21

ELECTRIC POWER GENERATION AND ITS TRANSMISSION

21.1 INTRODUCTION

Electricity is by far the most popular form of energy. It exists in nature but in nonusable form. You must have observed during rainy days the clouds producing lightning thunderbolt that contains millions of volts, you know that this type of electricity cannot be used. How do you get the electricity at your home? At once you will say that it is from electricity boards, power houses, like Delhi Vidyut Board, Bombay Electric Supply and Transport etc. These are the supply undertaking. They only distribute the electricity received from generating stations which convert different forms of energy into electrical energy e.g. thermal, hydroelectric, nuclear power etc.

As you know that generation of electricity may take place some hundereds of kilometer's away from your place, at sites, where the facilities are available like dams, coal mines, natural gas and oil reserviors, ect. From generating station to power houses (distributing agencies) and from there to your house, transmission of power is done through wires (transmission lines) and transformers which carry them from one place to the other. In this lesson you will learn on how the electricity is produced using different sources and how the electric power is being carried from generating plants to your home?

21.2 OBJECTIVES

After studying this lesson,you will should be able to :

- *explain principle, construction and working of A.C. generators (alternators) and D.C. generators (dynamo);*
- *differentiate between the two types of generators;*
- *differentiate between motor and generator;*
- *state the principle on which transformer works;*
- *explain the construction and working of a transformer;*
- *differentiate between a step-up and a step-down transformer;*
- *write the uses of transformer; and*
- *understand the problem of low voltage and load sheding.*

21.3 A.C. AND D.C. GENERATOR (ALTERNATORS AND DYNAMO)

One of the most important sources of electrical power is the electromagnetic source called ***generator***. ***A generator is a device that converts mechanical energy into electrical energy with the help of magnetic field.*** No other source of electric power can produce as large amounts of electric power as the generators. A conductor or a set of conductors is rotated in a magnetic field and voltage are developed in the rotating conductor due to electromagnetic induction (about which you have studied in the previous lesson). The energy for the rotation of the conductors can be supplied by diesel, steam, water falls or even by nuclear reactors. Accordingly, we have diesel generators, hydrogenerators, thermal generators and atomic generators.

There are ***two types of generators***

(i) alternating current generator or A.C. generator also called alternators.

(ii) direct current generator or D.C. generator or dynamo.

Both these generators works on the principle of electromagnetic induction.

21.3.1 A.C. Generator or Alternators

Basic principle: A generator basically involves a loop of wire rotating in a magnetic field. In Fig 21.1 we show a rectangular loop of wire placed in a uniform magnetic field. As the loop is rotated along an horizantal axis, the magnetic flux through the loop changes. To see this, recall that the magnetic flux through the loop as slown in the figure in given by

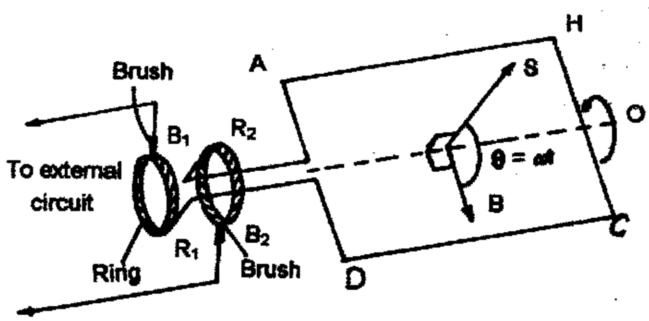

Fig. 21.1 : Rectangular loop placed in a magnatic field.

$$\phi(t) = \mathbf{B}.\hat{\mathbf{n}}\,\mathbf{A}$$

Where **B** is the field, $\hat{n}$ is a unit vector normal to the plane of the loop and A is its area. If the angle between the field direction and the loop is denoted by θ,

$$\phi(t) = AB\cos\theta$$

When we rotate the loop with a constant angular velocity ω, the angle θ changes as

$$\theta = \theta_o + \omega t$$

Thus, the flux through the loop changes in the following manner

$$\phi(t) = AB\cos(\theta_o + \omega t)$$

Now, using Faraday's law of electromagnetic induction, we can calculate the emf induced in the loop to be,

$$\varepsilon(t) = -\frac{d\phi}{dt} = \omega AB \sin(\theta_o + \omega t)$$

Thus, a sinusoidal emf is produced in the loop. In this manner, the mechanical energy of rotation is converted into an emf which can be used to derive current in an external circuit. The emf. induced through a coil with N number of turns is given by,

$$\varepsilon(t) = N\omega AB \sin(\theta_o + \omega t)$$

Construction : When a loop of wire is rotated in a magnetic field it develops a voltage across its terminals as discussed above. The nature of out put voltage has the form of a sine wave.

An A.C. generator consists of four parts as shown in Fig. 21.2,
(i) Armature, (ii) Field magnet, (iii) Slip-rings, (iv) Brushes.

(i) Armature : Armature is a coil of large number of turns of insulated copper wire wound on a cylindrical soft iron drum. It is capable of rotating at right angles to magnetic field on a rotor shaft passing through it along the axis of the drum. This drum of soft iron serves two purposes (i) support the coil, and (ii) increases the magnetic induction through the coil.

Armature is actually a collection of inductors (coil) mounted on a shaft and arrange to rotate in a magnetic field with a provision for collecting the current induced in the induction coil. A Simple loop or turn of wire connected to rings may be considered as the simplest form of armature.

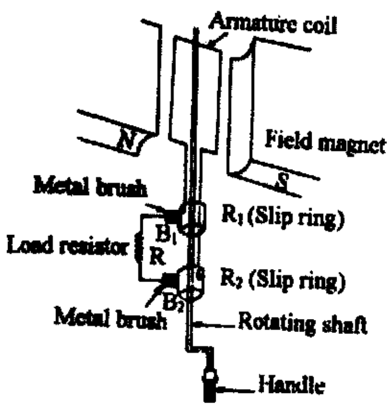

Fig. 21.2: Construction of A.C. generator

(ii) Field Magnet : Field magnet provides a magnetic field, through which the conducting loop arranged on a central hub and forming the armature are carried, or the flux cerried through them, so that they are successively filled and emptied of magnetic lines. The magnetic field is produced by a permanent magnet in case of very small low power a.c. generators and by electromagnet in the case of big alternators.

The real distinction between on armature and field magnet is that the name field magnet is properly given to that part which whether stationary or revolving, maintains its magnetism steady during operation, the name armature is given to the part which, whether revolving or fixed has its magnetism changed in a regularly repeated fashion when the machine is in motion.

(iii) Slip Rings : A device for causing alternating current generated in armature to flow in the circuit. These are two metal rings to which the two ends of the armatures are connected. These rings are fixed to the shaft as shown in Fig (21.2). They are insulated from the shaft as well as from each others.

(iv) Brushes : These are two flexible metal or carbon rods (B_1 and B_2 (Fig. 21.2), which are fixed and constantly in touch with revolving rings. It is with the help of these brushes that the current is passed on from the armature and rings to the main wires which supply the current to the outer circuit.

Working : The principle of working of an A.C. Generator will be made clear using Fig. 21.1 and Fig. 21.3 (a), (b) & (c).

Suppose the armature coil AHCD rotates in the anticlockwise direction. As it rotates, the magnetic flux linked with it changes and the current is induced in the coil, the direction of which is given by Fleming's Right hand rule. Considering the armature to be in the verticle position and as it rotates anticlockwise, the wire AH move down ward and DC moves upwards, the direction of induced emf is from H to A and D to C i.e., in the coil it flows along DCHA. In the external circuit the current flows along B_1 L B_2 Fig. 21.3 (a). This direction of current remains the same during the first half turn of the armature. During the second half revolution, Fig. 21.3(b), the wire AH move upward while the wires CD moves downwards. The current flows in the direction AHCD in the armature coil i.e., the direction of induced current in the coil is reversed. In the external circuit the current flows along B_2 L B_1. Therefore, the direction of the induced emf and the current changes in the external circuit also after every half a revolution. Hence, the current thus produced is alternating in nature Fig. 21.3 (c).

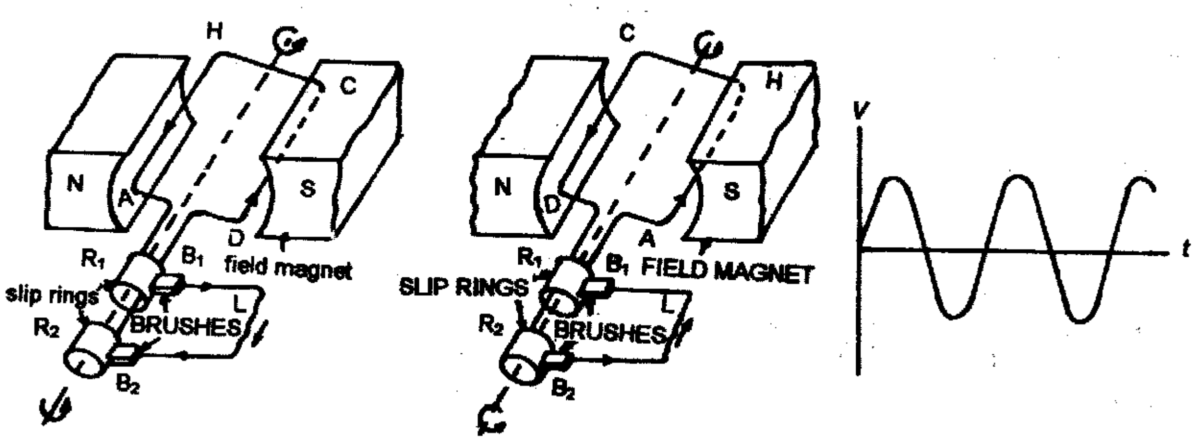

Fig. 21.3 : Working of an A.C. generator.

The arrangement of slip rings and brushes creates problems of insulation and sparking when large output powers are involved. Therefore, in most practical generators the field is rotated and the armature (coil) is kept stationary. In such a generator armature coils are fixed permanently around the inner circumference of the housing of the generator while the field coil pole pieces are rotated on a shaft within the stationary armature.

21.3.2 Dynamo (D.C. Generator)

A dynamo is a machine in which the machanical energy is changed into electrical energy in the form of direct current. You must have seen dynamo attached to the bicycle for lightening purpose. In energy automobiles dynamo has a dual function for lightening and charging the batterey.

The essential parts of dynamo are : (1) field magnet , (2) armature and (3) commutator – split rings.

Armatures and field magnets differ in dynamo and alternator. In the dynamo the field magnets are stationary part and the armature is the rotating one; while in alternator the reverse condition is usually obtained i.e., armature is stationary (stator) and the field magnet (rotor)rotates. A dynamo does not create electricity, but generates or produces an induced pressure which causes a current of electricity to flow through a circuit of conductors in the same way as a force pump causes a current of water to flow in pipes. The pressure generated in the dynamo causes the current of electricity to pass from a lower to a higher pressure in the machine and from the higher, back to the lower pressure in the external circuit; that is the dynamo generates electric pressure which overcome the resistance or opposition to the current flow in the circuit. The pump produces mechanical pressure which, for instance, may be used to force water into an elevated reservior against the back pressure due to its weight.

Basic principle: Basically all generators are A.C.generators, but the A.C. wave form or the sine wave produced by an A.C.generator can be converted into D.C. form by the commutator and brushes. A commutator consists of two semicylinderical pieces of conducting materials sperated by an insulating material. The brushes are made up of soft conducting material that can easily slid on the commutator surface. Each half of the commutator is connected permanently to one end of the loop and the commutator rotates with the loop. Each brush presses against one segment of the commutator. The brushes remains stationary while the commutator rotates. The brushes press against opposite segments of the commutator and every time the voltage reverses polarity, brushed also switch from one segment of commutator to the other. This means that one brush always developes positive polarity and the other, negative polarity with respect to each other. Although the voltage developed across the brushes will be fluctuating. It will always have the same polarity and a D.C. fluctuating voltage.

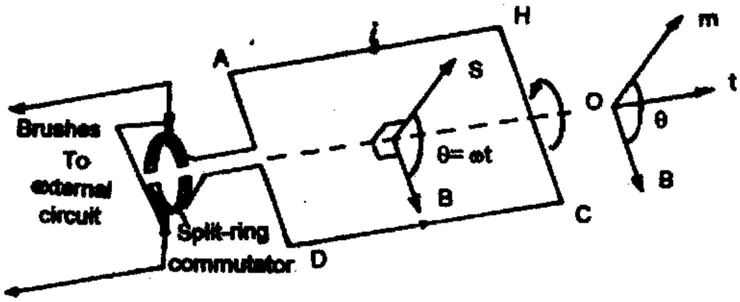

Fig. 21.4: Principle of D.C. generator

The variations in the voltage produced by a single rotating loop is called a ripple which makes the output unsuitable for any practical applications. The ripples can be reduced either by the use of a filter network or by the use of two rotating loops arranged at right angles to each other. The two ends of each loop are connected to two seperate segments on the commutator which now has four segments. Since the two loops are positioned at right angles to each other when the voltage in one loop is decreasing, the voltage in the other loop is increasing, and vice versa. This makes the output voltage across the two brushes more steady with less variation and less ripples than in the case of a single loop. By using more and more loops instead of one, the ripple in the generator output can be further reduced.

Construction of D.C. generator : Direct current Dynamo or a DC dynamo has almost the same construction as that of an A.C. dynamo but it differs from the latter in one respect. In place of slip rings we have got two split rings R_1 and R_2 which are the two half of the same ring as shown in Fig. 21.5 (a). The end of the armature coil are connected to these rings and the ring rotates with the armature and change the contact with the brushes B_1 and B_2. This part of the dynamo is known as ***commutator.***

Working : The working of a D.C. dynamo is similar to that of an AC one. Let the coil be rotated in the clockwise direction. The current produced in the armature is A.C. but the commutator changes it into D.C. in the outer circuit. In the first half cycle, Fig. 21.5 (a), current flows along DCHA. The current in the external circuit flows along $B_1 L B_2$. In the second half, Fig. 21.5(b), current in the armature is reversed and flows along AHCD and as the ring R_1 comes into contact with the brush B_2 and the ring R_2 comes into contact with B_1 the current flows from B_1 to B_2 along AHCD. The current in the external circuit flows from B_1 to B_2. Thus, the current in the external circuit always flows in same direction. The current produced in the outer circuit is graphically represented in Fig. 21.5(c) as the coil is rotated from the vertical position, perpendicular to the magnetic lines of force. The current generated by a such a simple D.C. dynamo is unidirectional but its value varies considerably and even falls to zero twice during each rotation of the coil.

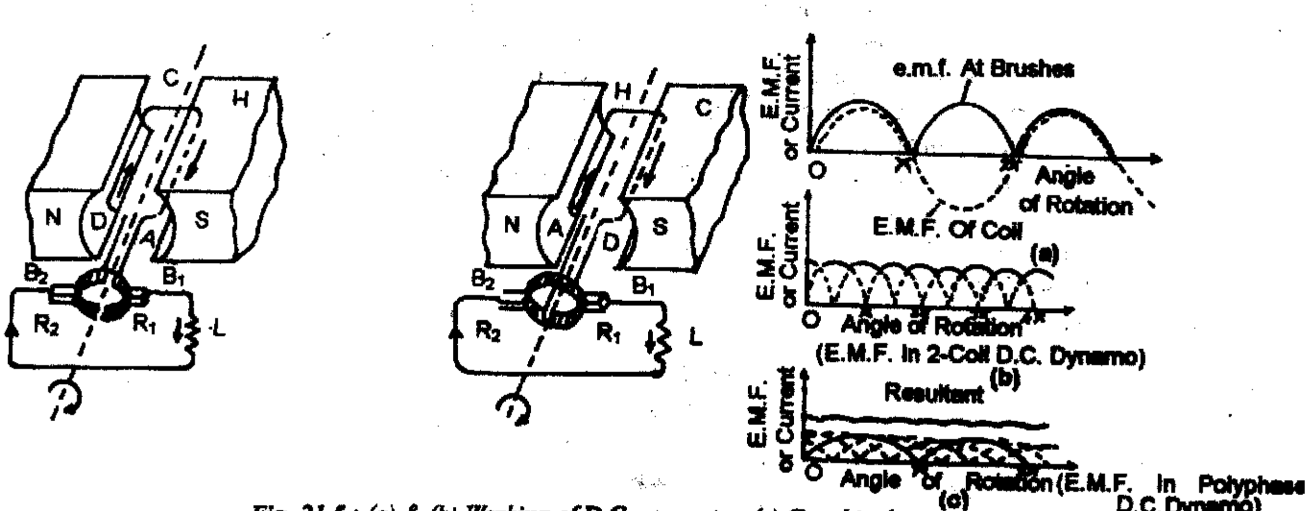

Fig. 21.5 : (a) & (b) Working of D.C. generator, (c) Graphical representation of D.C. current.

One step towards overcoming this objection would be to use two coils, mutually at right angles, and to divide the commutator ring into four sections, connected to the ends of the coils. In such a case both these coils produce emf of the same type but they differ in phase by $\pi/2$. The resultant current or emf is obtained by superposition of the two as shown (Fig. 21.5 (c)). In this way the fluctuations are much reduced. Similarly, in order to get a steady current, we use a large number of coils each consisting of good many turns. The commutator ring is divided into as many segments as the number of ends of coils, so that the coil work independently and sends a current into the outer circuit. The resultant current obtained is shown in Fig. 21.5 (c) which is practically parallel to the time axes.

INTEXT QUESTIONS 21.1

1. *Distinquish between an A.C and D.C generator.*

   ....

2. *What are the three essential parts of a generator ?*

   ....

3. *Why do we use a commutator in a D.C. generator ?*

   ....

4. *In which type of generator slip ring or a split-ring commutators are being used?*

   ....

5. *Where do you find the use of dynamo in daily life?*

   ....

21.4 TRANSFORMER

Transformer is a *device that increases or decreases the magnitude of a voltage or current through electromagnetic induction.* A transformer has at least two windings linked by a common magnetic flux but turns are electrically insulated from one another. The transformer winding connected across a supply source, which may be an ac main power or a output of a generator, is called ***primary windings***. The transformer winding connected across the load R_L is called a ***secondary winding***. In this winding emf is induced when A.C. is applied to the primary. The primary and secondary windings are said to be electrically isolated from each other but magnetically connected or coupled to one another with magnetic flux.

Basically, a transformer is a *device which transfers electric energy (or power) from a primary winding to a secondary winding*. There is no electrical connection between the primary winding and the secondary winding (s). The primary converts the changing electrical energy in to magnetic energy. The secondary converts the magnetic energy back into electric energy.

An ideal transformer is one in which
(i) the resistance of the primary coil is zero;
(ii) there is no flux leakage so that there is the same magnetic flux throughout each turn of the primary and secondary coils;
(iii) the secondary coil is an open circuit.

Construction : Figure (21.6) illustrates the configuration of a typical transformer. It consists of two coils called primary and secondary wound on the core (former) Here, coils of insulated wire are wound around a ring of iron made of the isolated laminated sheets instead of a solid core. The lamination minimize eddy currents in the iron. Energy loss in a transformer can be reduced by using this laminations of very "soft" (low carbon) iron and wire with langer cross-section or by winding the primary and secondary circuits with conductors that have very low resistance.

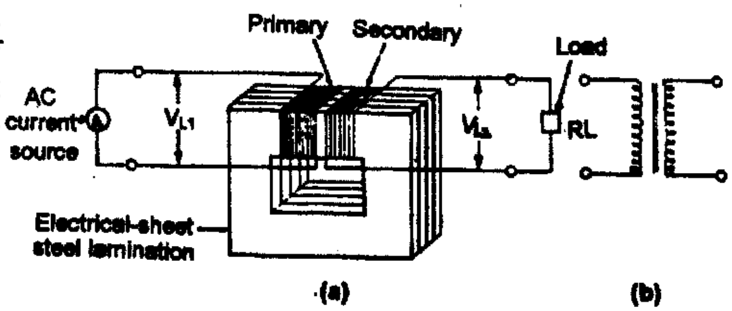

Fig. : 21.6: Principle diagram of a transformer

Theory : The secondary coil of a transformer can have two cases, which are discussed below,

(a) Secondary on open circuit : Suppose the current change in the primary, changes the flux through the core at the rate $d\phi/dt$.

Then the induced (back) emf in the primary with N_p turns is given by,

$$E_p = -N_p \frac{d\phi}{dt} = -N_p \frac{(\phi_1 - \phi_2)}{(t_1 - t_2)}$$

and the induced emf in the secondary coil is

$$E_s = -N_s \frac{d\phi}{dt} = N_s \frac{(\phi_1 - \phi_2)}{(t_1 - t_2)}$$

Applying loop equation to the primary

$$E_p + \left(N_p \frac{d\phi}{dt}\right) = IR = 0, \qquad (\because R = 0 \text{ open cirucit})$$

$$\therefore E_p = -N_p \frac{d\phi}{dt} = N_p \frac{(\phi_1 - \phi_2)}{(t_1 - t_2)}$$

From which, $\boxed{\frac{E_p}{E_s} = \frac{-N_p}{N_s}}$

The minus sign indicates that the two emf's are in opposit phase.

(b) ***Secondary not on open cirucit :*** Suppose a load resistance R_L is connected across the secondary, so that the secondary current is I_s and the primary current becomes I_p. If there is no energy loss from the system.

Power input = power output

$E_p . I_p = E_s . I_s$

So that, $\boxed{\frac{I_p}{I_s} = \frac{E_s}{E_p} = \frac{N_p}{N_s}}$

In practice, a non-ideal transformer shows some power losses. Energy losses results from the following causes,

(a) Resistive heating in the copper coils - *cooper loss*,
(b) Eddy current losses in the form of heat of iron core - *Eddy current lose*
(c) Magnetisation heating of the core ducing repeabed reversal of magnetization - *hysteresis loss*.
(d) Flux leakage from the *core*.

Coefficient of Coupling : The portion of the flux that links one coil to the other coil is referred to as the coefficient of coupling. The coefficient of coupling can range from 0 to 1. When all the fux is coupled, the coefficient of coupling is 1. Sometimes it is expressed as a percentage. Thus, 100 percent coupling means coefficient of coupling of 1.

Coupling in transformers with laminated iron core is very close to 100 percent. This is because all the flux is concentrated in the high permeability core on which the coils are wound. On the other band, air – core transformers can have very low coefficient of coupling. Coefficient of coupling in an air-core transformer can be controlled by spacing between the coils.

21.4.1 Efficiency of Transformers

The iron core and the copper coils of a transformer both convert some electric energy into heat energy. This, of course, is why a transformer heats up when in operation. The purpose of a transformer is not to provide heat but to transfer energy from the primary to secondary. Therefore, any heat produced by the transformer represents inefficiency.

Since, the energy is equal to power times time, the efficiency of a transformer (expressed as a percentage) is calculated by the following formula:

$$\text{Percent efficiency } \eta = \frac{P_{sec}}{P_{pri}} \times 100$$

Example 21.1 : *What is the efficiency of a transformer that requires 1880 W of primary power to provide 1730 W of secondary power ?*

Solution :

Given $P_{pri} = 1880\text{ W}$
$P_{sec} = 1730\text{ W}$

$$\text{Precentage efficiency} = \frac{P_{sec}}{P_{pri}} \times 100$$

$$\therefore \quad \text{\% efficiency} = \frac{1730\text{ W}}{1880\text{ W}} \times 100 = 92$$

Thus, the transformer is 92 % efficient.

In the above example $P_{pri} - P_{sec} = (1880 - 1730)\text{ W} = 150\text{ W}$, the difference between the received power and delivered power is lost in the transformer. The power loss in a transformer is caused by

1. Hysteresis loss
2. Eddy current loss
3. Copper (I^2R) loss

The first two of these losses occur in the transformer core material. The last occurs in the windings. All three convert electric energy to heat energy.

As the energy cannot be created, if transformer works efficiently than as many watts are developed in the secondary as are put into the primary; therefore, we have

(E_p, I_p) or $V_p I_p = V_s I_s$ (or $E_s I_s$)

$$\frac{E_s}{E_p} = \frac{V_s}{V_p} = \frac{I_p}{I_s}$$

Where I_p and I_s are the currents through the primary and secondary coils respectively.

$$\frac{V_s}{V_p} = \frac{E_s}{E_p} = \frac{I_p}{I_s} = \frac{N_s}{N_p} = K$$

Thus, when the induced e.m.f. becomes K times the applied e.m.f., the current induced is $1/K$ times the original current.

In other words what is gained in voltage is lost in current.

The efficiency of a transformer is very high. it being between 90 and 96%. It is one of the most efficient machine known. Maximum efficiency is obtained from a transformer when it is fully loaded. For small transformers (less than 10 W), maximum efficiency may be less than 70 percent. With transformers larger than 1000 W, it is more than 95% efficient.

As the load in the secondary circuit is decreased, the efficiency of the tranformer decreases. This is because current flow in a transformer's primary does not decrease in direct proportion to decrease in the load. The primary current still causes substantial core losses and copper losses even when the secondary is lightly loaded.

21.4.2 Types of Transformers

There are basically two types of transformers, step-up or step-down. ***Step up*** transformer increases the voltage (decreases the current) in the secondary windings. Where as a ***step-down*** transformer decreases the voltage (increases the current) across the secondary windings.

Here, you must keep one thing in mind that a transformer doesn't create more energy at the out put (secondary) of a step-up transformer. This is because, when voltage increases, the current decreases in the same proportion to keep the power same.

It should be recalled that mutual induction takes place only when the current/voltage in the primary is varying. If this current/voltage remains constant then the transformer can not work. *A transformer is a mutual inductor specially designed for the efficient exchange of energy between the two coils.*

Example 21.2 : *A transformer has 100 turns in its primary winding and 500 turns in its secondary winding. If the primary voltage and current are respectively 120 V and 3 A, what are the secondary voltage and current ?*

Solution : Given $N_1 = 100$, $N_2 = 500$, $V_1 = 120$ V and $I_1 = 3$ A

$$V_2 = \frac{N_2}{N_1} V_1 = \frac{500 \text{ turns}}{100 \text{ turns}} \times 120 \text{ V} = 600 \text{ V}$$

$$I_2 = \frac{N_1}{N_2} I_1 = \frac{100 \text{ turns}}{500 \text{ turns}} \times 3 \text{ A} = 0.6 \text{ A}.$$

Example 21.3: ***A transformer rated at a maximum power of 10 kW is used to connect 5000 V transmission line to a 240 V circuit.***

(a) What is the ratio of turns in the windings of the transformer ?

(b) What is the maximum current in the 240 V circuit ?

Solution : Given, $V_1 = 5000$V, $V_2 = 240$V, $P = 10$ kW = 10,000 W,

(a) $$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{5000\text{V}}{240\text{V}} = 20.8$$

(b) Since $P = IV$

$$I_2 = \frac{P}{V_2} = \frac{10{,}000\text{W}}{240 \text{ V}} = 41.7 \text{ A}$$

Example 21.4 : *A transformer for 240 V A.C. input has a primary coil which with 120 turns can take a current of 1.5 A without overheating. What is the maximum current that this transformer can supply? (Assume that you can choose any kind of secondary coil and that the output load has a very low resistance.)*

Solution:

Maximum current can be supplied by a one-turn secondary.

Transformer ratio 120 : 1 = $N_1 : N_2$

$$\frac{N_1}{N_2} = \frac{I_s}{I_p}, \quad I_s = 120\, I_p = 180 \text{ A}$$

INTEXT QUESTIONS 21.2

1. *Can a transformer work on D.C.? Why ?*

   ....

2. *Why does step-up transformer have more turns in the secondary than that of primary?*

   ....

3. *Isin a transformer, the secondary to primary current ratio same as the secondary to primary voltage ratio?*

   ....

4. *How do the eddy current effect the efficiency of a transformer?*

   ....

5. *Why are high voltage transformers used in power transmission?*

   ....

6. *Why are the high voltages from power lines reduced to lower voltages in the city? What kind of transformers are used?*

   ....

7. *Toy trans often use a transformer to supply power for the trains and controls. Would this transformer be step-up or a step-down?*

   ....

The basic action of a transformer has been outlined but there are some mysteries. One strange mystery is that of a door-bell transformer connected, day-in, day-out, to mains with the primary current flowing without, we hope, any dissipation of energy. Think of all the millions of transformers connected to mains supply waitihg ready to be used when some switch is closed in the secondary. Even when the transformers are 'standing by' with the secondary circuit open, a current is flowing in the primary, creating flux in the core. But, fortunately, no energy is being consumed (if we assume the transformer is 'ideal') because in a transformer primary coil which has high inductance but no resistance, the current is $\pi/2$ out of phase with the emf and so, although a current is flowing, no power is consumed.

21.5 ELECTRIC POWER TRANSMISSION

The first central electric generating and distributing facility in the world went into operation in 1882. It was built by Thomas Edison on Pearl street in New York city and supplied *direct current* at 100 V, through underground mains to an area roughly 3.2 km (2 miles) in diameter. For some years, D.C. electricity was practically the only type in use, but today almost all electricity generated is A.C. (alternating current). When A.C. systems first appeared, there were some definite opinions against alternating current. Advocates of D.C. branded A.C. as dangerous because of the high voltage used.

The development of the transformer and of the induction motor led to a change over to A.C. electric power system. The transformer provided a convenient way to vary voltages and made high voltage power transmission possible. The A.C. induction motor is simple and economical. In your home, the motors on the washing machine, furnance, fan, and refrigerator are ***induction motors***. In such motors, the current in the armature or rotor is induced by the changing magnetic field of alternating current in the stationary (static) field coils. With a current in rotor on a magnetic field, the rotor experiences a force and rotates.

21.5.1 Transmission of Electric Power

You have learnt about the process of generation of electricity through device known as A.C. or D.C. generator. You must have come across small unit of generating sets in shops, offices and cinema hall when power goes, the mains is switched over to generatet. In commercial generators which produces power of million of watts at about 15 kV (kilo volt) is common. These generating plants are hundreds kilometers away from your town or villages. Very large mechanical power (kinetic energy) is, therefore, necessary to rotate the rotor which produces magnetic field inside enormously large coils. The rotors are rotated by what are called a turbines. These turbines are driven by various sources of energy.

In order to minimise current in the transmission lines and still transmit the desired amount of electrical energy, power companies use transformers. As you have studied in earlier section that with a transformer A.C. potential differences can be raised or lowered as needed. At a power plant, potential differences are made large (typically 330 kV) and currents are made small for power transmission. Then at the consumer end of the transmission lines, the potential differences can be lowered still further for the operation of doorbells, night lamp etc.

21.5.2 The Role of Transformers in Transmitting Electric Power

Let us see how transformer help to minimize thermal energy losses in transmission lines. In essence, an electric power system consists of a transformer to "step-up" emf at the generating site, a transformer to "step-down" the emf at the consumer end, and a transmission line connecting the two facilities (Fig. 21.7). At the generating site, the potential difference across

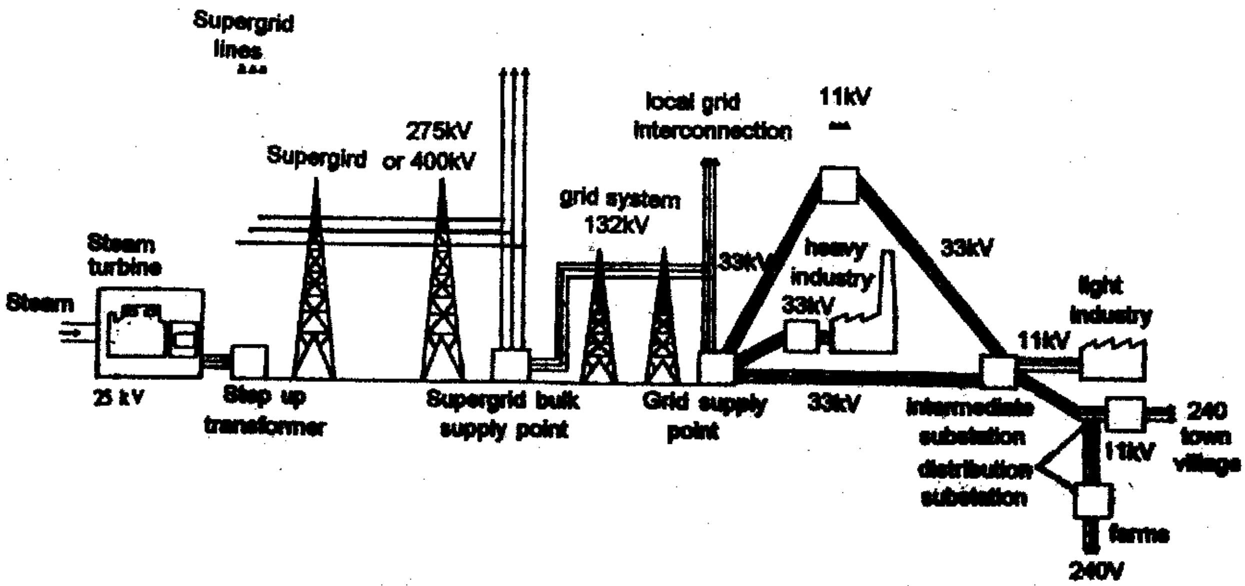

Fig. 21.7: Distribution of electric power.

the secondary winding of a power tranformer is practically 4,00,000 V and in some instances it is close to 1,00,000 V. If for example, the power from the generator is 100 MW (10^8 W), and the potential difference across the secondary winding is 4,00,000V ($= 4 \times 10^5$V), then assuming no energy loss, we have for the current in the secondary winding :

$$I = \frac{P}{V} = \frac{10^8\text{W}}{4\times10^5\text{V}} = 250 \text{ A}$$

If the resistance of a transmission line in 11 Ω, then the thermal power produced in the lines, I^2R is $(250 \times 250 \times 11) = 6875$ W. This means that 0.69% of the power deliverded by the generator is lost as heat. Because of the resistance of the lines, a potential difference is produced across the ends of each line. This amounts to $V = IR = 250$ A $\times$ 11Ω = 2750 V. Thus, the potential difference across the primary winding of the step-down transformer is $40,000 - 2750 = 37,250$V. In practice. at the consumer end potential difference reduced to 230 V (rms). If the 100 MW had been produced at 230 V at the power plant, then the current would be $I = P/V = 10^8$W/230V $= 4.35 \times 10^5$A. A wire of sufficient size to carry this current would be proportionatly heavy and expensive.

A diagram of a typical A.C. power transmission system is shown in Fig. 21.7. Notice that the high voltages used in the transmission lines. Line losses are due to I^2R (Joule heat) losses of the power lines themselves. Although metal wires are used, there is still appreciable resistance, particularly over long distances. For example, heavy aluminium wire has a resistance of about 0.3 Ω per kilometre. Aluminium has almost, if not completely, replaced copper in long distance transmission lines because of its lightness, strength and cost. An important point to notice is that the (I^2R) Joule heating losses depends on the square of the current and hence our aim would be to keep current minimum so as to keep joule heating losses to be minimum. Therefore, high voltages at low currents would be preferable for transmission of power over long distances.

Long distance Transmission of Electrical Power In the largest modern power stations, electricity is generated at about 25 kV (50 Hz) and stepped up in the transformer to 275 kV or 400 kV for transmission over long distances. The potential difference is subsequently reduced in sub-stations by other transformers for distribution to local users at suitable potential difference : 33 kV for heavy industries, 11 kV for light industry and 220 V/230 V for homes, schools, shops, farms etc. (Fig. 21.7).

21.5.3 Problem of Low Voltage and Load Shading

(a) Low Voltages : For normal operation of any electrical device proper voltage is essential. If the voltage supplied by the suppliers is less then the desired voltage, we say that the problem of low voltage has been developed. In fact low voltage is not harmful to the appliance as the high voltages. However. due to low voltage atmost the appliance will not work properly. To overcome the low voltage problem one can use voltage stabilizers. If the low voltage is with in the range of the stabilizer, you will get constant voltage. You can use CVT (constant voltage transformers) also to get constant voltage.

(b) Load Shading : As you know that there is some supplier of electricity and you are the consumer. In order to avoide the dangers of burining off the transformers the supply undertakings will try to keep the load on the transformer to be within the specified rating. If the transfomer through which you receive the voltage is heavily loaded than the specified value, the supplier will either shade off the load by cutting the supply from the power source, or they will request the consumers to decrease the load by switching off the unnecessary equipments for lighting and decorations, heating equipments of higher wattages. This process is known as load shading.

In the case of load shading, you can use inverters. Inverters are low frequency circuits which convert direct current from battery to alternating current or to voltages of desired value and frequency (i.e. 230V and 50 Hz).
Why high potential differences are used to transmit electrical power over long distances ?

Let us take and examples, suppose electrical power P has a to be delivered at a potential difference V by supply lines of total resistance R. The current $I = P/V$ (since $P = IV$) more correctly ($P = I_{rms} V_{rms} \cos\theta$) and the loss in the lines $= I^2 R = \frac{(P^2) R}{V^2}$. Clearly, the greater V, the smaller is the loss, in fact doubling V, quarters the loss.

Electrical power is, thus, transmitted more economically at high potential difference, but on the other hand this creates insulation problem and raises installation cost. In 400 kV supergrid, currents of 2500 A are typical and the power loss is about 200 kW per kilometer of cable, i.e., 0.02% (percent) loss per kilometer. The ease and efficiency with which alternating potential differences are stepped-up and stepped-down in a transformer and the fact that alternators produces much higher potential difference than D.C. generators (25 kV compared with several thousands volts), are the main considerations influencing the use of high alternating rather than direct potential difference in most situations.

INTEXT QUESTIONS 21.3

1. *If the line losses in electric power transmission are reduced by stepping up the voltage, why not transmit electric power at even higher voltages than those normally used since the step-up depends only on the relative number of windings on the transformer core?*

   ....

2. *What is a major disadvantage of long distance D.C. power transmission?*

   ....

3. *Does the weather affect power line losses? Explain?*

   ....

4. *Why is it economical to produce and transport power through transmission lines at high voltage rather than at low voltages?*

   ....

21.6 WHAT YOU HAVE LEARNT

- Generator is a device which converts mechanical energy into electrical energy.
- Generator works on the principle of electromagnetic induction.
- D.C. generator (or dynamo) has two pairs of half split rings or commutator instead of slip rings.
- Co-efficient of coupling between two coils is the fraction of total flux from one coil linking another coil.
- A transformer is a static electric device used to convert one alternating voltage to another alternating voltage or voltages at the same frequency by mutual induction.

- The transformer has two windings connected by a common magnetic flux but electrically insulated from each other.
  (i) Primary winding connected across a supply source.
  (ii) Secondary winding connected across a load.
- Two types of transformers
  (i) Step-up : used to increase the voltage
  (ii) Step-down : used to decrease the voltage.
- The secondary to primary voltage ratio is in the same proportion as the secondary to primary turns ratio i.e.

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

- In a step-up transformer
  $N_s > N_p$, $V_s > V_p$ *and* $I_s < I_p$
  In a step-down transformer
  $N_p > N_s$, $V_p > V_s$, $I_p < I_s$
- Main sources of power losses in a transformer are
  (i) Heating up of the windings which is avoided by a cooling agent or by using wires which are thick and heavy with less resistance such that I^2R is less.
  (ii) Eddy current i.e. current produced in the iron core by the induced voltage. This is greater at higher frequencies when air core transformers are used instead. At low frequencies laminated core is used to reduce eddy current.
- For transmission of power from a power station to your house transformers and transmission lines are used.

21.7 TERMINAL QUESTIONS

1. Suppose the frequency of a generator is increased from 60 H to 120 H_z. What effect would this have on out-put voltage?
2. A motor and a generator basically perform opposite functions. Yet some one makes a statement that a motor really acts as a motor and a generator at the same time? Is this really true?
3. Give three ways the voltage output of a generator could be increased?
4. If the line losses in electric power transmission are reduced by stepping up the voltage, why not transmit electric power at even higher voltages than these normally used since the step-up depends only on the relative number of windings on the transformer core?
5. What is a major disadvantage of long distance D.C. power transmission?
6. Where are step-down transformers used in electric power transmission system?
7. Does the whether affect power line losses? Explain?
8. Explain how electricity is distributed from the power plant to the user?
9. A light bulb in series with an A.C. generator and the primary winding of a transformer, glows dimly when the secondary leads are connected to a load, such as a resistor, the bulb in the primary winding will brighten, why?
10. If the terminals of a battery are connected to the primary winding of transformer, why will a steady potential difference not appear across the secondary windings.
11. The power supply for a picture tube in a colour television (TV) set typically requires 15,000 V A.C.. How can this potential difference be provided if only 230 V are available at a household electric out-let?

12. Would two coils acts as transformer without an iron core? If so, why not omit the core to save money?
13. What would be the effect(s) if the primary and the secondary of a transformer had the same number of windings? What kind of "step" transformer would this be?
14. An ac source has a 10-volt out-put. A particular circuit requires only a 2 V A.C. input. How would you accomplish this? Explain?
15. A person has a single transformer with 50 turns on one part of the core and 500 turns on the other. Is this a step-up or a step-down transformer? Explain.
16. Does transformer operate on self induction or mutual induction? Does it have both? If so, what are the effects?
17. Some transformers have various terminals or "taps" on the secondary so that connecting to different tap puts different functions of the total number of secondary windings into a circuit? What is the advantage of this?
18. A transformer in an electric welding machine draws 3 A from a 240-V A.C. power line and delivers 400 A. What is the potential difference across the secondary of the transformer?
19. A 240-V, 400 W electric mixer is connected to a 120-V power line through a transformer. What is the ratio of turns in the transformer ? and How much current is drawn from the power line?
20. A step-up transformer has 150 turns in the primary coil and 25,000 turns in the secondary coil. If the primary is connected to a 220 V A.C. line, find the voltage delivered at the secondary terminals.
21. The primary of a step-up transformer having 125 turns is connected to a house lighting circuit of 220 V A.C. If the secondary is to deliver 15,000 volts, how many turns must it have?
22. The secondary of a step-down transformer has 25 turns of wire and the primary is connected to a 220 V A.C. line. If the secondary is to deliver 2.5 volt at the out-put terminals, how many turns should the primary have?
23. The primary of a step-down transformer has 600 turns and is connected to a 120 V A.C. line. If the secondary is to supply 5 volts at its terminal and electron current of 3.5A, find the number of turns in the secondary and the electron current in the primary?
24. A step-up transformer with 350 turns in the primary is connected to a 220 V A.C. line. The secondary delivers 10,000 volts at its terminal and a current of 40 milliampere.
    (a) How many turns are in the secondary?
    (b) What is the current in the primary?
    (c) What power is drawn from the line?

CHECK YOUR ANSWERS

Intext Questions 21.1

1. (i) The A.C. generator has slip rings whereas the D.C. generator has two split rings or a commutator.
   (ii) A.C. generator produces current/voltage in sinusoidal form but D.C. generator produces direct current.
2. Three essential parts of a generator are - armature, field magnet, and the slip rings.
3. The commutator is converts A.C. wave form to D.C. wave form.
4. Slip rings in an A.C. generators, and split rings in a D.C. generator.
5. Attached to the bicycle for lightening purpose.

Intext Questions 21.2

1. No, because the working of a transformer depends on the principle of electromagnetic induction which requires time varying current.
2. Because, the ratio of the voltage in primary and secondary coils are proportional to the ratio of number of their turns.
3. No. they are reciprocal to each other.
4. Because, the eddy currents causes wastage of energy through heating.
5. So as to minimise the loss of power due to heating.
6. Because they are dangerous to the living beings. Step-down transformer is used.
7. Step-down transformer.

Intext Questions 21.3

1. The cost of installation is very high, and there are chances of breaking of insulation. Special cables have to be installed for very high voltages.
2. D.C. can not be produced at very high voltages and no transformer can be used in it. Hence, the heat losses will be more in D.C. transmission.
3. Yes, heat dissipation will be more and during rains sparking also cause power loss.
4. Line losses will be less because the current will be low. Since $V_1 I_1 = V_2 I_2$.

EXTENDED LEARNING

STATUS OF POWER IN INDIA : In India the power producing capacity at the time of independence was only 1,400 MW. By the end of 1994-95 it was increased to 81,164.41 MW. out of which 20,829.04 MW is hydroelectric, 58,110.37 MW is thermal (which include, gas, diesel, etc) and 2,225 MW is atomic power (nuclear power). In 1995-96 target was 377.15 (units) out of which 297 unit from thermal power stations, 72.3 unit from hydroelectric stations, and 78.5 units from atomic power plants. This target was 7.4% more than the target of *1994-95.*

Non- Conventional Sources in India

For the remaining period of eight five year plan the target for non-conventional power is kept to 2000 MW against original 500-600 MW.

(a) **Wind energy** : In India the potential for wind energy is 20,000 MW. In Asia the largest 150 MW, plant to produced electric power is in Mupandal (Tamilnadu). In India there are 179 wind mapping, and 83 wind monitoring centres at work. In Tamilnadu, Andhra Pradesh, Karnataka, Kerala, M.P., Maharashtra & Lakshyadeep, 80 places have been identified and it is expected to give 3,000 MW wind energy power. The country has a capacity of 870 MW. wind energy power generation.

(b) **Biomass energy** : The electrical power programme based on biomass was initiated in Jan. 1994. During eight five year plan the target was 300 MW. To supply raw material for this purpose nearly 420 old and 90 new sugar mills have been identified.

(c) **Solar photo voltaic system** : There are about 60,000 photo voltaic systems working whose total capacity is 4 MW. 50% subsidy has been given to promote this alternate source of elecetric power. Solar cells (panel) convert direct sun light into electricity. During eight five year plan 25 MW total capacity will be installed. Of 200 kW capacity partial grid interactive solar photovoltaic electricity generating unit (schemes) have been installed at Kalyanpur in Aligarh Distt. (U.P.) and Saresedi in Mhow district. In Maithenia in Jodhpur Distt. of Rajasthan, Government is planning to set-up 35 MW capacity plant based solar heater electric power.

(d) Chemical energy as source : There are two types of chemical energy that can be converted into electrical energy from either fuel cell or electrochemical storage batteries. 2.5 kW capacity phosphoric acid fuel cell have been developed and are under experimental stage.

(e) Tidal energy : Tidal waves carry enormous potential to generate electricity. Government is considering to install a unit of 900MW capacity costing 4000 crores rupees at Bay of Kutch. In India the estimated capacity of tidal power is 8000 MW - 90,000 MW. Government is exploring the possibilities to install 7000 MW plant at Khambat, Bay of Kutch 900 MW. Whether such schemes are economically viable or not.

(f) Ocean waves : Energy generating capacity in India is to be 40,000 MW. Based on W C 150 MW (Max.) capacity, ocean wave plate form to generate electric power has been installed in Vghinjam near Tiruanant puram, and another is under construction in Andaman & Nicobar Islands of capactiy 1 MW.