CHAPTER – I

SOLAR ENERGY

1.1 ENERGY

Energy is the foundation on which human civilization rests, for which there is no substitute. It is the basic natural resources without which existence of human life is impossible. Energy, a crucial factor in technological development, has always been the key to man's greatest goals and his dreams of a better world.

The modern civilization revolves around the axis of energy and we all become the fish in the sea of energy. The importance of the role of energy in the economy was made evident by the oil embargo of 1973. The energy consumed by the human on the planet earth increases day by day with the increase in human population. The consumption of energy by a person has increased from 2930 kW in the 19th century to 17600 kW in the 20th century.

The operation of our technological society depends upon the production and use of large amounts of energy. Many of the world's present problems are closely related to problems of energy distribution, dwindling fossil-fuel supplies and environmental effects of various methods of energy production and its utilization. Energy is not only a commodity; it is also an idea, an intellectual concept that stands out in the history of modern scientific and engineering thought.

It has long been recognized that a major turning point in the history of the human race occurred when man changed from a nomadic hunter gatherer to a cultivator. Given that food is the most fundamental form of energy that enables any living being to survive, the development of agriculture marks the point of time, when man began to create more energy than needed for mere survival. Up to that point man retained a delicate balance with nature, following migratory herds of wild animals and gathering what little he could derive from natural vegetation.

A second stage in human development occurred with the onset of the industrial revolution, which is also in a way another energy revolution. Food sustains only muscular energy either human or animal, but another source of energy was in need to fuel the machines that man had begun to invent. This energy was initially met partly by firewood, but later mostly by coal. The industrial revolution which is still continuing marked the most rapid advance seen so far in human civilization in principle made possible by the tremendous surplus Energy.

1.2 DEVELOPMENT OF ENERGY

Primitive man required energy primarily in the form of food. He derived this by eating plants or animals which he hunted. Initially he discovered fire and as his energy needs increased he started to make use of wood and other biomass to supply the energy needs for cooking as well as for keeping himself warm. With the passage of time, man started to cultivate land for agriculture for further need of energy; man began to use the wind for sailing ships and for driving wind mills and the force of falling water to turn water wheels. At present without energy, we cannot sustain life on earth. Since, it fulfills our basic needs, as well as to travel and communicate everything, whether directly or indirectly.

A new source of energy-nuclear energy came on the scene after the Second World War. Nuclear energy is providing a small but significant amount of the energy requirements of many countries. We can broadly categorize the energy sources as Commercial and Non-Commercial. In an industrialized country like U.S.A most of the energy requirements are filled by the commercial sources, while in an industrially less developed country like India the use of commercial and noncommercial sources is more or less equal.

In the past few years, it has become obvious that fossil fuel resources are fast depleting and that the fossil fuel era is gradually coming to an end. This is particularly true for oil and natural gases. So we need an alternative energy option, which is safe, clean and free from pollution.

1.3 ENERGY CRISIS

In recent years we have experienced what is often called an "Energy Crisis." A crisis is a turning point in the course of history and recent events clearly fit this definition, since it is a basic economic commodity. Energy is available to users to the extent that they are willing to pay the price that is asked by the seller. The relevant questions are how much customers will demand at a given price at a given time and how much business can afford to spend to supply the energy. At some point the answers to these questions match, and the market of supply and demand meet. This theoretical economic action is altered by regulatory and other government controls. During the past few years we have experienced a period of rising prices, shifting relationships among energy suppliers, uncertain supply, and political influences on fuel supply. Each of these factors constitutes an important element of change.

In addition, there is the problem of overcoming the threat of excessive damage to the environment due to extensive use of fossil fuels in transportation and industry. The process of compensating for these Environmental effects will consume more energy and will require new approaches. Recycling of materials, rapid transit, sewage treatment, and air-pollution control equipment often consume additional energy and thus increase our total use of energy.

The energy crisis, which we have been facing, is mainly due to the following three factors:

1. Increase in population
2. Increase in per capita energy consumption and
3. Depletion of fossil fuels.

Man has used energy at an increasing rate for his sustenance and well being ever since he came into existence. Primitive man consumed only $2x10^3$ kcal/day for food. Later, industrial man consumed $77x10^3$ kcal/day. Now the technological man consumes $230x10^3$ kcal/day for the various technological advancements. Estimates indicate that in every 15 years, the demand will be nearly doubled at the present rate of consumption. India, being a developing nation, our per capita consumption of power is increasing at a rapid rate.

Source of energy available for mankind are grouped into two categories.

1. Resources such as coal, petroleum, natural gases, natural fuels and geothermal power which are called Non-Renewable Sources of Energy or fossil fuels.

2. Resources of energy such as wood, hydro power and wind power, solar and nuclear fusion, which are available for millions of years, called Renewable sources of Energy.

As the life standard of a country is measured through the per capita energy consumption of its population. In this respect India ranks quite low among other countries in the world not much energy has been used per person for thousands of years until about 100 years ago. In the rural sector the directly identifiable energy sources are human effort, animal power, wood, solar, biomass biogas and wind energy. Our present civilization has been built up on the energy provided by the fossil present in our nature.

1.4 SOLAR ENERGY

Solar Energy runs the engines of the earth. It heats its atmosphere and its lands, generates winds, drives the water cycle, warms its oceans, grows its plants, feeds its animals, and even (over the long haul) produces its fossil fuels. This energy can be converted into heat and cold, driving force and electricity.

Solar energy from the sun is free and inexhaustible. This vast, clean energy resource represents a viable alternative to the fossil fuels that currently pollute our air and water, threaten our public health, and contribute to global warming. Failing to take advantage of such a widely available and low-impact resource would be a grave injustice to our children and all future generations.

In the broadest sense, solar energy supports all life on Earth and is the basis for almost every form of energy we use. The Sun makes plants grow, which can be burned as "biomass" fuel or, if left to rot in swamps and compressed underground for millions of years, in the form of coal and oil. Heat from the sun causes temperature differences between areas, producing wind that can power turbines. Water evaporates because of the sun, falls on high elevations, and rushes down to the sea, spinning hydroelectric turbines as it passes.

Solar energy can be a major source of power. Its potential is 178 billion MW which is about 20000 times the world's demand. But so far it could not be developed on a large scale. The total potential of solar energy in our country is estimated as equivalent to 6000 MW based on incidence alone. The solar power where sun hits atmosphere is 10^{17} Watts, whereas the solar power on earth's surface is 10^{16} Watts. The total world wide power demand of all needs of civilization is 10^{13} Watts. Therefore, the sun gives us 1000 times more power than what we need. If we can use 5% of this energy, it will be 50 times what the world will require.

1.5 FUNDAMENTALS OF SOLAR INSOLATION

The Sun is a huge hot sphere of intensely hot gaseous matter with 1.89×10^{30} kg of mass and 13.9×10^{5} km distance. The outermost layer of the sun from which energy is radiated into the solar system to an equivalent black body of 5760 K, although the center of the sun may be 20×10^{6} K which is located 150 million km from the sun.

Solar radiation is an electromagnetic radiation characteristic of a black body at temperature of 5760 K. The nature of the energy generation in the sun is still, the basic unanswered question about this star. Spectral instruments have confirmed the presence of the known elements in the sun; however 80% of the sun is hydrogen and 19 % Helium. Therefore the remaining elements comprise only a tiny fraction of the composition of the sun. It is generally accepted that Hydrogen to Helium thermonuclear reaction is the source of the sun's energy.

Fusion energy is a form of nuclear energy released by the fusion (for combination) of two light nuclei (i.e. nuclei of low mass number) to produce a heavier nucleus. For two nuclei to fuse, they must come close enough to interact. Earth receives radiant energy from sun, which is vast and hot mass of hydrogen and helium gases in the proportion of 3:1. In the sun, energy is generated in its central core, which may be considered as a giant nuclear reactor. The energy is released in accordance with the following reaction,

$$4\ {}^{1}H_{1} \rightarrow 2He_{4} + 26.7\ \text{MeV}$$

In Solar Energy utilization process, the useful wavelength range is between 3000 Å to 30000 Å. This carries some 98% of the total emitted energy. The major factor is scattering from the molecules and dust particle absorption. The radiation finally received on Earth's surface consists partially of beam radiation and partially of diffused radiation.

One can see that the sun is the ultimate source of most forms of energy available to us. The sun is a massive body. It is as big as 1.3 million earths. Some facts about the sun are staggering. The core of the sun is unimaginably hot at 15,000,000 °C. The sun converts 650,000,000 of tons of hydrogen into helium every second and in the process throws up an amount of energy equal to thousands of millions of hydrogen bombs. Only a small fraction of this energy reaches the earth. The energy that reaches the earth is enough to meet the energy demand of the whole world 10000 time over, the power from the sun is intercepted by the earth is approximately 1.8×10^{11} MW. Particularly in our India, the total potential of solar energy is estimated as equivalent to 6000 MW based on incident alone. In India the total solar radiation falls on the earth surface is 4-7 kWm^2/day.

1.6 ADVANTAGES AND DISADVANTAGES OF SOLAR POWER

1.6.1 Advantages

- The 89 peta watts of sunlight reaching the earth's surface are plentiful compared to the 15 tera watts of average power consumed by Humans. Additionally, solar electric generation has the highest power density (global mean of 170 W/m^2) among renewable energies.
- Solar power is pollution free during use. Production end wastes and emissions are manageable using existing pollution controls. End-of-use recycling technologies are under development.
- Facilities can operate with little maintenance or intervention after initial setup.
- Solar electric generation is economically competitive where grid connection or fuel transport is difficult, costly or impossible. Examples include satellites, island communities, remote locations and ocean vessels.
- When grid-connected, solar electric generation can displace the highest cost electricity during times of peak demand (in most climatic regions), can reduce grid loading, and can eliminate the need for local battery power for use in times of darkness and high local demand; such application is encouraged by net metering. Time-of-use net metering can be highly favorable to small photovoltaic systems.

- Grid-connected solar electricity can be used locally thus minimizing transmission/distribution losses (approximately 7.2%).
- Once the initial capital cost of building a solar power plant has been spent, operating costs are low compared to existing power technologies.

1.6.2 Disadvantages

- Solar electricity is expensive compared to grid electricity.
- Solar heat and electricity are not available at night and may be unavailable due to weather conditions; therefore, a storage or complementary power system is required for most applications.
- Limited power density: Average daily isolation in the contiguous is 3-9 kWh/m^2 usable by 7-19.7% efficient solar panels
- Solar cells produce DC which must be converted to AC when used in currently existing distribution grids. This incurs an energy loss of 4-12%.

1.7 Conversion of Solar Energy

1.7.1 Thermal Conversion

Converting the sun's radiant energy in to heat is the most common and well developed solar conversion technology today. In all collection devices, the principle usually followed is to expose the dark surface to solar radiation so that the radiation is observed. A part of the observed solar radiation is then transferred in the form of heat to a fluid like air or water. The collection of solar energy achieved by a flat surface in the absence of optical concentration is called Flat Plate Collector. This type of collector has a greater importance because capability of working fluid temperature ranging from 40^oC to 100^oC without tracking mechanism. For the temperature higher than 100 ^oC the solar radiation must be concentrated in a particular point. This can be achieved by focusing or concentrating collectors associated with tracking mechanism.

1.7.2. Photovoltaic Conversion

The most useful way of harnessing solar energy is by directly converting it into electricity by means of solar photovoltaic cells. When sunshine is incident on solar cell, they generate DC electricity without involvement of any mechanical generators. In recent years, photovoltaic power generation has been receiving considerable attenuation as one of the more promising energy alternative. The reasons for this rising interest are due to

- PV's are direct conversion of sunlight into electricity,
- the non-polluting nature of PV conversion process and
- Non-dependence on fossil and nuclear fuels.

Silicon cells are the widely used Solar cells. When the radiation falls on a cell it is absorbed and electron hole pairs are created. The direct current is produced by the movement of electron hole pair and they are collected by the metal electrodes which are connected to external load. Conversion efficiencies obtained for silicon cells is in range between 10% to 15%. In early stages it was exclusively used for space application. Although it is costly, arrays of solar cells suitably mounted on panels are already being used extensively to supply electricity for many small commercial and agricultural applications in remote areas and it is used in a small capacity water pumping unit used for irrigation in rural areas. One of the most interesting large applications is the satellite solar power stations.

1.8 Storage of Solar Energy

Solar energy is a time dependent and intermittent energy resource. There is thus marked need for storage of energy or another product of solar process, if the solar energy is to meet the energy needs. Energy storage may be in the form of sensible heat of solid or liquid medium, as heat of fusion in chemical systems or as chemical energy of products in the reversible chemical reaction. Solar energy storage systems may be broadly classified as

(i) Electrical storage

(ii) Chemical storage

(iii) Hydro storage

(iv)Thermal storage

1.8.1 Electrical storage

Theoretically the capacitors could store large amounts of electrical energy for long period of time. The total energy stored is given by

$$H_{cap} = ½ V\epsilon E^2$$

where

V - is the volume of the dielectric material

Є - is the dielectric constant

E- is the electric field strength

The electric energy from solar radiation through photovoltaic array can be directly stored in capacitors for a short periods. Practically the electric field strength is limited by the break down strength of the dielectric (Є). So the electrical energy stored in dielectric is limited. More over the conductivity of a dielectric is never nil, there will always a leakage loss. So the capacity is economical for times no longer then 12 hours. To increase this time much research is needed. Therefore, unless better and cheaper dielectric materials for storing electric energy are found, capacitive storage on large scale will remain uneconomical.

1.8.2 Chemical Storage

It is possible to design a storage battery in which the reactant is regenerated by a photochemical reaction brought about by solar radiation. In this case the converter itself acts as storage battery. The battery is charged photo chemically and discharged electrically whenever needed. Some of the reactions that could be potentially useful for storage of solar energy is each one of these reactions

$$2NaCl + Photons \longrightarrow 2No + Cl_2$$

$$AgCl(s) + Photons \longrightarrow Ag(s) + ½\, Cl_2$$

$$No_2 + Photons \longrightarrow No + ½\, O_2$$

$$H_2O + ½\, O_2 \longrightarrow H_2O_2$$

It is also possible to electrolyze water with solar generated electrical energy; stored oxygen and hydrogen are recombined in a fuel cell to regain electrical energy. Hydrogen is one of the most efficient and partial fuel.

1.8.3 Hydro Storage

There are many coastlines near the oceans in arid zones that could be used for hydraulic storage of solar energy. A dam could be built across a valley not to far away from the sea. Seawater could be pumped behind the dam by using solar energy and the electric energy would then be produced, by conventional hydroelectric plant. This method of Solar energy storage has the advantage of avoiding the intermittent inherent to Solar energy and of producing ac power directly.

1.8.4 Thermal Energy Storage

Solar thermal energy storage can be classified into two types.

a. Sensible Heat Storage

b. Latent Heat Storage

(a) Sensible Heat Storage

Sensible heat storage is accomplished by raising temperature of a substance without changing its composition or phase. Heat is then recovered when the temperature is lowered. The amount of heat stored or recovered is given by

$$Q = mc\Delta t = V(\rho_c)\Delta t$$

where

c - is the material specific heat per unit mass.

ρ_c - is the density of the material.

Once a storage material has been selected, the amount of heat that can be stored is determined by the amount of material and temperature change that it will be permitted to undergo. Water has the highest value of ρ_c, so that water is used as a most common heat transfer fluid. Generally materials used for this type of storage are

(i) Water
(ii) Rock, gravel or crushed stone
(iii) Iron shot
(iv) Iron, Red oxide
(v) Concrete.

(b) Latent Heat Storage

A material when heated undergoes a phase change (usually melting) due to its Latent heat storage. The amount of energy stored in this case depends upon the mass and latent heat of fusion of the material. Equation governing this reaction is given by

Thus

$$E = m\lambda$$

where

λ = is the latent heat of fusion.

m = is the mass of the storage material.

It has advantage of the fact that large quantities of heat are needed to cause a small volume of substance to change its phase or chemical composition. A very significant reduction in the size of the storage container is then possible. Usually water, NaCl, $Na_2So_4.10H_20$ and KCl have low melting points and serve the purpose of storing energy above ambient temperatures. Substances like $CaCl_2.6H_2O$, $Na_2So_4.10H_2O$ and paraffin wax have melting points in the range of 30 -50ºC can be considered for energy conversion application. The Sodium Sulphate Deca Hydrate (Glauber's salt) is the best example of latent heat storage system. The basic reaction is

$$Na_2So_4.10H_20 \rightleftharpoons Na_2So_4 + 10H_20$$

The energy storage takes place by the reaction proceeding from left to right on addition of heat. Energy extraction from storage is the reverse procedure with the reaction, proceeding from right to left and the thermal effects reversed. It has been found that the performance decays on repeated cycling. With the thermal capacity of the system reduced $Na_2So_4.10H_20$ has an incongruent melting point, it separates into liquid phase and solid Na_2So_4 since density of solution a phase separation occurs.

In thermal heat storage system, the sensible heat storage method is usually employed due to less economic and easy maintenance. The Solar Pond is a combination of solar energy collection and Sensible heat storage device, which is the option among other storage systems.

1.9 NEED FOR DESALINATION OF WATER

Along with food and air, water is a basic necessity of man. The consumption of water until for drinking on account of bacteria/germs or excess of salts constitutes a major health hazard. Considering the fact that an estimated two billion persons in the world go without portable water, the UNO has declared the present decade as the International Drinking Water Supply and Sanitation Decade (IDWSSD).

More than 60% of the world regions have no source of fresh water. Hence man has to dependent on rivers, lakes and underground water reservoirs for fresh water requirements to fulfill his commodities in domestic life, agricultural, scientific laboratory and industry. The supply of drinking water to the population and the cattle is a major problem. Fresh water supply by trucks or by laying long pipelines carrying portable water from far off region is usually not economically feasible. So there is a need for desalination of brackish salt water.

The problem of pollution of the rivers and lakes by industrial wastes and large amount of sewages results in the contamination of water quality. Thus, there is a scarcity of fresh water even in cities, towns and villages near lakes and rivers. Many of the coastal areas and deserts portable water for drinking is the main problem. They get only salt water. So desalination of water gets more importance.

1.10 SOLAR DISTILLATION

The brackish or saline water is evaporated using thermal energy and the resulting steam is collected and condensed as final products. This method is called Desalination.

Desalination process is considered to be one of the simplest and widely adopted techniques for converting seawater into fresh water. One of the main advantages of the distillation process is that it requires heat only up to 120 °C which can be supplied from solar energy or other cheap fuels, while in reverse osmosis, vapour compression, and electro dialysis processes, some mechanical or electrical energy is used.

The direct use of solar energy to distill water was first commercially done in the19th century. Since then solar stills have been used on a small-scale basis in isolated communities and house for purifying brackish and salt water. The essential technique of the solar stills is to admit solar radiation through transparent plastic or glass cover to the shallow basin of salt water. Pure water quickly evaporates from the brine when light strikes it, and the evaporated vapour gets condensed on the transparent sloped cover, to collect the condensed water into a collection trough.

Oceans are the largest water reservoir of the Earth. Ocean water contains on the average 3.5% by weights of dissolved salts, a concentration that makes the water unsuitable for many uses in household, industry and irrigation sectors. So desalination is necessary for producing good water.

Renewable energy in many arid and semi-arid regions throughout the world where problem of good quality water is crucial and hence one finds these energy sources being used for desalination.

Adequate quality and reliability of drinking water supply is the fundamental need of the people. Water is the key to man's prosperity; it is intimately associated with the evolution of civilization. Fresh water that was obtained from river, lake and ponds in plenty is becoming scarce because of industrialization and population explosion. The shortage of fresh water existed but it was confined to regions where only brackish water is available (arid and the semi-arid regions).

1.11 THE GLOBAL WATER CRISIS

Water has always been earth's most valuable resource. All ecosystems and every field of human activity depend on water. The world's supply of fresh water is running out. Already one person in five has no access to safe drinking water. The amount of water in the world is limited. The human race, and the other species which share the planet, cannot expect an infinite supply. 97.5% of the total global stock of water is saline and only 2.5% is fresh water. Approximately 70% of this global freshwater stock is locked up in polar icecaps and a major part of the remaining 30% lies in remote underground aquifers. Population growth and the increasing need for fresh water for industrial and agricultural uses indicate there will be no letup in the increasing demand for water in the years to come. These factors account for the concern over water shortages that exist now in some areas of the country and over the more serious shortages that are projected for the near future.