secondary emf and the maximum flux in the core. Neglect leakage and no-load primary current.

4.5 DISTRIBUTION OF ELECTRICITY

The ever increasing use of electricity and electric power has necessitated to have well planned distribution system. The distribution system should be efficient and economical for the consumers.

4.5.1 Distribution System

The arrangement of conveying electric power from generating stations or sub-stations to the various consumers is called 'distribution system'.

Classification of Distribution System

Distribution system may be classified as :

(i) Primary distribution system.

(ii) Secondary distribution system.

Primary Distribution System

The system in which electric power is conveyed at 11 kV or 6.6 kV or 3.3 kV to different sub-stations for distribution or to big consumers is called **high voltage** or **primary distribution system** (Ref : *Textbook of Elementary Electrical Engineering* by V. K. Mehta).

Electric power from the generating stations is transmitted at high voltage (33 kV to 400 kV) to various sub-stations located in or near the city. At these sub-stations, this high voltage is stepped down to 11 or 6.6 or 3.3 kV with the help of step-down transformers. Power is given to various sub-stations for distribution or to big consumers at this voltage. This forms the high voltage or primary distribution. Figure 4.15 shows the schematic diagram for a typical primary distribution system.

The primary distribution is dependent on the voltage employed, power to be distributed and the distance of sub-stations.

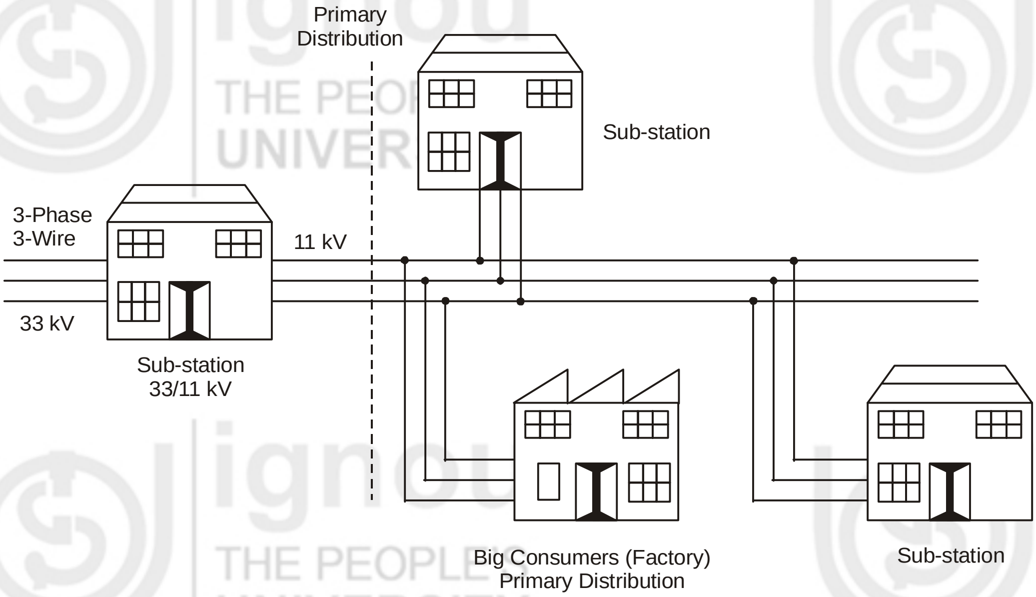

Figure 4.15 : Primary Distribution

Secondary Distribution System

The system in which electric power is distributed at 400/230 V to various consumers is called **Low Voltage** or **Secondary Distribution System**.

When the primary distribution of electric power is successful, the power is delivered to various sub-stations which are located normally at consumers localities and called as distribution sub-stations. At each distribution sub-station, the voltage is stepped down to 0.4 kV and electric power is distributed by 3-phase 4 wire AC system. The voltage between any two phases is 400 V and between any phase and neutral is 230 V. The line diagram of a typical secondary distribution system is shown in Figure 4.16. Domestic loads such as lamps, refrigerators, fans, heaters and other domestic appliances operate with

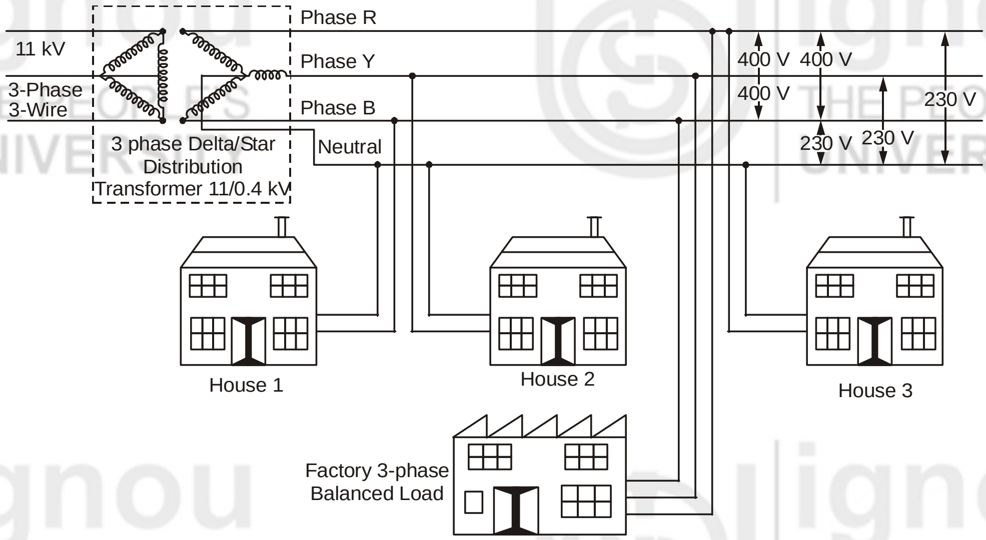

Figure 4.16 : Secondary Distribution

two wires at low voltage (230 volts) and therefore, they are all connected between any one phase and neutral. Such loads are called 'single phase loads'. On the other hand, industrial loads, e.g. motors operate with 3 or 4 wires at higher voltage (400 V) and, therefore, they are connected to the three phases. Such loads are called 3-phase loads.

Distinction between Primary and Secondary Distribution

Distinction between primary (HT) and secondary (LT) distribution is listed below in the tabular form.

Sl. No.	Particular Features	Primary Distribution	Secondary Distribution
1.	Voltage	Generally 11, 6.6 or 3.3 kV	440/230 V.
2.	System	3-phase 3 wire	3-phase 4 wire
3.	Tapping	No tapping is taken	Tappings are taken from distribution lines

4.5.2 Identification of Wires

In low voltage distribution system, poles carrying the wires are run in the streets or along the road side. On any pole, there are six wires (namely, earth wire, 3 phase wires, neutral wire and street light wire) within the municipal limits or where there is provision for street light.

Earth Wire

The fifth wire from top supported on the cross arm without insulator is the earth wire. The area of cross-section of this wire is half of the phase wire.

Phase Wire

There are three phase wires (first, second, and third from top) suspended from the phase by insulators. The three phases are named as Red, Yellow and Blue (RYB). The voltage between any two phase wires is 400 V. They are also called live wires.

Street Light Wire

It is a live wire (fourth from top) and is connected to one of the phase wires. It is used for street light only and is controlled from the sub-stations.

Neutral Wire

It is the bottommost wire and is supported on the cross arm by an insulator. It is not the live wire. The voltage between any phase wire and neutral is 230 V.

4.5.3 Identification of Voltage

It is worthwhile to identify the voltage available in a low voltage distribution system. The different voltages available in such a system are :

(a) 400 volts between any two phases. This is also called 'line voltage', and

(b) 230 volts between any one phase wire and neutral. This is called 'phase voltage'.

There is a definite relation between line voltage and phase voltage in 3-phase 4 wire AC system.

$$\text{Phase Voltage} = \frac{\text{Line Voltage}}{\sqrt{3}}$$

If line voltage is 400 V, then phase voltage is $\frac{400}{\sqrt{3}} = 230$ V.

4.5.4 Overhead and Underground System

A distribution system may be divided into the following two classes on the basis of construction :

(a) Overhead system, and

(b) Underground system.

In the overhead system, as the name suggests, power is carried by overhead *bare* conductors laid on suitably spanned poles. The conductors are fixed to the insulators which are themselves fixed to cross arm of the pole. This system is still being widely used in India. However, in big cities, overhead system is being replaced by underground system. In the underground system, insulated cables are laid in the trenches or pipes under the surface of the earth.

Comparison between Overhead and Underground System

Comparison between overhead and underground system is given below in the tabular from (**Ref :** *Textbook of Elementary Electrical Engineering* by V. K. Mehta).

Sl. No.	Particular Features	Overhead System	Underground System
1.	Public safety	It is less safe	It is more safe
2.	Initial cost	It is less expensive	It is more expensive
3.	Maintenance	It has high maintenance cost.	It has low maintenance cost.
4.	Appearance	It gives shabby look.	It gives good look as the wires are not visible
5.	Frequency of faults	Faults occur frequently	Very little chances of

			faults
6.	Location of faults	Faulty point can be easily located.	Faulty point cannot be easily located
7.	Repair	Overhead lines can be easily repaired.	Underground lines cannot be easily repaired
8.	Frequency of accidents	It has more chances of accidents.	Very little chances of accidents.
9.	Flexibility	It is more flexible as new conductors can be laid along the existing ones for load expansion.	It is not flexible. New conductors are to be laid in new channels.
10.	Supply interruption	It has more chances of supply interruptions.	It has very little chance of interruptions.

After studying the above comparison, we are able to conclude that overhead systems are more widely used as compared to underground system, in India. However, in big cities underground systems are also of great importance.

SAQ 4

(a) What is meant by a distribution system?

(b) Explain primary and secondary distribution systems.

(c) What is the meaning of 400 V/230 V in 3-phase 4 wire AC system?

SAQ 5

How much power will be required to light a factory in which 250 lamps each taking 1.3 amperes at 230 Volts are used. Calculate the cost of energy @ Rs. 3/- per unit for 24 hours.

SAQ 6

An electrically driven pump lifts 15 tonnes of water in a minute to a height of 10 metres. Assuming an efficiency of 70% for the pump and 90% for the motor, calculate :

(a) Motor output in kW.

(b) Input current to the motor if the supply voltage is 500 Volts.

(c) Cost of running the pump for 3 hours per day for 30 days if the rate of electrical energy is Rs. 3 per unit.

4.6 SUMMARY

After going through this unit, you should have understood the principles of operation of DC machines, the working and types of DC motor and generators. You would be able to deduce the significance of transformers and electricity distribution.

4.7 ANSWER TO SAQs

SAQ 1

(a) (ii) Given $\phi = 0.05$ Webers, $Z = 960$

$N = 200$ rpm, $P = 8$

The connection is lap, i.e. $A = P$ (parallel paths).

The Equation is, $E = \frac{\phi Z N}{60} \times \frac{P}{A}$

$$= \frac{0.05 \times 960 \times 200}{60} \times \frac{8}{8}$$

$$= 160 \text{ Volts}$$

(b) Induced voltage $E = 125$ Volts

Terminal voltage $V = 120$ volts

$$E = V + I_a R_a$$

or $$I_a = \frac{E - V}{R_a} = \frac{125 - 120}{0.05} = 100 \text{ Amp.}$$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{120}{15} = 8 \text{ Amp.}$$

Thus, load current

$$I_L = I_a - I_s = 100 - 8 = 92 \text{ Amp.}$$

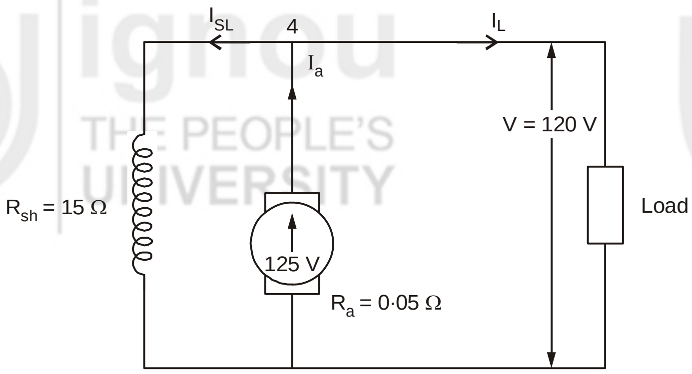

Figure for SAQ 1(b)

(c) V_b = Brush Voltage drop = 1.5 V.

$$I_{sh} = \frac{V}{R_{sh}} = \frac{220}{110} = 2 \text{ Amp.}$$

$I_a = I_L + I_{sh} = 50 + 2 = 52$ ampere

$I_{se} = I_a = 52$ amp.

EMF induced = V + drops in R_a, R_{se} and brushes

$= V + I_a (R_a + R_{se}) + 2 V_b$

$= 220 + 52 (0.02 + 0.01) + 2 \times 1.5$

$= 224.56$ volts

Power developed in generator

$= E \times I_a = 224.56 \times 52$

$= 11677$ Watts

$= 11.677$ kW

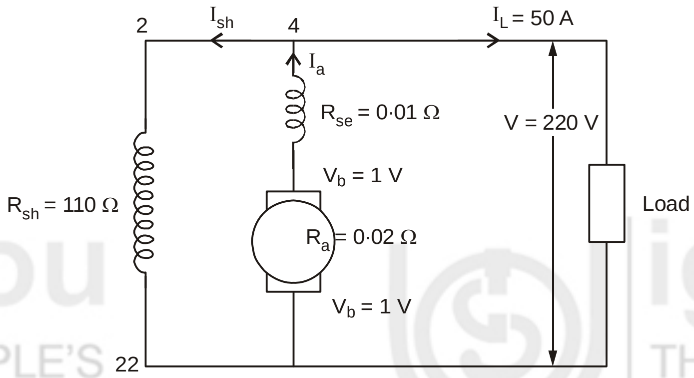

Figure for SAQ 1(c)

SAQ 2

(a) (i) Current in shunt field winding $I_{sh} = \frac{V}{R_{sh}}$

$$= \frac{250}{200} = 1.25 \text{ amps}$$

Current in the armature $I_a = I - I_{sh}$

$= 20 - 1.25$

$= 18.75$ Amps

(ii) Back EMF, $E_b = V - I_a R_a$

$= 250 - 18.75 \times 0.3$

$= 244.375$ Volts

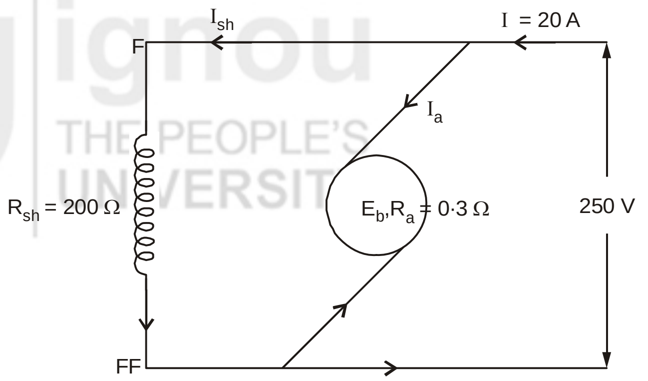

Figure for SAQ 2(a)

(b) $Z = 774$, $\phi = 2.4 \times 10^{-2}$ (Webers), $A = 2$, $P = 4$, $I_a = 50$ amp

Now, Take $T = 0.159 \ \phi \dfrac{P}{A} I_a$ (Newton Meter)

$$= 0.159 \times 2.4 \times 10^{-2} \times 774 \times \frac{4}{2} \times 50.$$

$$= 295.3 \text{ Nm}$$

(c) Total armature circuit resistance = 0.5 + 0.3 = 0.8 Ω

$I_a = I_{se} = 25$ ampere

$Eb_1 = V - I_{a1} R_1 = 200 - 25 \times 0.8 = 180$ volts

$Eb_2 = V - I_{a2} R_2 = (200 - 25 \times R_2)$ Volts (since $I_{a2} = I_{a1}$)

Now given that $I_a = I_{se}$ is constant and $\phi \ \alpha \ I_{se}$, so ϕ is constant

$$\frac{Eb_2}{Eb_1} = \frac{\phi_2 N_2}{\phi_1 N_1} = \frac{N_2}{N_1} \ (\phi_2 = \phi_1 = \text{constant})$$

or $$\frac{200 - 25 R_2}{180} = \frac{250}{500}$$

or $R_2 = 4.4$ Ohms

Thus, additional resistance required = 4.4 – 0.8 = 3.6 ohms

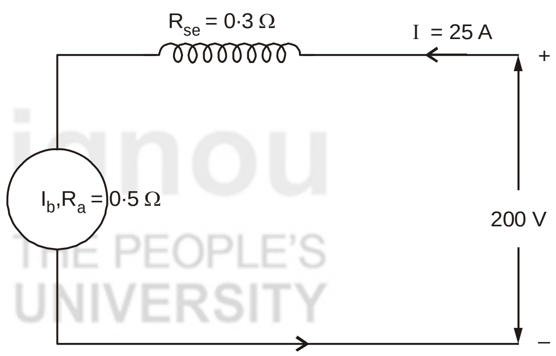

Figure for SAQ 2(c)

(d) Terminal voltage, $V = 240$ Volts

Armature resistance, $R_a = 0.1$ ohm

Shunt field resistance $R_{sh} = 400$ ohm

Normal speed = 1000 RPM

Speed required = 1200 RPM

Armature current (which remains unchanged), $I_a = 50$ Amp.

At initial step

$$I_{sh_1} = \frac{V}{R_{sh}} = \frac{240}{400} = 0.6 \text{ Amp.}$$

Let R ohm be the resistance to be added in the field to increase the speed to 1200 RPM.

Then $$I_{sh_2} = \frac{V}{R_{sh} + R} = \frac{240}{400 + R} \text{ Amp.} \quad \ldots (1)$$

As I_a is same in both cases, EMFs involved,

$$E_1 = E_2 = V - I_a R_a$$

$$= 240 - 50 \times 0.1 = 235 \text{ Volts.}$$

Now, $$E = \frac{\phi Z N}{60} \times \frac{P}{A}$$

or, $$N \propto \frac{E}{\phi}$$

in $$N_1 \propto \frac{E_1}{\phi_1} \text{ and } N_2 \propto \frac{E_2}{\phi_2}$$

or $$\frac{N_2}{N_1} = \frac{E_2}{\phi_2} \times \frac{\phi_1}{E_1} = \frac{\phi_1}{\phi_2} \quad [\because E_1 = E_2 = 235 \text{ volts}]$$

as the magnetisation curve is a straight line

$$\phi_1 \propto I_{sh1} \text{ and } \phi_2 \propto I_{sh2}$$

Thus, $$\frac{N_2}{N_1} = \frac{I_{sh_1}}{I_{sh_2}} \text{ or } I_{sh_2} = \frac{N_1}{N_2} \times I_{sh_1} = \frac{1000}{1200} \times 0.6 = 0.5 \text{ A} \quad \ldots (2)$$

From Eqs. (1) and (2),

$$\frac{240}{400 + R} = 0.5 \quad \text{or} \quad R = 80 \text{ ohms}$$

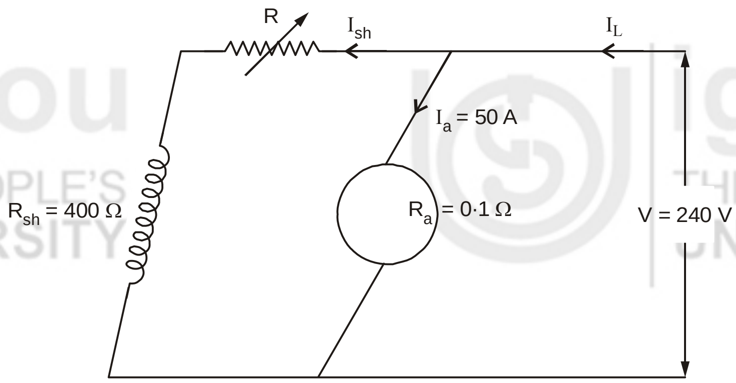

Figure for SAQ 2(d)

SAQ 3

$$k = \frac{N_2}{N_1} = \frac{50}{500} = \frac{1}{10}$$

Full load primary current, $I_1 = \frac{25000}{3300} = 7.58$ A

and full load secondary current, $I_2 = \frac{I_1}{k} = 7.58 \times 10 = 75.8$ A .

emf/turn on primary side = emf/turn on secondary side $= \frac{3300}{500} = 6.6$ V .

$\therefore$ Secondary emf $= 6.6 \times 50 = 330$ V

or, $E_2 = k\,E_1 = 3300 \times \frac{1}{10} = 330$ V

Also, $E_1 = 4.44\, f\, \phi_m\, N_1$

or, $3300 = 4.44 \times 50 \times 500 \times \phi_m$

or, $\phi_m = 29.7$ m Wb .

SAQ 5

Power required for one lamp = $V \times I$ = 230 × 1.3 = 299 Watt

Total power required in 250 lamps = 299 × 250 = 74750 W = 74.75 kW.

Energy consumed in 24 hours = Power × Time

= 74.75 × 24 = 1794 kWh = 1794 units

$\therefore$ Cost of energy @ Rs. 3/- per unit kWh = 1794 × 3 = Rs. 5382.

SAQ 6

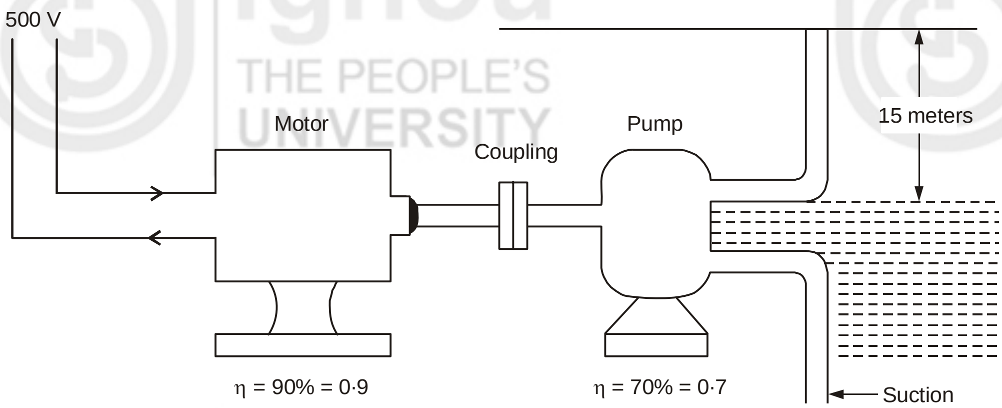

Figure 1.33

(a) Weight of water lifted = 15 tonnes = 15000 kg wt

$\therefore$ Mg = 15000 × 9.81 Newton = 147150 Newton

Height (h) = 10 metre

Work done per minute = mgh = 147150 × 10 Joule/minute

or Output power $= \frac{147150 \times 10}{60}$ Joules/Second = 24525 Watts

or Pump output = 24525 Watts

Pump efficiency = 70% = 0.7

$\therefore$ Pump input $= \frac{24525}{0.7} = 35035.71$ Watts or Motor output = Pump input $= \frac{35035.71}{1000}$ kW

$= 35.026$ kW.

(b) Motor efficiency = 90% = 0.9

$$\text{Motor input} = \frac{35036}{0.9} = 38930 \text{ Watts} = V\,I$$

∴ Current drawn by power

$$= \frac{\text{Motor input}}{\text{Volts}} = \frac{38928.89}{500} = 77.86 \text{ Amps}$$

(c) Pumping time of pump = 30 × 3 = 90 Hours

Energy consumed by motor = Motor input × Time = ($P \times T$)

= 38.93 × 90 = 3503.7 kWh

= 3503.7 units

∴ Cost of running the pump = 3503.7 × 3 = Rs. 10511.1.