CHAPTER

1

Introduction

General

Energy is the basic necessity for the economic development of a country. Many functions necessary to present-day living grind to halt when the supply of energy stops. It is practically impossible to estimate the actual magnitude of the part that energy has played in the building up of present-day civilisation. The availability of huge amount of energy in the modern times has resulted in a shorter working day, higher agricultural and industrial production, a healthier and more balanced diet and better transportation facilities. As a matter of fact, there is a close relationship between the energy used per person and his standard of living. The greater the per capita consumption of energy in a country, the higher is the standard of living of its people.

Energy exists in different forms in nature but the most important form is the *electrical energy*. The modern society is so much dependent upon the use of electrical energy that it has become a part and parcel of our life. In this chapter, we shall focus our attention on the general aspects of electrical energy.

1.1 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. The survival of industrial undertakings and our social structures depends primarily upon low cost and uninterrupted supply of electrical energy. In fact, the advancement of a country is measured in terms of per capita consumption of electrical energy.

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.

1.2 Generation of Electrical Energy

The conversion of energy available in different forms in nature into electrical energy is known as **generation of electrical energy**.

Electrical energy is a manufactured commodity like clothing, furniture or tools. Just as the manufacture of a commodity involves the conversion of raw materials available in nature into the desired form, similarly electrical energy is produced from the forms of energy available in nature. However, electrical energy differs in one important respect. Whereas other commodities may be produced at will and consumed as needed, the electrical energy must be produced and transmitted to the point of use at the instant it is needed. The entire process takes only a fraction of a second. This instantaneous production of electrical energy introduces technical and economical considerations unique to the electrical power industry.

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. The arrangement essentially employs (see Fig. 1.1) an alternator coupled to a prime mover. The prime mover is driven by the energy obtaimed from various sources
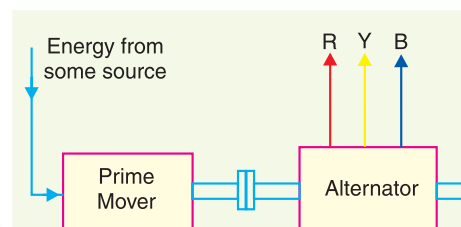

Fig. 1.1

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. Similarly, other forms of energy can be converted into electrical energy by employing suitable machinery and equipment.

1.3. Sources of Energy

Since electrical energy is produced from energy available in various forms in nature, it is desirable to look into the various sources of energy. These sources of energy are :

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

Out of these sources, the energy due to Sun and wind has not been utilised on large scale due to a number of limitations. At present, the other three sources *viz.*, water, fuels and nuclear energy are primarily used for the generation of electrical energy.

(*i*) **The Sun.** The Sun is the primary source of energy. The heat energy radiated by the Sun can be focussed 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.

Nevertheless, there are some locations in the world where strong solar radiation is received very regularly and the sources of mineral fuel are scanty or lacking. Such locations offer more interest to the solar plant builders.
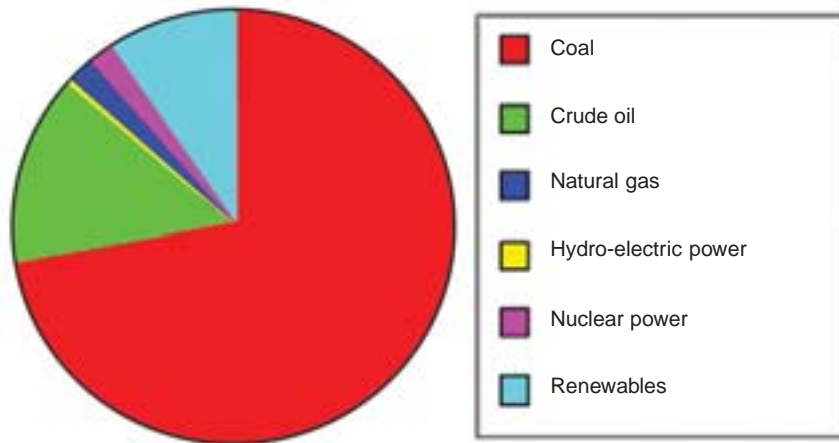
(*ii*) **The Wind.** This method can be used where wind flows for a considerable length of time. The wind energy is used to run the wind mill which drives a small generator. In order to obtain the electrical energy from a wind mill continuously, the generator is arranged to charge the batteries. These 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 utilised 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.

Energy Utilisation

1.4 Comparison of Energy Sources

The chief sources of energy used for the generation of electrical energy are water, fuels and nuclear energy. Below is given their comparison in a tabular form :

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

1.5 Units of Energy

The capacity of an agent to do work is known as its 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 realised that since mechanical, electrical and thermal energies are interchangeable, it is possible to assign the same unit to them. This point is clarified in Art 1.6.

(*i*) **Mechanical energy**. The unit of mechanical energy is *newton-metre* or *joule* on the M.K.S. or 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 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)

$$= \text{voltage in volts} \times \text{current in amperes} \times \text{time in seconds}$$

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.

$$1 \text{ watt-hour} = 1 \text{ watt} \times 1 \text{ hr}$$
$$= 1 \text{ watt} \times 3600 \text{ sec} = 3600 \text{ watt-sec}$$
$$1 \text{ kilowatt hour (kWh)} = 1 \text{ kW} \times 1 \text{ hr} = 1000 \text{ watt} \times 3600 \text{ sec} = 36 \times 10^5 \text{ watt-sec.}$$

(*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 1°C $i.e.$,

$$1 \text{ calorie} = 1 \text{ gm of water} \times 1°C$$

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 1°C $i.e.$,

$$1 \text{ kilocalorie} = 1 \text{ kg} \times 1°C = 1000 \text{ gm} \times 1°C = 1000 \text{ calories}$$

B.Th.U. It is the amount of heat required to raise the temperature of 1 lb of water through 1°F $i.e.$,

$$1 \text{ B.Th.U.} = 1 \text{ lb} \times 1°F$$

C.H.U. It is the amount of heat required to raise the temperature of 1 lb of water through 1°C $i.e.$,

$$1 \text{ C.H.U.} = 1 \text{ lb} \times 1°C$$

1.6 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. This is amply established by the fact that there exists a definite relationship among the units assigned to these energies. It will be seen that these units are related to each other by some constant.

(*i*) **Electrical and Mechanical**

$$1 \text{ kWh} = 1 \text{ kW} \times 1 \text{ hr}$$
$$= 1000 \text{ watts} \times 3600 \text{ seconds} = 36 \times 10^5 \text{ watt-sec. or Joules}$$
$$\therefore \qquad 1 \text{ kWh} = 36 \times 10^5 \text{ Joules}$$

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

(*ii*) **Heat and Mechanical**

(*a*) $\qquad 1 \text{ calorie} = 4 \cdot 18 \text{ Joules}$ (By experiment)

(*b*) $\qquad 1 \text{ C.H.U.} = 1 \text{ lb} \times 1°C = 453 \cdot 6 \text{ gm} \times 1°C$
$$= 453 \cdot 6 \text{ calories} = 453 \cdot 6 \times 4 \cdot 18 \text{ Joules} = 1896 \text{ Joules}$$
$$\therefore \qquad 1 \text{ C.H.U.} = 1896 \text{ Joules}$$

(*c*) $\qquad 1 \text{ B.Th.U.} = 1 \text{ lb} \times 1°F = 453 \cdot 6 \text{ gm} \times 5/9 \text{ °C}$
$$= 252 \text{ calories} = 252 \times 4 \cdot 18 \text{ Joules} = 1053 \text{ Joules}$$
$$\therefore \qquad 1 \text{ B.Th.U.} = 1053 \text{ Joules}$$

It may be seen that heat energy can be expressed in Joules instead of thermal units $viz.$ calorie, B.Th.U. and C.H.U.

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* The SI or MKS unit of thermal energy being used these days is the *joule*—exactly as for mechanical and electrical energies. The thermal units $viz.$ calorie, B.Th.U. and C.H.U. are obsolete.

(*iii*) **Electrical and Heat**

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

$$= \frac{36 \times 10^5}{4 \cdot 18} \text{ calories} = 860 \times 10^3 \text{ calories}$$

∴   1 kWh = 860×10^3 calories   or   860 kcal

(*b*)   1 kWh = 36×10^5 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 = $\frac{36 \times 10^5}{1053}$ B.Th.U. = 3418 B.Th.U.

[∵ 1 B.Th.U. = 1053 Joules]

∴   1 kWh = 3418 B.Th.U.

The reader may note that units of electrical energy can be converted into heat and *vice-versa*. This is expected since electrical and thermal energies are interchangeable.

1.7 Efficiency

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 arrangement. In this process of conversion, some energy is *lost* in the sense that it is converted to a form different from electrical energy. Therefore, the output energy is less than the input energy. *The output energy divided by the input energy is called* **energy efficiency** *or simply* **efficiency** *of the system*.

Measuring efficiency of compressor.

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

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

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

Example 1.1. *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*) *What is the percentage efficiency of the generator ?*

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

Solution.

(*i*) Input power, $\qquad\qquad\quad P_i$ = 4200 J/s = 4200 W

Output power, $\qquad\qquad P_o$ = EI = 120 × 32·2 = 3864 W

∴ Efficiency, $\qquad\qquad\quad \eta$ = $\dfrac{P_o}{P_i} \times 100 = \dfrac{3864}{4200} \times 100$ = **92 %**

(*ii*) Power lost, $\qquad\qquad\quad P_L$ = $P_i - P_o$ = 4200 − 3864 = 336 W

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

$\qquad\qquad\qquad\qquad\qquad$ = $P_L \times t$ = 336 × 60 = **20160 J**

Note that efficiency *is always less than 1 (or 100 %)*. In other words, every system is less than 100 % efficient.

1.8 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*. Below is given a table of various types of fuels and their calorific values along with composition.

S.No.	Particular	Calorific value	Composition
1.	**Solid fuels**		
	(*i*) Lignite	5,000 kcal/kg	C = 67%, H = 5%, O = 20%, ash = 8%
	(*ii*) Bituminous coal	7,600 kcal/kg	C = 83%, H = 5·5%, O = 5%, ash = 6·5%
	(*iii*) Anthracite coal	8,500 kcal/kg	C = 90%, H = 3%, O = 2%, ash = 5%
2.	**Liquid fuels**		
	(*i*) Heavy oil	11,000 kcal/kg	C = 86%, H = 12%, S = 2%
	(*ii*) Diesel oil	11,000 kcal/kg	C = 86·3%, H = 12·8%, S = 0·9%
	(*iii*) Petrol	11,110 kcal/kg	C = 86%, H = 14%
3.	**Gaseous fuels**		
	(*i*) Natural gas	520 kcal/m^3	CH_4 = 84%, C_2H_6 = 10% Other hydrocarbons = 5%
	(*ii*) Coal gas	7,600 kcal/m^3	CH_4 = 35%, H = 45%, CO= 8%, N = 6% CO_2 = 2%, Other hydrocarbons = 4%

1.9 Advantages of Liquid Fuels over Solid Fuels

The following are the 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. However, liquid fuels leave no or very little ash after burning.

(*v*) The firing of liquid fuels can be easily controlled. This permits to meet the variation in load demand easily.

1.10 Advantages of Solid Fuels over Liquid Fuels

The following are the 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.

SELF-TEST

1. **Fill in the blanks by inserting appropriate words/figures.**

(*i*)   The primary source of energy is the ....

(*ii*) The most important form of energy is the ....

(*iii*) 1 kWh = ... kcal

(*iv*) The calorific value of a solid fuel is expressed in ....

(*v*)   The three principal sources of energy used for the generation of electrical energy are .... and ....

2. **Pick up the correct words/figures from the brackets and fill in the blanks.**

(*i*)   Electrical energy is .... than other forms of energy.   (*cheaper, costlier*)

(*ii*) The electrical, heat and mechanical energies .... be expressed in the same units. (*can, cannot*)

(*iii*) .... continue to enjoy the chief source for the generation of electrical energy. (*fuels, radioactive substances, water*)

(*iv*) The basic unit of energy is ....   (*Joule, watt*)

(*v*)   An alternator is a machine which converts .... into .... (*mechanical energy, electrical energy*)

ANSWERS TO SELF-TEST

1. (*i*) Sun, (*ii*) electrical energy, (*iii*) 860, (*iv*) cal/gm or kcal/kg, (*v*) water, fuels and radioactive substances.

2. (*i*) Cheaper, (*ii*) can, (*iii*) fuels, (*iv*) Joule, (*v*) mechanical energy, electrical energy.

CHAPTER REVIEW TOPICS

1. Why is electrical energy preferred over other forms of energy ?

2. Write a short note on the generation of electrical energy.

3. Discuss the different sources of energy available in nature.

4. Compare the chief sources of energy used for the generation of electrical energy.

5. Establish the following relations :

(*i*) $1 \text{ kWh} = 36 \times 10^5$ Joules   (*ii*) 1 kWh = 860 kcal

(*iii*) 1 B.Th.U. = 1053 Joules   (*iv*) 1 C.H.U. = 1896 Joules

6. What do you mean by efficiency of a system ?

7. What are the advantages of liquid fuels over the solid fuels ?

8. What are the advantages of solid fuels over the liquid fuels ?

DISCUSSION QUESTIONS

1. Why do we endeavour to use water power for the generation of electrical energy ?

2. What is the importance of electrical energy ?

3. What are the problems in the use of nuclear energy ?

4. Give one practical example where wind-mill is used.

5. What is the principal source of generation of electrical energy ?