Lecture 1-Part 2: Electrical Energy

1.6 Importance of Electrical Energy

Energy may be needed as heat, as light, as motive power etc. The present-day advancement in science and technology has made it possible to convert electrical energy into any desired form. This has given electrical energy a place of pride in the modern world.

Electrical energy is superior to all other forms of energy due to the following reasons :
(*i*) Convenient form. Electrical energy is a very convenient form of energy. It can be easily converted into other forms of energy. For example, if we want to convert electrical energy into heat, the only thing to be done is to pass electrical current through a wire of high resistance *e.g.*, a heater.
Similarly, electrical energy can be converted into light (*e.g.* electric bulb), mechanical energy (*e.g.* Electric motors) etc.

(*ii*) Easy control. The electrically operated machines have simple and convenient starting, control and operation. For instance, an electric motor can be started or stopped by turning on or off a switch.
Similarly, with simple arrangements, the speed of electric motors can be easily varied over the desired range.

(*iii*) Greater flexibility. One important reason for preferring electrical energy is the flexibility that it offers. It can be easily transported from one place to another with the help of conductors.
(*iv*) Cheapness. Electrical energy is much cheaper than other forms of energy. Thus it is overall economical to use this form of energy for domestic, commercial and industrial purposes.
(*v*) Cleanliness. Electrical energy is not associated with smoke, fumes or poisonous gases. Therefore, its use ensures cleanliness and healthy conditions.

(*vi*) High transmission efficiency. The consumers of electrical energy are generally situated quite away from the centres of its production. The electrical energy can be transmitted conveniently and efficiently from the centres of generation to the consumers with the help of overhead conductors known as transmission lines.

1.7 Generation of Electrical Energy

*The conversion of energy available in different forms in nature into electrical energy is known a*s **generation of electrical energy.** Electrical energy is produced from the forms of energy available in nature. Electrical energy must be produced and transmitted to the point of use at the instant it is needed.

Energy is available in various forms from different natural sources such as pressure head of water, chemical energy of fuels, nuclear energy of radioactive substances etc. All these forms of energy can be converted into electrical energy by the use of suitable arrangements.

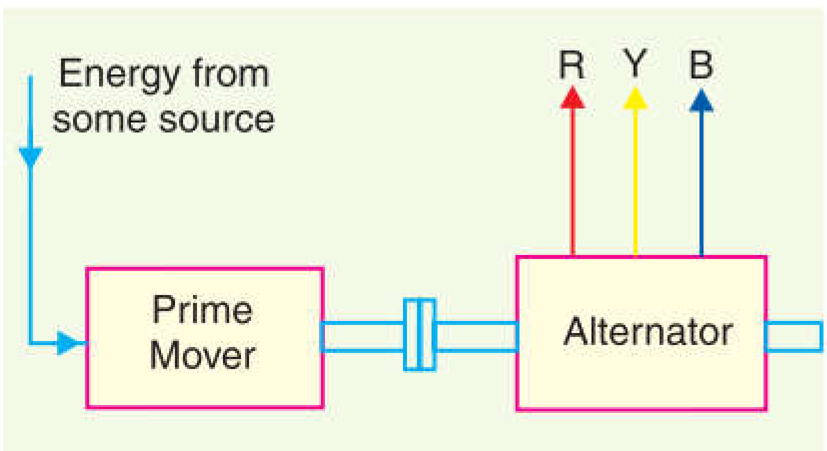

Fig. 1.1

The arrangement essentially employs (see Fig. 1.1) an alternator coupled to a prime mover.

The prime mover is driven by the energy obtained from various sources such as burning of fuel, pressure of water, force of wind etc. For example, chemical energy of a fuel (*e.g.*, coal) can be used to produce steam at high temperature and pressure. The steam is fed to a prime mover which may be a steam engine or a steam turbine. The turbine converts heat energy of steam into mechanical energy which is further converted into electrical energy by the alternator.

1.8 Sources of Energy

(*i*) The Sun **(*ii*)** The Wind **(*iii*)** Water **(*iv*)** Fuels **(*v*)** Nuclear energy

(*i*) The Sun.

The Sun is the primary source of energy. The heat energy radiated by the Sun can be focused over a small area by means of reflectors. This heat can be used to raise steam and electrical energy can be produced with the help of turbine-alternator combination. However, this method has limited application because:

a. it requires a large area for the generation of even a small amount of electric power
b. it cannot be used in cloudy days or at night
c. it is an uneconomical method

(*ii*) The Wind. This method can be used where wind flows for a considerable length of time. The wind energy is used to run the wind mill which drives a small generator. In order to obtain the electrical energy from a wind mill continuously, the generator is arranged to charge the batteries. These batteries supply the energy when the wind stops. This method has the advantages that maintenance and generation costs are negligible. However, the drawbacks of this method are **(*a*)** variable output, **(*b*)** unreliable because of uncertainty about wind pressure and **(*c*)** power generated is quite small.

(*iii*) Water. When water is stored at a suitable place, it possesses potential energy because of the head created. This water energy can be converted into mechanical energy with the help of water turbines. The water turbine drives the alternator which converts mechanical energy into electrical energy. This method of generation of electrical energy has become very popular because it has low production and maintenance costs.

(*iv*) Fuels. The main sources of energy are fuels *viz*., solid fuel as coal, liquid fuel as oil and gas fuel as natural gas. The heat energy of these fuels is converted into mechanical energy by suitable prime movers such as steam engines, steam turbines, internal combustion engines etc. The prime mover drives the alternator which converts mechanical energy into electrical energy. Although fuels continue to enjoy the place of chief source for the generation of electrical energy, yet their reserves are diminishing day by day. Therefore, the present trend is to harness water power which is more or less a permanent source of power.

(*v*) Nuclear energy. Towards the end of Second World War, it was discovered that large amount of heat energy is liberated by the *fission* of uranium and other fissionable materials. It is estimated that heat produced by 1 kg of nuclear fuel is equal to that produced by 4500 tonnes of coal. The heat produced due to nuclear fission can be utilized to raise steam with suitable arrangements. The steam can run the steam turbine which in turn can drive the alternator to produce electrical energy. However, there are some difficulties in the use of nuclear energy. The principal ones are (*a*) high cost of nuclear plant (*b*) problem of disposal of radioactive waste and dearth of trained personnel to handle the plant.

1.9 Comparison of Energy Sources

S.No.	Particular	Water-power	Fuels	Nuclear energy
1.	*Initial cost*	High	Low	Highest
2.	*Running cost*	Less	High	Least
3.	*Reserves*	Permanent	Exhaustable	Inexhaustible
4.	*Cleanliness*	Cleanest	Dirtiest	Clean
5.	*Simplicity*	Simplest	Complex	Most complex
6.	*Reliability*	Most reliable	Less reliable	More reliable

1.10 Units of Energy

The most important forms of energy are mechanical energy, electrical energy and thermal energy. Different units have been assigned to various forms of energy. However, it must be realized that since mechanical, electrical and thermal energies are interchangeable, it is possible to assign the same unit to them.

(*i*) Mechanical energy. The unit of mechanical energy is *newton-metre* or *joule* on the SI system. The work done on a body is one newton-metre (or joule) if a force of one newton moves it through a distance of one metre *i.e.*, Mechanical energy in joules = Force in newton × distance in metres
(*ii*) Electrical energy. The unit of electrical energy is *watt-sec* or *joule* and is defined as follows: One watt-second (or joule) energy is transferred between two points if a potential difference(p.d.) of 1 volt exists between them and 1 ampere current passes between them for 1 second *i.e.*,

Electrical energy in watt-sec (or joules) = voltage in volts × current in amperes × time in seconds

Joule or watt-sec is a very small unit of electrical energy for practical purposes. In practice, for the measurement of electrical energy, bigger units *viz*., watt-hour and kilowatt hour are used.

1 watt-hour = 1 watt × 1 hr = 1 watt × 3600 sec = 3600 watt-sec
1 kilowatt hour (kWh) = 1 kW × 1 hr = 1000 watt × 3600 sec = 36 x 10^5 watt-sec.

(***iii***) **Heat.** Heat is a form of energy, which produces the sensation of warmth. The unit* of heat is calorie, British thermal unit (B.Th.U.) and centigrade heat units (C.H.U.) on the various systems.
Calorie. It is the amount of heat required to raise the temperature of 1 gm of water through 1ºC *i.e*.,1 calorie = 1 gm of water × 1ºC

Sometimes a bigger unit namely *kilocalorie* is used. A kilocalorie is the amount of heat required to raise the temperature of 1 kg of water through 1ºC *i.e*.,

1 kilocalorie = 1 kg × 1ºC = 1000 gm × 1ºC = 1000 calories

B.Th.U. It is the amount of heat required to raise the temperature of 1 lb of water through 1ºF *i.e*.,
1 B.Th.U. = 1 lb × 1ºF

C.H.U. It is the amount of heat required to raise the temperature of 1 lb of water through 1ºC *i.e*.,
1 C.H.U. = 1 lb × 1ºC

***Lb=Pound**

1.11 Relationship among Energy Units

The energy whether possessed by an electrical system or mechanical system or thermal system has the same thing in common *i.e*., it can do some work. Therefore, mechanical, electrical and thermal energies must have the same unit.

(i) Electrical and Mechanical

1 kWh = 1 kW × 1 hr

= 1000 watts × 3600 seconds = 36 × 10^5 watt-sec. or Joules

∴ 1 kWh = 36 × 10^5 Joules

It is clear that electrical energy can be expressed in Joules instead of kWh.

(ii) Heat and Mechanical

(a) 1 calorie = 4·18 Joules (By experiment)

(b) 1 C.H.U. = 1 lb × 1ºC = 453·6 gm × 1ºC

= 453·6 calories = 453·6× 4·18 Joules = 1896 Joules

∴ 1C.H.U. = 1896 Joules

(c) 1 B.Th.U. = 1 lb × 1ºF = 453·6 gm × 5/9 ºC

= 252 calories = 252 × 4·18 Joules = 1053 Joules

∴ 1 B.Th.U. = 1053 Joules

(iii) Electrical and Heat

(a) 1 kWh = 1000 watts × 3600 seconds = 36×10^5 Joules

$$= \frac{36 \times 10^5}{4.18}\ calories = 860 \times 10^3\ calories$$

1 kWh = 860 × 103 calories or 860 kcal

(b) 1 kWh = 36 × 105 Joules = $36 \times 10^5/1896$ C.H.U. = 1898 C.H.U.

[1 C.H.U. = 1896 Joules]

∴ 1 kWh = 1898 C.H.U

(c) 1 kWh = 36×10^5 Joules = $36\ X10^5 = \frac{36\times10^5}{1053}$

[1 B.Th.U. = 1053 Joules]

∴ 1 kWh = 3418 B.Th.U

1.12 Efficiency

The output energy divided by the input energy is called energy efficiency or simply efficiency of the system.

Efficiency, $\eta = \frac{\text{Output energy}}{\text{Input energy}}$

As power is the rate of energy flow, therefore, efficiency may be expressed equally well as output power divided by input power *i.e.*

Efficiency, $\eta = \frac{\text{Output power}}{\text{Input power}}$

Example 1. Mechanical energy is supplied to a d.c. generator at the rate of 4200 J/s. The generator delivers 32·2 A at 120 V.

(*i*) W*hat is the percentage efficiency of the generator?*

(*ii*) *How much energy is lost per minute of operation?*

Solution.

(i) Input power, Pi = 4200 J/s = 4200 W

Output power, Po = EI = 120 × 32·2 = 3864 W

∴ *Efficiency,* $\eta = \frac{p_o}{p_i} \times 100 = \frac{38\ 64}{4\ 2\ 00} \times 100 = 92\%$

(ii) Power lost, PL = Pi − Po = 4200 − 3864 = 336 W

∴ *Energy lost per minute (= 60 s) of operation*

$= P_L \times t = 336 \times 60 = 20160\ J$

1.13 Calorific Value of fuels

The amount of heat produced by the complete combustion of a unit weight of fuel is known as its **calorific value**.

Calorific value indicates the amount of heat available from a fuel. The greater the calorific value of fuel, the larger is its ability to produce heat. In case of solid and liquid fuels, the calorific value is expressed in *cal/gm* or *kcal/kg*. However, in case of gaseous fuels, it is generally stated in *cal/litre* or *kcal/litre*

No.	Particular	Calorific value	Composition
1	**Solid fuels** (*i*) Lignite (*ii*) Bituminous coal (*iii*) Anthracite coal	5,000 kcal/kg 7,600 kcal/kg 8,500 kcal/kg	C = 67%, H = 5%, O = 20%, ash = 8% C = 83%, H = 5·5%, O = 5%, ash = 6·5% C = 90%, H = 3%, O = 2%, ash = 5%
2	**Liquid fuels** (*i*) Heavy oil (*ii*) Diesel oil (*iii*) Petrol	11,000 kcal/kg 11,000 kcal/kg 11,110 kcal/kg	C = 86%, H = 12%, S = 2% C = 86·3%, H = 12·8%, S = 0·9% C = 86%, H = 14%
3	**Gaseous fuels** (*i*) Natural gas (*ii*) Coal gas	520 kcal/m3 7,600 kcal/m3	CH4 = 84%, C2H6 = 10% Other hydrocarbons = 5% CH4 = 35%, H = 45%, CO= 8%, N = 6% CO2 = 2%, Other hydrocarbons = 4%

1.14 Advantages of Liquid Fuels over the Solid Fuels

i. The handling of liquid fuels is easier and they require less storage space.
ii. The combustion of liquid fuels is uniform.
iii. The solid fuels have higher percentage of moisture and consequently they burn with great difficulty. However, liquid fuels can be burnt with a fair degree of ease and attain high temperature very quickly compared to solid fuels.
iv. The waste product of solid fuels is a large quantity of ash and its disposal becomes a problem.
v. However, liquid fuels leave no or very little ash after burning.
vi. The firing of liquid fuels can be easily controlled. This permits to meet the variation in load demand easily.

1.15 Advantages of Solid Fuels over the Liquid Fuels

i. In case of liquid fuels, there is a danger of explosion.
ii. Liquids fuels are costlier as compared to solid fuels.
iii. Sometimes liquid fuels give unpleasant odours during burning.
iv. Liquid fuels require special types of burners for burning.
v. Liquid fuels pose problems in cold climates since the oil stored in the tanks is to be heated in order to avoid the stoppage of oil flow