NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

POWER GENERATION SYSTEM

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EE-400

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ABSTRACT

Electricity is one of most essential needs of modern world. Human life is impossible on this earth without electricity. This electricity is generated from different energy sources (water, fossil fuels, wind, solar, geothermal etc) by converting them into electrical energy. In this project, the ways and methods of conversions from one energy form to another energy form have been explained. During this conversion some times environment is badly polluted especially when fossil fuels are burn (thermal power plants). It is preferred that power plants should be out side cities in remote areas or close to lakes, rivers and sea. Power plants are constructed after detail surveys on a appropriate location suited for that particular power generation. Every power generation system has its own necessary equipment which is different from others but Turbines and generators are mainly most common elements in every power generation system. Cost factors have been discussed as well.

INTRODUCTION

As the population of this world is growing day by day, the demand of electricity for domestic and industrial purpose has been diversely increased. If we have a look on some details taken in past 10 years, we will see the major difference (increment) in electricity consumption. So in order to meet these challenges we have to increase our power generation capacity. Before we had traditional power resource water, many hydropower plants were built. Then methods of converting fossil fuels in to energy were discovered which led in the construction of thermal power plants every where in the world. After the discovery of atomic fusion and fission, we came to know that we can get energy from nuclear as well. But these methods and ways were not enough to fulfill the power needs of world. Scientists continued research and discovered many alternative powers generating ways in the form of wind energy, solar energy, geothermal energy etc.

Chapter one of this project deals with that traditional way of hydropower generation. The function of turbines, objective of dams, controlling task done by power house has been explained with appropriate figures .Types of hydro power plants are described.

Chapter two is about thermal power generation. Gas, oil and coal are mainly used as fuel to burn and produce energy. Boilers, pumps, turbines, condenser, reheater, burners, fans and generators are main components of a thermal power plant. The environmental changes made by thermal power plants are illustrated too.

Chapter three elaborates nuclear energy and nuclear power plants. Atomic fission and fusion, chain reaction, uranium isotopes and their occurrence, types of nuclear reactors are main concern of this chapter. Heavy water and light water reactors are also explained.

The subject of chapter four is to give information about alternative power generating sources (solar energy, wind energy and geothermal energy).solar energy is the solar radiation that reaches earth. Solar conversion system, photovoltaic energy, solar thermal heat, solar resource, solar collectors etc are mainly discussed. Wind is simple air in motion. But this wind's kinetic energy can push the turbines which cause generator motion resulting in generation of power. Geothermal energy means the heat of earth. In some parts of earth this geothermal energy (hot water, steam etc) is used to produce power

1. CHAPTER ONE
HYDROELECTRIC POWER

It's a form of energy. A renewable resource. Other renewable resources include geothermal, wave power, tidal power, wind power, and solar power. Hydroelectric power plants do not use up resources to create electricity nor do they pollute the air, land, or water, as other power plants

Hydroelectric power comes from flowing water. Winter and spring runoff from mountain streams and clear lakes. Water, when it is falling by the force of gravity, can be used to turn turbines and generators that produce electricity.

Hydropower is an essential contributor in the national power grid because of its ability to respond quickly to rapidly varying loads or system disturbances, which base load plants with steam systems powered by combustion or nuclear processes cannot accommodate. Reclamation's 58 power plants throughout the Western United States produce an average of 42 billion kWh (kilowatt-hours) per year, enough to meet the residential needs of more than 14 million people. This is the electrical energy equivalent of about 72 million barrels of oil.

Hydroelectric power plants are the most efficient means of producing electric energy. The efficiency of today's hydroelectric plant is about 90 percent. Hydroelectric plants do not create air pollution, the fuel--falling water--is not consumed, projects have long lives relative to other forms of energy generation, and hydroelectric generators respond quickly to changing system conditions. These favorable characteristics continue to make hydroelectric projects attractive sources of electric power.

1.1. How hydropower works?

Hydroelectric power comes from water at work, water in motion. It can be seen as a form of solar energy, as the sun powers the hydrologic cycle which gives the earth its water. In the hydrologic cycle, atmospheric water reaches the earth's surface as precipitation. Some of this water evaporates, but much of it either percolates into the soil or becomes surface runoff. Water from rain and melting snow eventually reaches ponds, lakes, reservoirs, or oceans where evaporation is constantly occurring.

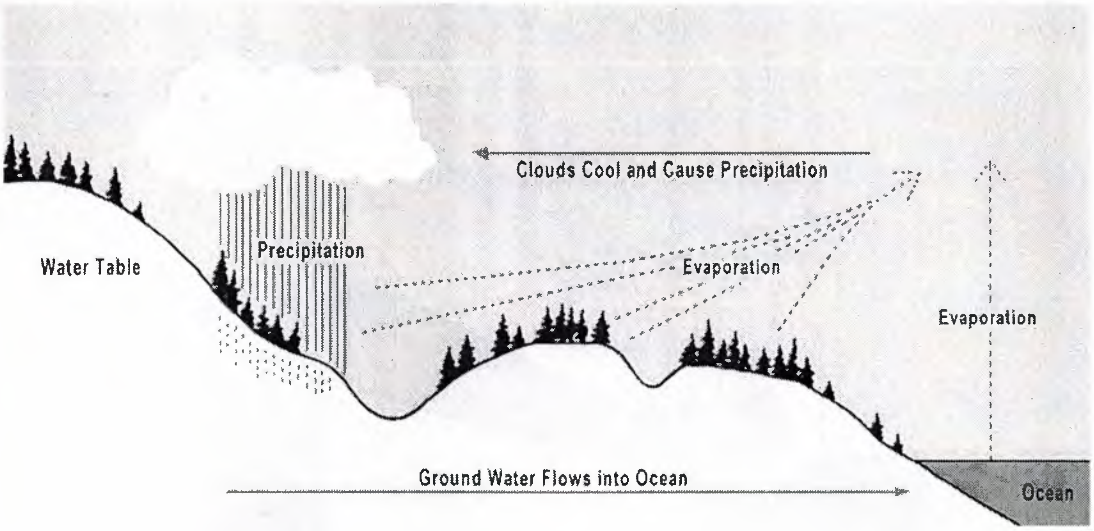

Figure 1.1 Water cycle

Moisture percolating into the soil may become ground water (subsurface water), some of which also enters water bodies through springs or underground streams. Ground water may move upward through soil during dry periods and may return to the atmosphere by evaporation. Water vapor passes into the atmosphere by evaporation then circulates, condenses into clouds, and some returns to earth as precipitation. Thus, the water cycle is complete. Nature ensures that water is a renewable resource.

1.2. Generating Power

In nature, energy cannot be created or destroyed, but its form can change. In generating electricity, no new energy is created. Actually one form of energy is converted to another form. To generate electricity, water must be in motion. This is kinetic (moving) energy. When flowing water turns blades in a turbine, the form is changed to mechanical (machine) energy. The turbine turns the generator rotor which then converts this mechanical energy into another energy form -- electricity. Since water is the initial source of energy, we call this hydroelectric power or hydropower for short. At facilities called hydroelectric power plants, hydropower is generated. Some power plants are located on rivers, streams, and canals, but for a reliable water supply, dams are needed. Dams store water for later release for such purposes as irrigation, domestic and industrial use, and power generation. The reservoir acts much like a battery, storing water to be released as needed to generate power.

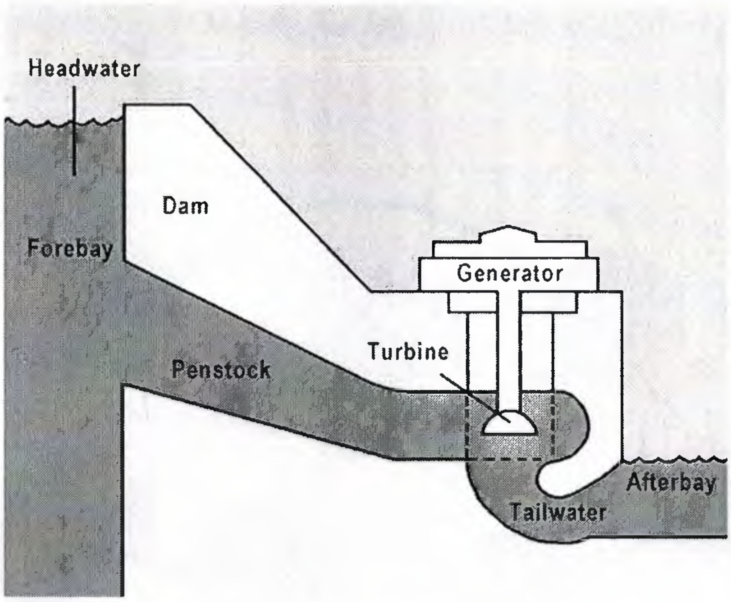

Figure 1.2 Structure of hydropower plant

The dam creates a head or height from which water flows. A pipe (penstock) carries the water from the reservoir to the turbine. The fast-moving water pushes the turbine blades, something like a pinwheel in the wind. The waters force on the turbine blades turns the rotor, the moving part of the electric generator. When coils of wire on the rotor sweep past the generator's stationary coil (stator), electricity is produced. This concept was discovered by Michael Faraday in 1831 when he found that electricity could be generated by rotating magnets within copper coils. When the water has completed its task, it flows on unchanged to serve other needs.

1.3. Transmitting Power

Once the electricity is produced, it must be delivered to where it is needed - our homes, schools, offices, factories, etc. Dams are often in remote locations and power must be transmitted over some distance to its users. Vast networks of transmission lines and facilities are used to bring electricity to us in a form we can use. All the electricity made at a power plant comes first through transformers which raise the voltage so it can travel long distances through power lines. (Voltage is the pressure that forces an electric current through a wire.) At local substations, transformers reduce the voltage so electricity can be divided up and directed throughout an area.

Transformers on poles (or buried underground, in some neighborhoods) further reduce the electric power to the right voltage for appliances and use in the home.

When electricity gets to our homes, we buy it by the kilowatt-hour, and a meter measures how much we use.

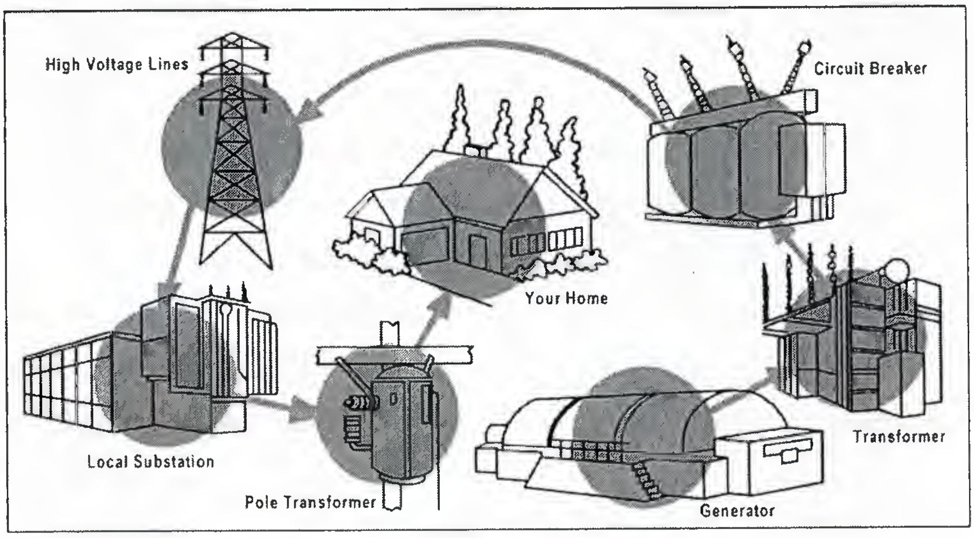

Figure 1.3 electricity distribution

While hydroelectric power plants are one source of electricity, other sources include power plants that burn fossil fuels or split atoms to create steam which in turn is used to generate power. Gas turbine, solar, geothermal, and wind-powered systems are other sources. All these power plants may use the same system of transmission lines and stations in an area to bring power to you. By use of this "power grid," electricity can be interchanged among several utility systems to meet varying demands. So the electricity lighting your reading lamp now may be from a hydroelectric power plant, a wind generator, a nuclear facility, or a coal, gas, or oil-fired power plant or a combination of these.

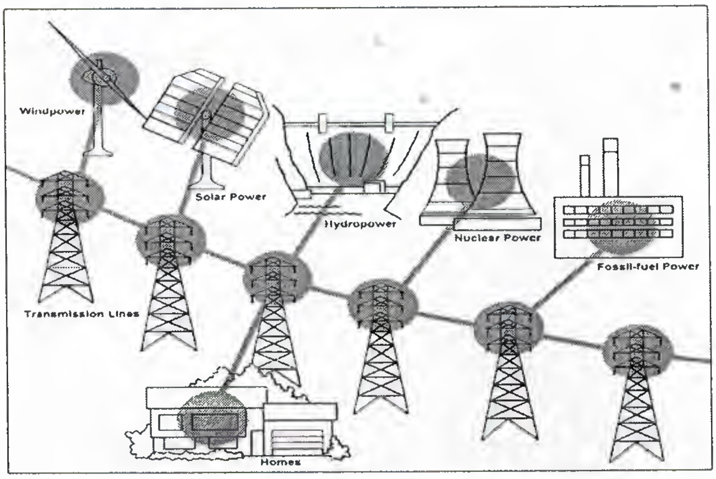

Figure 1.4 Transmission lines

1.4. How Power is computed

Before a hydroelectric power site is developed, engineers compute how much power can be produced when the facility is complete. The actual output of energy at a dam is determined by the volume of water released (discharge) and the vertical distance the water falls (head). So, a given amount of water falling a given distance will produce a certain amount of energy. The head and the discharge at the power site and the desired rotational speed of the generator determine the type of turbine to be used. The head produces a pressure (water pressure), and the greater the head, the greater the pressure to drive turbines. This pressure is measured in pounds of force (pounds per square inch). More head or faster flowing water means more power.

To find the theoretical horsepower (the measure of mechanical energy) from a specific site, this formula is used:

$$THP = (Q \times H)/8.8 \qquad \ldots\ldots (1.1)$$

Where: THP = theoretical horsepower

Q = flow rate in cubic feet per second (cfs)

H = head in feet

8.8 = a constant

A more complicated formula is used to refine the calculations of this available power. The formula takes into account losses in the amount of head due to friction in the penstock and other variations due to the efficiency levels of mechanical devices used to harness the power. To find how much electrical power we can expect, we must convert the mechanical measure (horsepower) into electrical terms (watts). One horsepower is equal to 746 watts (U.S. measure).

1.5. Makeup of hydropower plant

A hydropower installation consists of dams, water-ways and conduits that form a reservoir and channels the water towards the turbines. These, and other items described, enable us to understand some of the basic features and components of a hydropower plant.

1.5.1. Dams

Dams made of earth or concrete are made across river bed to create storage reservoirs. Reservoirs can compensate for the reduced precipitation during the dry season and for the abnormal flow that accompany heavy rain and melting snow. Dams permit us to regulate the water flow through out the year, so that the power house may run at close to full capacity.

Spillways adjacent to the dam are provided to discharge water when ever the reservoir is too high. We have seen that the demand for electricity varies through out a day and from season to season. Consequently the available water cannot always be used to supply energy to the system. If the water reservoir is small or non-existent (such as in run-of river situation), we unfortunately have to let the water through the spillway without using it. Dams often serve a dual purpose, providing irrigation and navigation facilities, in addition to their power generation role. The integrated system of the Tennessee Valley Authority is a good example.

1.5.2. Conduits, Penstocks and scroll case.

In large installations, conduits lead the water from the dam site to the generating plant. They may be open canals or canals carved through rocks. The conduits feed one or more penstocks (huge steel pipes), which bring the water to the individual turbines. Enormous valves, sometimes several meters in diameter, enable the water supply to be shut off in the conduits.

The penstock channels the water into the scroll-case that surrounds the runner (turbine) so that the water is evenly distributed around its circumference. Guides vanes and wicket gates control the water so that it flows smoothly into the runner blades. The wicket gates open and close in response to powerful hydraulic mechanism that is controlled by respective turbine governors.

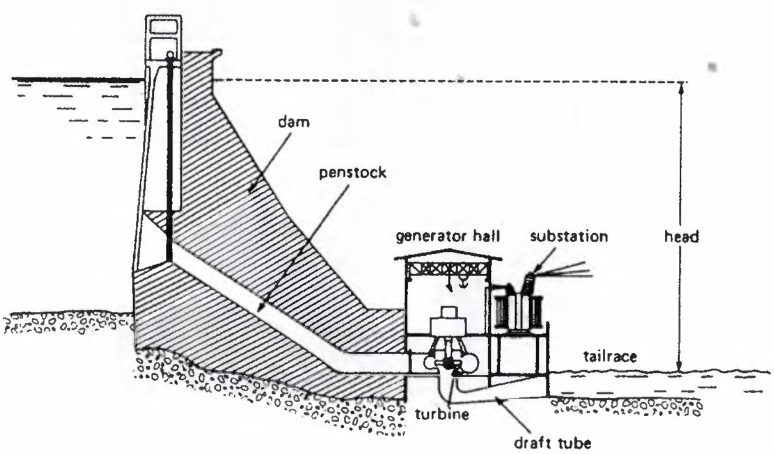

Figure 1.5. Cross-section view of a medium-head hydropower plant

1.5.3. Draft tube and Tailrace

Water that has passed through runner moves next through a carefully designed vertical channel, called draft tube. The draft tube improves the hydraulic efficiency of the turbine. It leads out to the tail race which channels the water into downstream river bed.

1.5.4. Powerhouse

The powerhouse contains the synchronous generators, transformers, circuit breakers etc. and associated control apparatus. Instrument, relays, and meters are contained in a room where the entire station can be monitored and controlled. Finally, many other devices (too numerous to mention here) make up a complete hydropower station.

1.5.5. Turbines

While there are only two basic types of turbines (impulse and reaction), there are many variations. The specific type of turbine to be used in a power plant is not selected until all operational studies and cost estimates are complete. The turbine selected depends largely on the site conditions. A reaction turbine is a horizontal or vertical wheel that operates with the wheel completely submerged a feature which reduces turbulence. In theory, the reaction turbine works like a rotating lawn sprinkler where water at a central point is under pressure and escapes from the ends of the blades, causing rotation. Reaction turbines are the type most widely used.

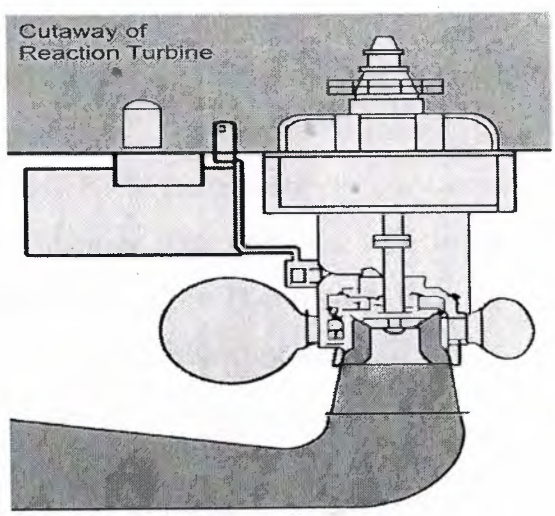

Figure 1.6 a Structure of reaction turbine

An impulse turbine is a horizontal or vertical wheel that uses the kinetic energy of water striking its buckets or blades to cause rotation. The wheel is covered by a housing and the buckets or blades are shaped so they turn the flow of water about 170 degrees inside the housing. After turning the blades or buckets, the water falls to the bottom of the wheel housing and flows out.

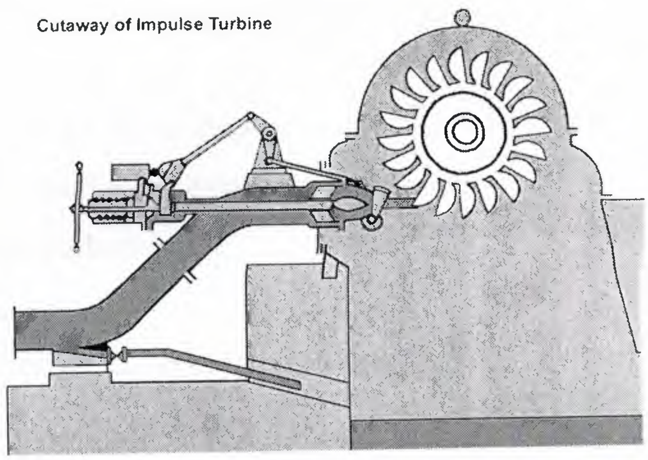

Figure 1.6 b structure of impulsive turbine

1.6. Modern Concepts and Future Role

Hydropower does not discharge pollutants into the environment; however, it is not free from adverse environmental effects. Considerable efforts have been made to reduce environmental problems associated with hydropower operations, such as providing safe fish passage and improved water quality in the past. Efforts to ensure the safety of dams and the use of newly available computer technologies to optimize operations have provided additional opportunities to improve the environment. Yet, many unanswered questions remain about how best to maintain the economic viability of hydropower in the face of increased demands to protect fish and other environmental resources. Reclamation actively pursues research and development (R&D) programs to improve the operating efficiency and the environmental performance of hydropower facilities. Hydropower research and development today is primarily being conducted in the following areas:

- Fish Passage, Behavior, and Response
- Turbine-Related Projects
- Monitoring Tool Development
- Hydrology
- Water Quality

- Dam Safety
- Operations & Maintenance
- Water Resources Management

Reclamation continues to work to improve the reliability and efficiency of generating hydropower. Today, engineers want to make the most of new and existing facilities to increase production and efficiency. Existing hydropower concepts and approaches include:

- Uprating existing power plants
- Developing small plants (low-head hydropower)
- Peaking with hydropower
- Pumped storage
- Tying hydropower to other forms of energy

1.7. Uprating

The uprating of existing hydroelectric generator and turbine units at power plants is one of the most immediate, cost-effective, and environmentally acceptable means of developing additional electric power. Since 1978, Reclamation has pursued an aggressive uprating program which has added more than 1,600,000 kW to Reclamation's capacity at an average cost of $69 per kilowatt. This compares to an average cost for providing new peaking capacity through oil-fired generators of more than $400 per kilowatt. Reclamation's uprating program has essentially provided the equivalent of another major hydroelectric facility of the approximate magnitude of Hoover Dam and Power plant at a fraction of the cost and impact on the environment when compared to any other means of providing new generation capacity.

1.8. Types of hydro power stations

Hydropower stations are divided into three groups depending upon the head of water.

1. high-head development
2. medium head development
3. low head development

1.8.1. High-head developments

High-head developments have heads in excess of 300 m and high-speed. Pelton turbines are used. Such generating stations are found in Alps and other mountainous region. The amount of impounded water is usually small.

1.8.2. Medium-head developments

Medium-head developments have head between 30 and 300 m and medium speed Francis turbines are used. The generating station is fed by a huge reservoir of water retained by dikes and a dam. The dam is usually built across a river bed in a relatively mountainous region. A great deal of water is impounded behind the dam.

1.8.3. Low-head developments

Low-head developments have heads under 30 m and low-speed Kaplan or Francis turbines are used. These generating stations often extract energy from flowing rivers. The turbines are designed to handle large volume of water at low pressure. No reservoir is provided. A low-head dam is one with a water drop of less than 65 feet and a generating capacity less than 15,000 kW. Large, high-head dams can produce more power at lower costs than low-head dams, but construction of large dams may be limited by lack of suitable sites, by environmental considerations, or by economic conditions. In contrast, there are many existing small dams and drops in elevation along canals where small generating plants could be installed. New low-head dams could be built to increase output as well. The key to the usefulness of such units is their ability to generate power near where it is needed, reducing the power inevitably lost during transmission.

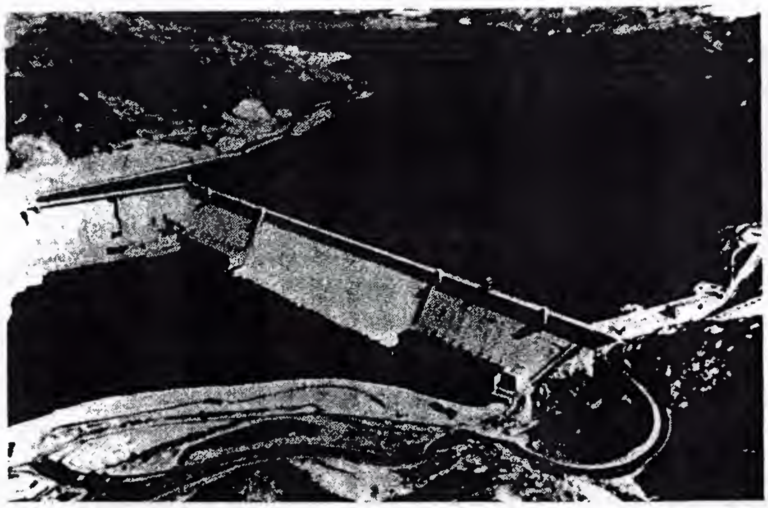

Figure 1.7 Grand Coulee dam on the Columbia River is the state of Washington is 108m high and 1270 m wide. It is the largest hydropower plant in the world having 18 generating unites of 125 MW each and 12 generating units of 1600 MW each, for a total of 9450 MW installed capacity. The spillway can be seen in the middle of the dam.

Figure 1.8 Spiral case feeds the water around the circumference of a 483 MW turbine.

Figure 1.9 Inside the spiral case, a set of adjustable wicket gates control the amount of water flowing into turbine.

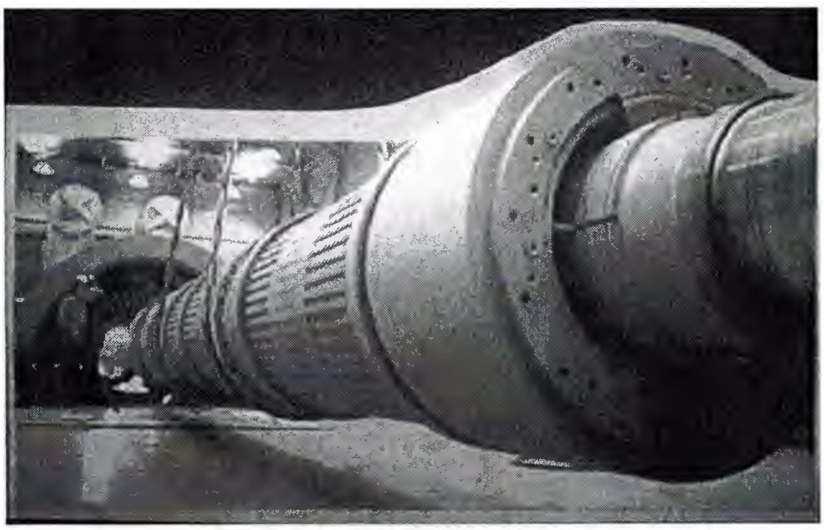

Figure 1.10 Power house turbine

1.9. Peaking with Hydropower

Demands for power vary greatly during the day and night. These demands vary considerably from season to season, as well. For example, the highest peaks are usually found during summer daylight hours when air conditioners are running. Nuclear and fossil fuel plants are not efficient for producing power for the short periods of increased demand during peak periods. Their operational requirements and their long startup times make them more efficient for meeting baseload needs. Since hydroelectric generators can be started or stopped almost instantly, hydropower is more responsive than most other energy sources for meeting peak demands. Water can be stored overnight in a reservoir until needed during the day, and then released through turbines to generate power to help supply the peak load demand. This mixing of power sources offers a utility company the flexibility to operate steam plants most efficiently as base plants while meeting peak needs with the help of hydropower. This technique can help ensure reliable supplies and may help eliminate brownouts and blackouts caused by partial or total power failures. Today, many of Reclamation's 58 power plants are used to meet peak electrical energy demands, rather than operating around the clock to meet the total daily demand. Increasing use of other energy-producing power plants in the future will not make hydroelectric power plants obsolete or unnecessary. On the contrary, hydropower can be even more important. While nuclear or fossil-fuel power plants can provide base loads, hydroelectric power plants can deal more economically with varying peak load demands. This is a job they are well suited for.

1.10. Tying Hydropower with Other Energy Forms

When we hear the term "solar energy," we usually think of heat from the sun's rays which can be put to work. But there are other forms of solar energy. Just as hydropower is a form of solar energy, so too is wind power. In effect, the sun causes the wind to blow by heating air masses that rise, cool, and sink to earth again. Solar energy in some form is always at work -- in rays of sunlight, in air currents, and in the water cycle. Solar energy, in its various forms, has the potential of adding significant amounts of power for our use. The solar energy that reaches our planet in a single week is greater than that contained in all of the earth's remaining coal, oil, and gas resources. However, the best sites for collecting solar energy in various forms are often far removed from people, their homes, and work places. Building thousands of miles of new transmission lines would make development of the power too costly.

Because of the seasonal, daily, and even hourly changes in the weather, energy flow from the wind and sun is neither constant nor reliable. Peak production times do not always coincide with high power demand times. To depend on the variable wind and sun as main power sources would not be acceptable to most lifestyles. Imagine having to wait for the wind to blow to cook a meal or for the sun to come out from behind a cloud to watch television! As intermittent energy sources, solar power and wind power must be tied to major hydroelectric power systems to be both economical and feasible. Hydropower can serve as an instant backup and to meet peak demands.

Linking wind power and hydropower can add to the Nation's supply of electrical energy. Large wind machines can be tied to existing hydroelectric power plants. Wind power can be used, when the wind is blowing, to reduce demands on hydropower. That would allow dams to save their water for later release to generate power in peak periods.

The benefits of solar power and wind power are many. The most valuable feature of all is the replenishing supply of these types of energy. As long as the sun shines and the wind blows, these resources are truly renewable.

1.11. Future Potential

What is the full potential of hydropower to help meet the world's energy needs? Finding solutions to the problems imposed by natural restraints demands extensive engineering efforts. Sometimes a solution is impossible, or so expensive that the entire project becomes impractical. Solution to the societal issues is frequently much more difficult and the costs are far greater than those imposed by nature. Developing the full potential of hydropower will require consideration and coordination of many varied needs.

1.12. Hydropower, the Environment, and Society

It is important to remember that people, and all their actions, are part of the natural world. The materials used for building, energy, clothing, food, and all the familiar parts of our day-to-day world come from natural resources. Our surroundings are composed largely of the "built environment" -- structures and facilities built by humans for comfort, security, and well-being. As our built environment grows, we grow more reliant on its offerings.

To meet our needs and support our built environment, we need electricity which can be generated by using the resources of natural fuels. Most resources are not renewable; there is a limited supply. In obtaining resources, it is often necessary to drill oil wells, tap natural gas supplies, or mine coal and uranium. To put water to work on a large scale, storage dams are needed.

We know that any innovation introduced by people has an impact on the natural environment. That impact may be desirable to some, and at the same time, unacceptable to others. Using any source of energy has some environmental cost. It is the degree of impact on the environment that is crucial.

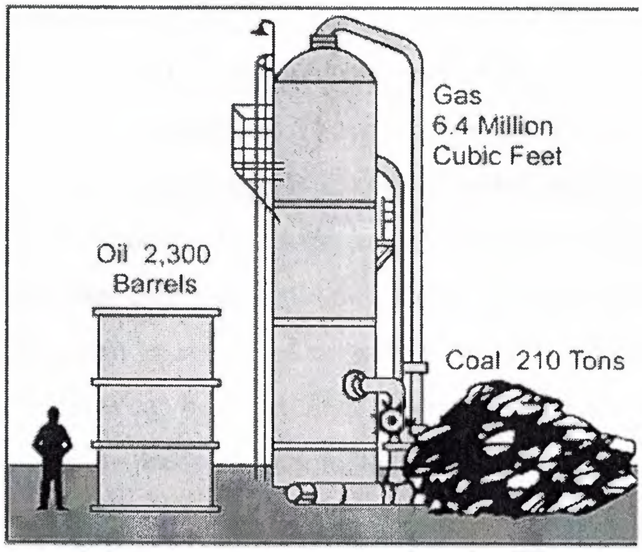

Figure 1.11. How much energy each of us uses in a lifetime

Some human activities have more profound and lasting impacts than others. Techniques to mine resources from below the earth may leave long-lasting scars on the landscape. Oil wells may detract from the beauty of open, grassy fields. Reservoirs behind dams may cover picturesque valleys. Once available, use of energy sources can further impact the air, land, and water in varying degrees.

People want clean air and water and a pleasing environment. We also want energy to heat and light our homes and run our machines. What is the solution? The situation seems straightforward: The demand for electrical power must be curbed or more power must be produced in environmentally acceptable ways. The solution, however, is not so simple. Conservation can save electricity, but at the same time our population is growing steadily. Growth is inevitable, and with it the increased demand for electric power. Since natural resources will continue to be used, the wisest solution is a careful, planned approach to their future use. All alternatives must be examined, and the most efficient, acceptable methods must be pursued. Hydroelectric facilities have many characteristics that favor developing new projects and upgrading existing power plants:

- Hydroelectric power plants do not use up limited nonrenewable resources to make electricity.
- They do not cause pollution of air, land, or water.
- They have low failure rates, low operating costs, and are reliable.
- They can provide startup power in the event of a system wide power failure.

As an added benefit, reservoirs have scenic and recreation value for campers, fishermen, and water sports enthusiasts. The water is a home for fish and wildlife as well. Dams add to domestic water supplies, control water quality, provide irrigation for agriculture, and avert flooding. Dams can actually improve downstream conditions by allowing mud and other debris to settle out. Existing power plants can be uprated or new power plants added at current dam sites without a significant effect on the environment. New facilities can be constructed with consideration of the environment. For instance, dams can be built at remote locations, power plants can be placed underground, and selective withdrawal systems can be used to control the water temperature released from the dam. Facilities can incorporate features that aid fish and wildlife, such as salmon runs or resting places for migratory birds.

In reconciling our natural and our built environments there will be tradeoffs and compromises. As we learn to live in harmony as part of the environment, we must seek the best alternatives among all ecologic, economic, technological, and social perspectives. The value of water must be considered by all energy planners. Some water is now dammed and can be put to work to make hydroelectric power. Other water is presently going to waste. The fuel burned to replace this wasted energy is gone forever and, so, is a loss to our Nation. The longer we delay the balanced development of our potential for hydropower, the more we unnecessarily use up other vital resources.

Owing to friction loses in the water conduits, turbine casing and the turbine itself, the mechanical power output of the turbine is somewhat less than that calculated by the above mentioned equation. However, the efficiency of large hydraulic turbines is between 90 and 94 percent. The generator efficiency is even higher, ranging from 97 to 99 percent, depending upon the size of generator.

1.13. Pumped Storage

Like peaking, pumped storage is a method of keeping water in reserve for peak period power demands. Pumped storage is water pumped to a storage pool above the power plant at a time when customer demand for energy is low, such as during the middle of the night. The water is then allowed to flow back through the turbine-generators at times when demand is high and a heavy load is place on the system. The reservoir acts much like a battery, storing power in the form of water when demands are low and producing maximum power during daily and seasonal peak periods. An advantage of pumped storage is that hydroelectric generating units are able to start up quickly and make rapid adjustments in output. They operate efficiently when used for one hour or several hours. Because pumped storage reservoirs are relatively small, construction costs are generally low compared with conventional hydropower facilities.

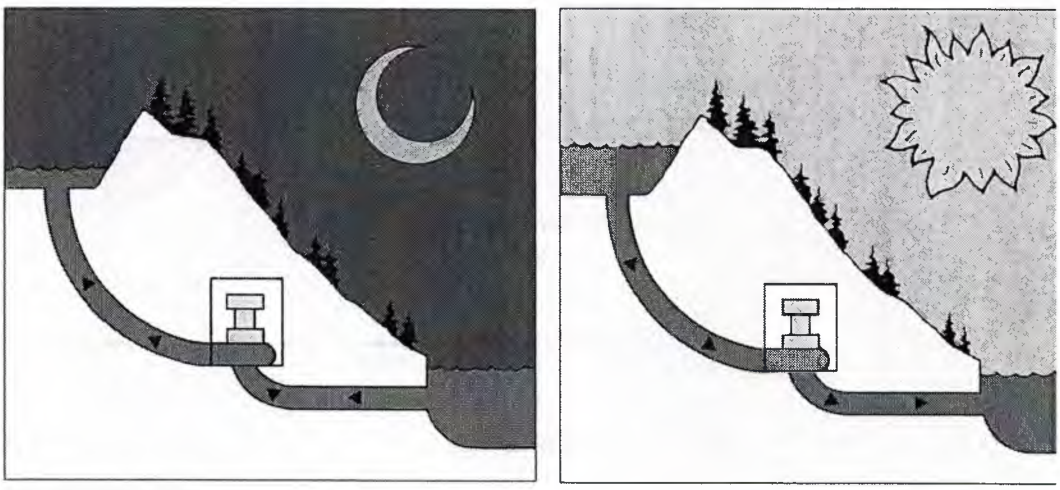

Figure 1.12 Left: at night customer demand for energy is low. Water is pumped to storage pool above dam.

Right: when demand is high and heavy load is placed on the system, water is allowed to flow back through the turbine generators.

We have already seen that the peak-power stations are needed to meet the variable system demand. To understand the different types of peaking system used, consider a network (electric system) in which the daily demand varies between 100 MW and 160 MW as shown in the figure. One obvious solution to this demand is to install a 100 MW base-power station and a peak-power unit of 60 MW, driven intermittently by a gas turbine.

However another solution is to install a larger base-power unit of 130 MW and a smaller peaking station of 30 MW. The peaking station must both be able to deliver and absorb 30 MW of electric power. During lightly loaded periods (indicated by a minus sign in the figure), the peaking stations receives and stores the energy provided by the base power generating plant. Then, during the periods of heavy demand (shown by a plus sign in the figure), the peaking stations returns the energy it had previously stored.

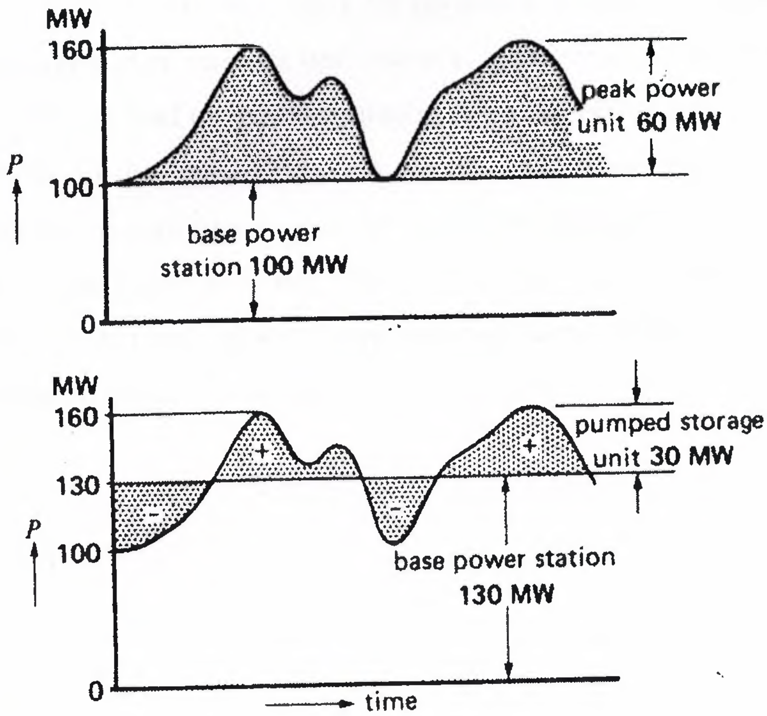

Figure 1.13. Above: a 100 MW base power station and a 60 MW peak power station can supply the networks demands.

Below: A 130 MW base power station and a 30 MW pumped storage unit can also supply the network demand.

This second solution has two advantages:

1. the base power station is larger and consequently more efficient
2. the peak power station is much smaller and less costly

Large blocks on energy can only be stored mechanically and that is why we often resort to a hydraulic pumped-storage station. Such a peak power generating station consists of an upper and lower reservoir connected to a penstock and an associated generating/pumping unit. During the system peaks, the station acts like an ordinary hydropower generating station, delivering water flows from upper to the lower reservoir. However, during the load periods the process is reversed. The generator then operates as a synchronous motor, driving the turbine as an enormous pump. Water now flows from lower to the upper reservoir, thereby storing energy in preparation for the next system peak.

The generating or pumping cycle is repeated once or twice per day, depending upon the nature of the system load. Peak power generators have ratings between 50 MW to 500 MW. They are reversible because the direction of rotation has to be changed when turbines operates as a pump. Starting such big synchronous motors puts a heavy load on the transmission line and special methods must be used to bring them up to the speed. Pony motors are often used, but static electronic frequency converters are also gaining ground. (A pony motor is a machine that brings a much larger machine to a speed). Pumped-storage installations operating in conjunction with nuclear plants make a very attractive combination because nuclear plants give the best efficiency when operating at a constant load.

2. CHAPTER TWO
THERMAL GENERATING STATIONS

The hydraulic resources of most modern countries are already fully developed. Consequently, we have to rely on thermal and nuclear stations to supply the growing need for electrical energy.

Thermal generating stations produced electrical energy from the heat released by the combustion of the coal, oil or natural gas. In thermal power stations, mechanical power is produced by a heat engine, which transforms thermal energy, often from combustion of a fuel, into rotational energy. Most thermal power plants produce steam, and these are sometimes called steam power plants. Not all thermal energy can be transformed to mechanical power, according to the second law of thermodynamics. Therefore, is found for the heat, it is lost to the environment. If reject heat is employed as useful heat, for industrial processes or district heating, the power plant is referred to as a cogeneration power plant or CHP (combined heat-and-power) plant. In countries where district heating is common, there are dedicated heat plants called heat-only boiler stations. An important class of power stations in the Middle East uses byproduct heat for desalination of water. Most stations have rating between 200 MW to 1500 MW so as to attain the high efficiency and economy of large station. Such a station has to be seen as to appreciate its enormous and complexity and size.

Thermal stations are usually located near a river or lake because large quantity of cooling water is needed to condense the steam as it exhausts from the turbines. The efficiency of thermal heat energy is always low because of inherent low efficiency of the turbines. The maximum efficiency of any machine that converts heat energy into mechanical energy is given by equation

$$\eta = (1 - T_2/T_1)\ 100 \quad \ldots\ldots (2.1)$$

Where

η = efficiency of the machine (%)

T_2 = Temperature of gas leaving the turbine (K)

T_1 = Temperature of gas entering the turbine (K)

In most thermal energy generating stations, the gas is steam. In order to obtain high efficiency, the quotient T_2/T_1 should be as small as possible. However, the temperature T_2 cannot be lower than the ambient temperature, which is usually about 20°C. As a result T_2 cannot be less than

$$T_2 = 20^\circ + 273^\circ = 293 \text{ K}$$

This means that to obtain high efficiency, T_1 should be as high as possible. The problem is that we cannot use temperature above those that the steel and other metals can safely withstand bearing in mind the high steam pressure. It turns out that the highest feasible temperature T_1 is 550oC.

$$T1 = 550^\circ + 273^\circ = 823 \text{ K}$$

It follows that the maximum possible efficiency of a turbine driven by steam that enters at 823 K and exists at 293 K is

$$\eta = (1 - 293/823)\ 100$$
$$= 64.4\ \%$$

Due to other losses, some of the most of the efficient steam turbines have efficiencies of 45%. This means that 65% of the thermal energy is lost during the thermal-to-mechanical conversion process. The enormous loss of heat and how to dispose of it represents one of the major aspects of thermal generating stations.

2.1. Make up of a thermal generating station

The basic structure and principal component of thermal generating stations are shown in the figure. They are itemized and described below.

- A huge boiler (1) acts as a furnace, transferring heat from burning fuel to row upon row of water tubes S1, which entirely surround the flames. Water is kept circulating thought the tubes by a pump P_1
- A drum (2) containing water and steam under high pressure produces the steam required by the turbines. It also receives the water delivered by the boiler feed pump P_3. Steam races towards the highest pressure turbine HP after having passed through super heater S_2. The super heater, composed of a series of turbines, surrounding the flames, raises the steam temperature about 200°C. This increase in temperature ensures that the steam is absolutely dry and raises the overall efficiency of the station.

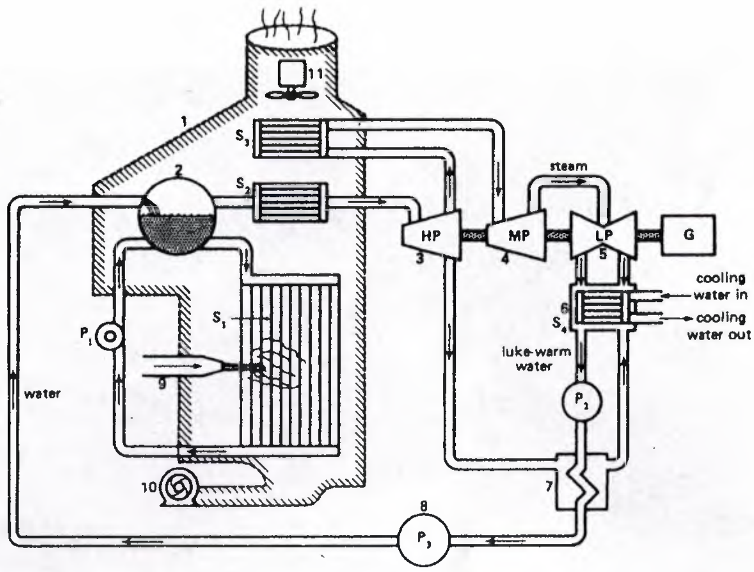

Figure 2.1. Principle components of thermal power plant

- A high pressure turbine HP (3) converts the thermal energy into mechanical energy by letting the steam expand as it moves through the turbine blades. The temperature and pressure at the output of the turbine are, therefore, less than at the input. In order to raise the thermal efficiency and to prevent premature condensation, the steam passes through a reheater S_3, composed of a third set of heated tubes.
- The medium pressure MP turbine (4) is similar to high pressure turbine, except that it is bigger so that the steam may expand still more.
- The low pressure LP turbine (5) is composed of two identical left-bands and right-band sections. The turbines sections remove remaining available energy from the steam. The steam flowing out of LP expands into an almost prefect vacuum created by the condenser (6).

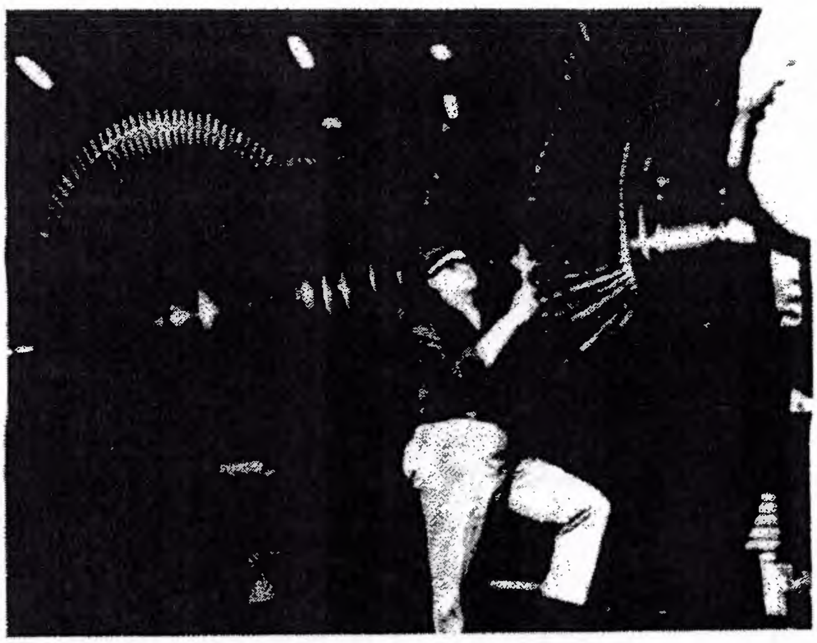

Figure 2.2 Low pressure section of a 375 MW, 3600 r/min steam-turbine generator set, showing the radial blades

- Condenser (6) causes the steam to condense by letting it flow over the cooling pipes S_4. Cold water from outside source, such as a rive or lake, flows through pipes. Thus carrying away the heat. It is the condensing steam that creates the vacuum.
- A condensate pump P_2 removes the lukewarm condensed steam and drives it through a reheater (7) towards a feed water pump (8).
- The reheater (7) is a heat exchanger. It receives hot steam, bled off from high pressure turbine, to raise the temperature of feedwater. Thermodynamics studies show that the overall thermal efficiency is improved when some steam is bled off this way, rather than letting it flow its normal course through all three turbines.
- The burners (9) simply supply and control the amount of gas, oil or coal injected into the boiler. Coal is pulverized before it is injected. Similarly, heavy bunker oil is preheated and is injected as an atomized jet to improve surface contact (and combustion) with surrounding air.
- A force draft fan (10) furnishes enormous quantities of air needed for combustion.
- An induced draft fan (11) carries the gases and other products of combustions towards cleansing apparatus and from there to the stack and the outside air.

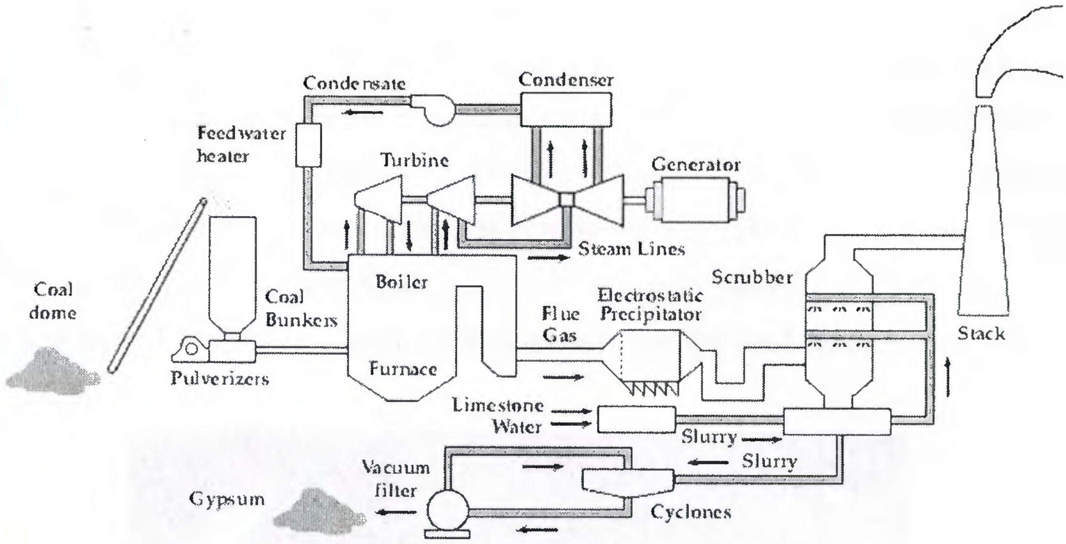

Figure 2.3. Figure presents a schematic of the thermal power generation process used at the belledune (Canada) thermal station, including the combustion process, steam and power cycle also with air pollution equipment

- Generator G, directly coupled to all three turbines, converts mechanical energy in electrical energy.

In practice, a steam engine has hundreds of other components and accessories to ensure high efficiency, safety and economy. For example, valves regulate the amount of steam flowing to the turbines, complex water purifiers maintains the required water cleanliness and chemical composition of the feed water; oil pumps keeps the bearing properly lubricated. However, the basic components we have just described enable us to understand the operation and some of the basic problems of a thermal station.

2.1.1. Turbines

The low, medium and high pressure turbines processes a number of blades mounted on the drive shaft. The steam is deflected by blades producing a powerful torque. The blades are made of up of steel to withstand the high temperature and high centrifugal forces. The HP, MP and LP turbines are coupled together to drive a common generator. However, in some large installations, one HP turbines drives one generator while the MP and LP turbine drives another one having the same rating.

2.1.2. Condenser

We have seen that one half of the energy produced in the boiler has to be removed from the steam when it exhausts into the condenser. Consequently, enormous quantities of cooling water are needed to carry away the heat. The temperature of cooling water typically increases by 5°C to 10°C as it flows through the condenser tube. The condensed steam (condensate) usually has a temperature between 27°C and 33°C and the corresponding absolute pressure is a near vacuum of about 5kPa. The cooling water temperature is only a few degrees below the condensate.

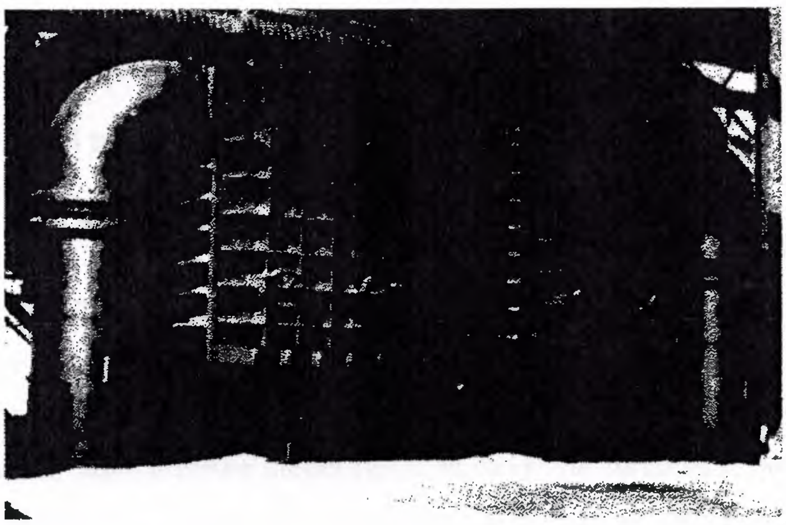

Figure 2.4 Condenser rated at 220 MW. Note the large pipes feeding cooling water into and out of the condenser. The condenser is as important as the boiler in thermal and nuclear power station.

2.1.3. Cooling Towers

If the thermal station is located in a dry region, or far away from a region or a lake, we still have to cool the condenser, one way or another. We often use evaporation to produce the cooling effect. To understand the principle, consider a lake that exposes a large surface to the surrounding air. A lake evaporates continually, even at low temperatures, and it is known that for every kilogram of water that evaporates, the lake loses 2.4 MJ of heat. Consequently, evaporation causes the lake to cool down.

Consider a tube now containing 100 kg of water at a certain temperature. If we can somehow cause 1 kg of water to evaporate, the temperature of the remaining 99 kg will inevitably drop by 8.5°C. Evaporation is therefore, very effective cooling process.

But how can we produce evaporation? All that needed to expose a expose a large surface of water to the surrounding air. The simplest way to do is to break up water into water and blow air through this artificial rain. In case of a thermal station, the warm cooling water flowing out of the condenser is piped to the top of the cooling tower where it is broken up into small droplets. As the droplets fall toward the open reservoir below, evaporation takes place and the droplets car chilled. The cool water is pumped from the reservoir and recirculated through the condenser where it again removes heat from the condensing steam. The cycle then repeats. Approximately 2 percent of the cooling water that flows through the condenser is lost by evaporation. This loss can be made up by a steam or small lake.

2.1.4. Boiler feed pump

The boiler feed pump drives the feedwater into the high pressure drum. The high back pressure together with the large volume of water flowing through the pump requires a very strong and powerful motor to drive it. In modern steam stations, the pumping power represents about 1 percent of the generator output. Although this appears to be a significant loss, we must remember that energy expanded in the pump is later recovered when high pressure steam flows through the turbines. Consequently, the energy supplied to the feed pump motor is not really lost except for the small portion consumed by the losses in the motor and in the pump.

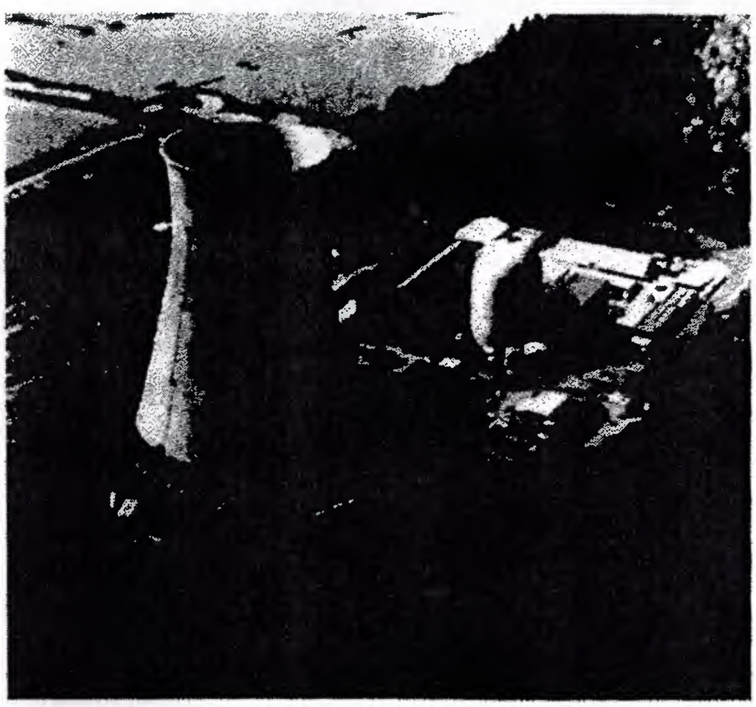

Figure 2.5 Cooling tower installed in a nuclear power station in Oregon. The generator output is 1280 MVA at a power factor of 0.88. Tower characteristics: height: 152m; diameter at the base: 117m; diameter at the top: 76m; cooling water: $27m^3/s$; water loss by evaporation: 0.7 m^3/s. the temperature of the cooling tower drops from 44.5° to 24° as it passes through the tower.

2.2. Energy flow diagram for a steam plant

Modern thermal energy generating stations are very similar through out the world because all the designers strive for high efficiency at low cost. This means that the materials are strained to the limit of the safety as far as temperature, pressure and centrifugal forces are concerned. Because the same materials are available to all, the resulting steam plants are necessarily similar. Figure below shows a typical 540 MW turbine generator set and the other figure shows the view of control room.

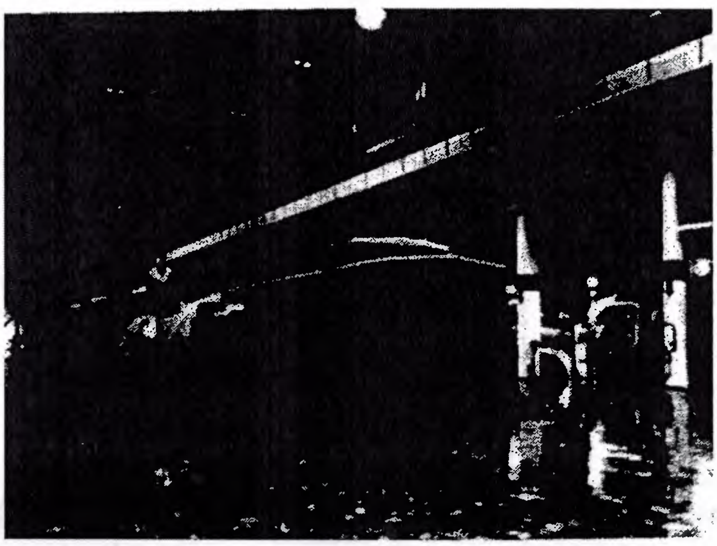

Figure 2.6 This 540 MW steam-turbine generator set runs at 3600r/min, generating a frequency of 60 Hz. The low pressure turbine and alternator are in the background.

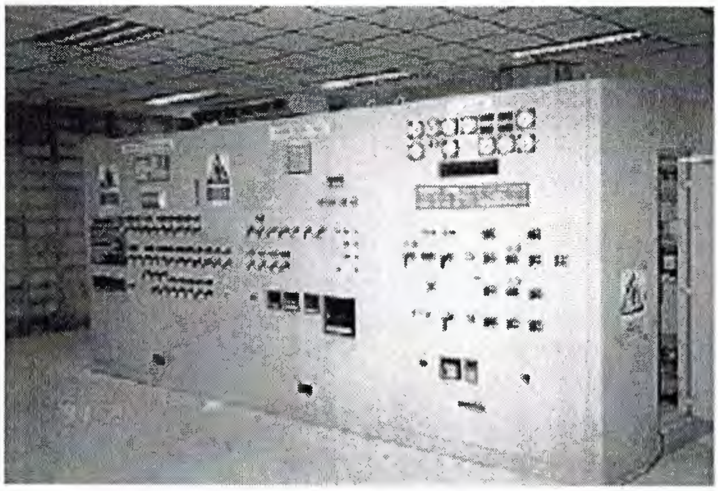

Figure 2.7 Power house of a thermal power station

Most modern boilers furnish steam at temperature of 550 degree centigrade and a pressure of 16.5 MPa. The overall efficiency (electrical output / thermal input) is then about 40%. The relative amounts of steam flows, energy, losses and so forth, do not change very much, provided the temperature and pressure have the approximate values indicated above. This enables us to draw a diagram showing the energy flow, the steam flow and so-on in reduced scale model of a typical thermal generators. Figure below shows such a model producing 12MW of electrical power.

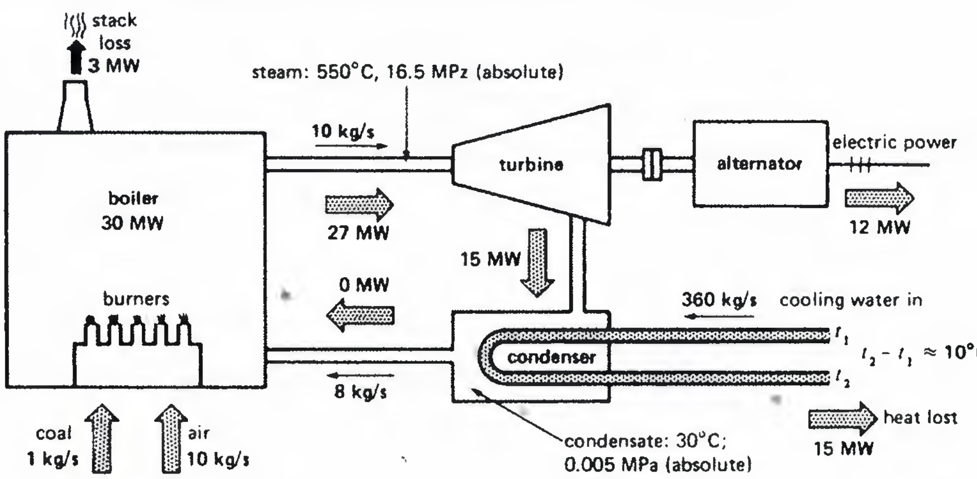

Figure 2.8 Scale model of a typical thermal generating station

Using this model, we can estimate the characteristics of any thermal power station. For example, a 480 MW power station (40 times more powerful than the model) has the following approximate characteristics:

Electric power output	40 × 12 MW	480 MW

Coal consumption	40 × 1 kg/s	40 kg/s
Air intake	40 × 10 kg/s	400 kg/s
Boiler thermal power	40 × 30 MW	1200 MW
Steam output	40 × 8 kg/s	320 kg/s
Cooling water	40 × 360 kg/s	14 400 kg/s
Heat carried away by the		
Cooling water	40 × 15 MW	600 MW

If large river or lake is not available and a cooling tower is required, it would have to evaporate

$$q = 2\ \% \times 14400 = 288\ \text{kg/s}$$

of cooling water. This loss of evaporation has to be made up by local source of water.

2.3. Thermal stations and the environment

The products of combustion of thermal generating station are increasing subject concern, due to their impact on the environment. Carbon dioxide, sulfur dioxide and water are the main products of combustion when oil, coal or gases are burned. Carbon dioxide and water produce no immediate environmental effects, but sulfur dioxide creates substances that give rise to acid rain. Dust and fly ash are other pollutants that may reach the atmosphere. Natural gas produces only water and carbon dioxide. This explains why gas is used rather than coal or oil, when atmospheric pollution must be reduced to minimum.

A good example of pollution control station is the large Eraring station located in Newcastle, Australia, about 100 km north of Sydney. It is equipped with a special fabric filter flue gas cleaning system. The fabric filters acts like huge vacuum cleaners to remove particles from boiler gas flue stream. The fabric filter for each boiler is composed of 48000 filter bas, each 5 m long and 16 cm in diameter. When a boiler operates at full capacity, they capture dust particle at the rate of 28 kg/s. a substantial portion of this material is later mixed with concrete for road building projects. The following technical specifications enable us to appreciate the size of this station.

Electric data

Number of generators: 4

Power per generator: 660 MW

Speed: 3000 r/min

Voltage: 23000 volts

Frequency: 50 Hz, phase 3

Thermal and mechanical data

Number of steam turbines: 4

Number of condensers: 4

Number of boilers: 4

Steam flow per turbine: 560 kg/s

Steam temperature: 540°C

Steam pressure: 16.55 MPa

Cooling water per condenser: 21000 kg/s

Coal consumption per boiler: 51.5 kg/s

Dust captured by the cleaning system: 28 kg/s

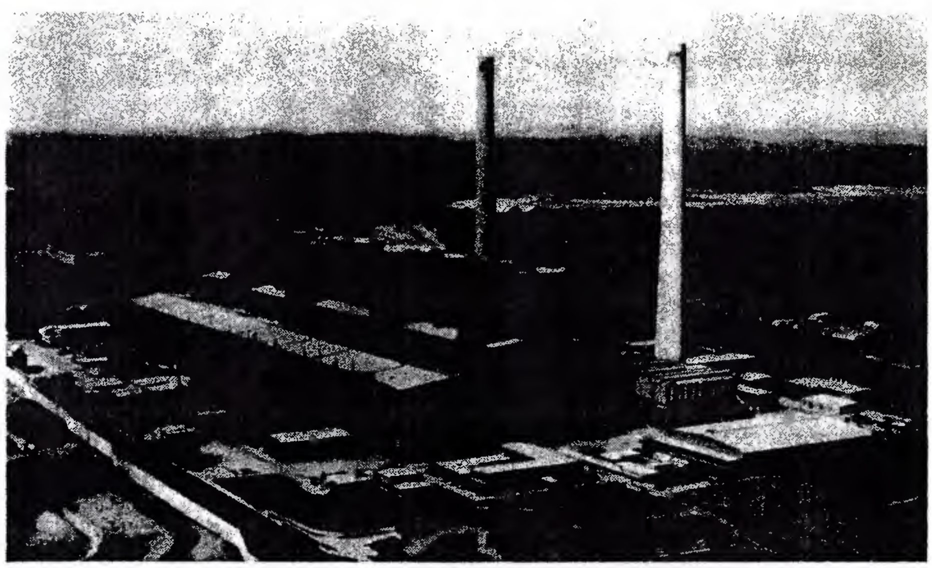

Figure 2.9 View of eraring power station in Newcastle, Australia. The large building on the left is the turbine generator hall: 27 m wide x 38 m high x 418 m long. To the right can be seen the four structures that hose the steam boilers. A portion of the flue gas cleaning system can be seen between the emission stack in the foreground and boiler structures.

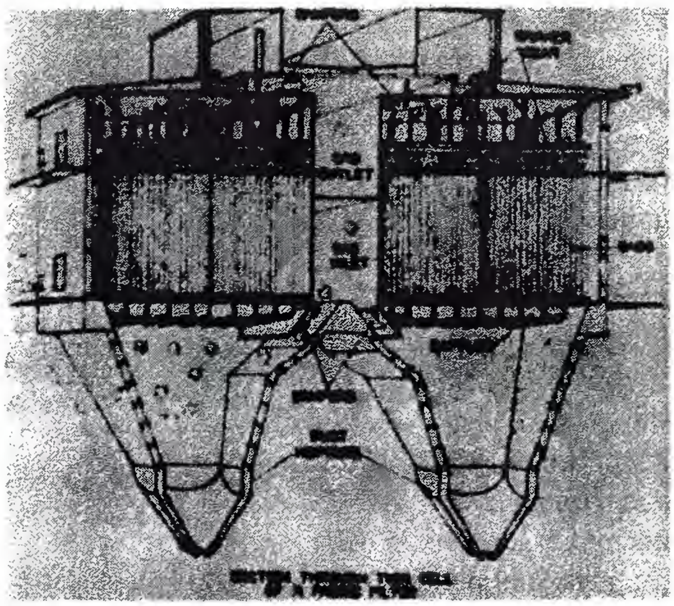

Figure 2.10 General construction of the flue gas cleaning system showing their filter bags that capture the dust, which the falls into the hoppers below.

Length of one turbine generator unit: 50 m

Weight of one turbine generator unit: 1342 tons

Number of emission stacks: 2

Height of emission stack: 200 m

Outside diameter at bottom: 20 m

Outside diameter at top: 11.6 m

Another interesting feature is that coal for the station is brought in by conveyor belts from two mines away that is only 1.5 km and 4.5 km away. Thus, the station is ideally location near its source of fuel and near its source of cooling water, on the shore of Lack Macquaire.

3. CHAPTER THREE

NUCLEAR GENERATING STATIONS

Nuclear generating stations produce electrical energy from the heat produced by the nuclear reaction. When the nucleus of an atom splits (a process called nuclear fission), considerable amount of energy is released. Note that a chemical reaction, such as combustion of coal, produces only a rearrangement of the atoms, without in any way affecting their nuclei.

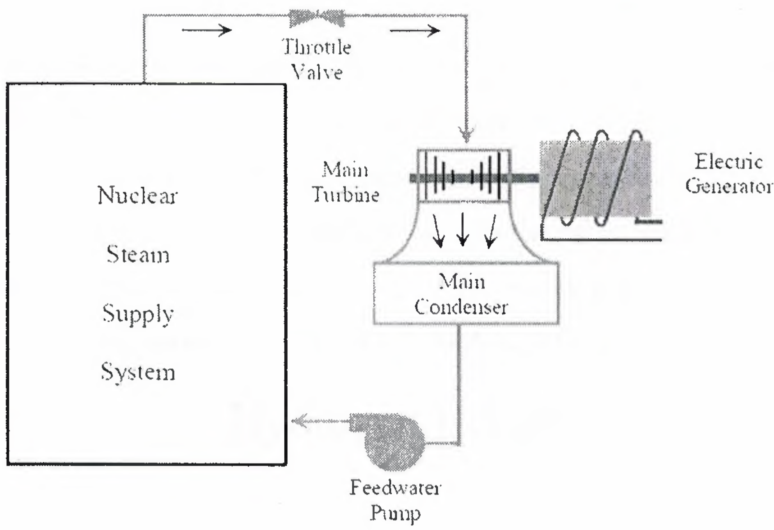

Figure 3.1 Nuclear fuel steam plant

A nuclear station is identical to a thermal station, except that the boiler is replaced by a nuclear reactor. The reactor contains fissile material that generates heat. A nuclear station, therefore, contains a synchronous generator, steam turbine, condenser and so on, similar to those found in conventional thermal station. The overall efficiency is also similar and a cooling system must be provided for. Consequently, nuclear station is also located close to rivers or lakes. In dry areas, cooling towers are installed. Owing to the similarities, we will only examine the operating principle of the reactor itself.

3.1. Composition on an atomic nucleus; isotopes

The nucleus of an atom contains of two parts – protons and neutrons. The protons carry a positive charge, equal to a negative charge on an electron. The neutron, as its name implies, has no electrical charge. Neutrons are, therefore, neither attracted nor repelled by protons or electrons.

Protons and neutrons have about the same mass and weigh about 1840 times as much as electron does. The mass on atom is concentrated in its nucleus.
The number of protons and neutrons in the nucleus depends upon the element. Furthermore, because an atom is electrically neutral, the number of electrons is equal to the number of protons. Table below gives atomic structure of a few elements used in the nuclear reactor. For example, there are two types of hydrogen atoms that can be distinguished from each other only by make up of their nucleus. First, there is ordinary hydrogen that contains only 1 proton and no neutrons.
Next, there is a rare form, deuterium, whose nuclei contain one neutron in addition to one usual proton. This is a rare form called the isotope of hydrogen.
When two atoms of ordinary hydrogen combine with one atom of hydrogen, we obtain ordinary water (H_2O) called light water. On the other hand, if 2 atoms of deuterium unite with 1 atom of oxygen, we obtain heavy water D_2O. The oceans contain about 1 kg of heavy water for every 7000 kg of sea water.

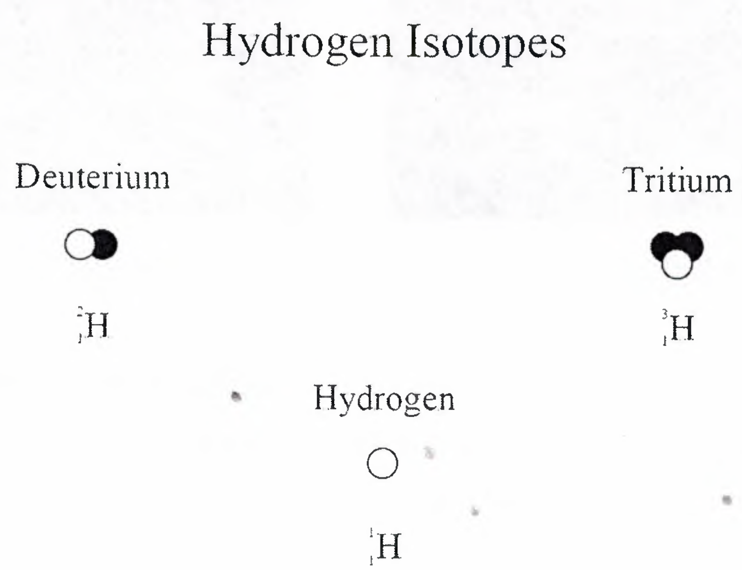

Figure 3.2 hydrogen isotopes

Table 3.1 atomic structure of elements

ATOMIC STRUCTURE OF SOME ELEMENTS

Element	Symbol	Protons	Electrons	Neutrons	Mass number (neutrons + protons)
hydrogen	H	1	1	0	1
deuterium	D	1	1	1	2
tritium	^3H	1	1	2	3
helium	He	2	2	2	4
carbon	C	6	6	6	12
iron	Fe	26	26	30	56
uranium 235	^{235}U	92	92	143	235
uranium 238	^{238}U	92	92	146	238

In the same way, two isotopes of uranium are found in nature: uranium 238 (^{238}U) and uranium 235 (^{235}U). Each contains 92 protons but ^{238}U has 146 neutrons and ^{235}U has 143 neutrons. Uranium 238 is very common but uranium 235 is very rare.

Uranium 235 and heavy water deserve our attention because both are essential to the operation of nuclear reactors we are about to discuss.

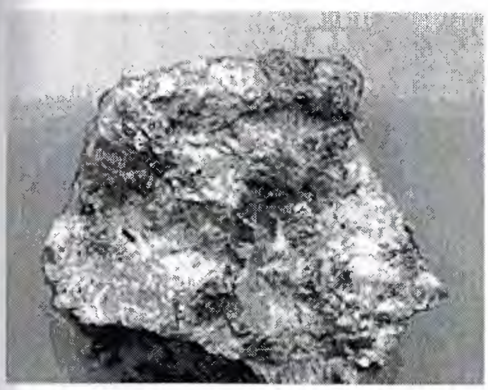

Figure 3.3 Uranium ore (0.7%) Fuel Pellet (3.5%)

3.2. The sources of uranium

Where does uranium come from? It is obtained from uranium ore found in uranium mines. This ore contains the compound U_3O_8 (3 atoms uranium and 8 atoms of oxygen). It so happens that U_3O_8 is actually composed of $^{238}UO_8$ and $^{235}UO_8$ in a relatively precise ratio of 1398:10.

In other words, the ore contains 1398 parts of less interesting ^{238}U for every ten parts of isotope of ^{235}U. It is very difficult to $^{238}UO_8$ and $^{235}UO_8$ because they possess same chemical properties.

In order to use these substances in nuclear reactors, they are processed into uranium dioxide. The natural UO_2 again contains $^{238}UO_2$ and $^{235}UO_2$ in the ratio 1398:10.Some nuclear reactor requires UO_2 that has more of the ^{235}U than natural

UO_2 does. This is produced by an enrichment process whereby the ratio of $^{235}UO_2$ to $^{238}UO_2$ is raised to 50:1398. In this enrichment process, a lot of $^{238}UO_2$ is obtained as a by product that must be stored. As we shall see this by product also has useful application.

The process of converting uranium ore into these uranium derivatives is shown in highly specified form.

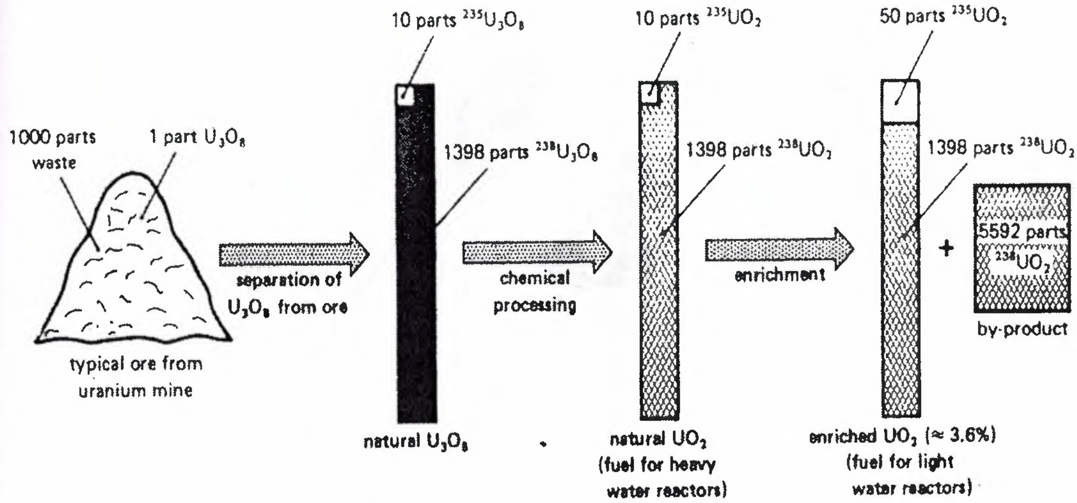

Figure 3.4 Various steps in the manufacture of the nuclear fuel for heavy water and light water reactors. This extremely simplified diagram shows that in the process of enrichment of uranium dioxide, it is inevitable that large amounts of $^{238}UO_2$ remain as a byproduct.

3.3. Energy released by atomic fission

When the nucleus of an atom fissions, it splits into two. The total mass of the two atoms formed in this way is usually less than that of the original atom. If there is a loss in mass; energy is released according to Einstein's equation:

$$E = m c^2 \; ..... (3.1)$$

Where

E = energy released [J]

m = loss of energy [kg]

c = speed of light [3×10^8 m/s]

an enormous amount is energy because, according to this formula, a loss in mass of only one gram produces 9×10^{13} J, which is equivalent to the heat given off by burning 3 thousands tons of coal. Uranium is one of those elements that losses mass when it fissions. However, uranium 235 is fissionable, whereas uranium 238 is not, and so large separating plants have been built to isolate molecules containing ^{235}U from those containing ^{238}U.

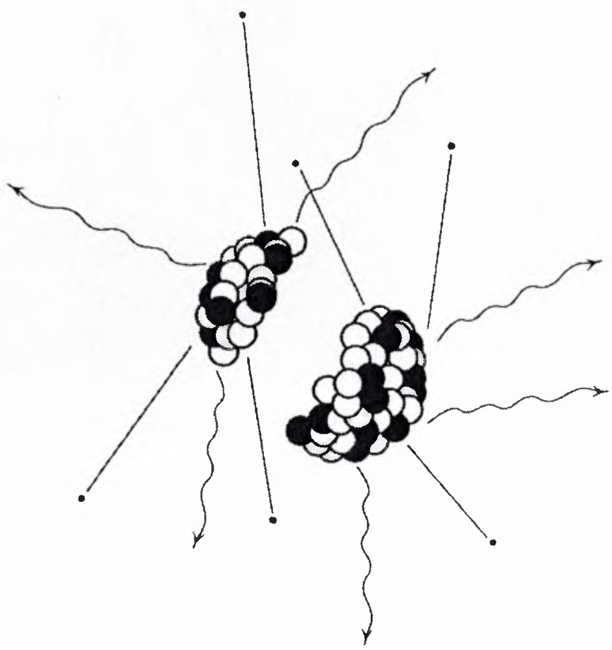

Figure 3.5 Fission product decay

3.4. Chain reaction

How can we provoke this fission of a uranium atom? One way is to bombard its nucleus with neutrons. A neutron makes an excellent projectile because it is not repelled as it approaches the nucleus and if its speed is not too great, it has a good chance of scoring a hit. If the impact is strong enough, the nucleus will split into 2 releasing energy. The fission of one atom of ^{235}U releases 218 MeV of energy, mainly in form of heat. Fission is very violent reaction on an atomic scale, and it produces a second important effect: it ejects 2 or 3 neutrons that move at high speed away from the broken nucleus. These neutrons collide with other uranium atoms, breaking them up, and a chain reaction quickly takes place, releasing a tremendous amount of heat. This is the principle that causes atomic bombs to explode. Although uranium mine also releases neutrons, the concentration of ^{235}U atoms is too low to produce a chain reaction.

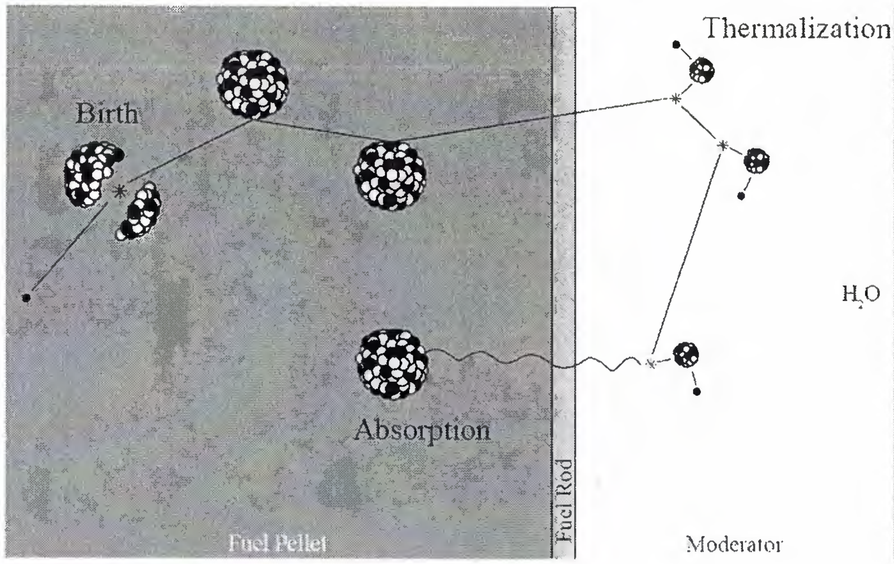

Figure 3.6 Absorption and thermalization process

In the case of nuclear reactor, we have to slow down the neutrons to increase their chance of striking other uranium nuclei. Towards this end, small fissionable masses of uranium fuel are immersed in a moderator. The moderator may be ordinary water, heavy water, graphite or any other material that can slow down neutrons without absorbing them. By using an appropriate geometrical distribution of the uranium fuel within the moderator, the speed of the neutrons can be reduced so they have the required velocity to initiate other fissions. Only then will a chain reaction that place, causing the reactor to go critical.

As soon as the chain reaction starts, the temperature rises rapidly. To keep it at an acceptable level, a liquid or a gas to flow rapidly through the reactor to carry away the heat. This coolant may be heavy water, ordinary water, liquid sodium or a gas like helium or carbon dioxide. The hot coolant moves in a closed circuit which includes a heat exchanger. The latter transfers the heat to a steam generator that drives the turbines. Thus, contrary to its name would lead us to believe the coolant is not cool but searingly hot.

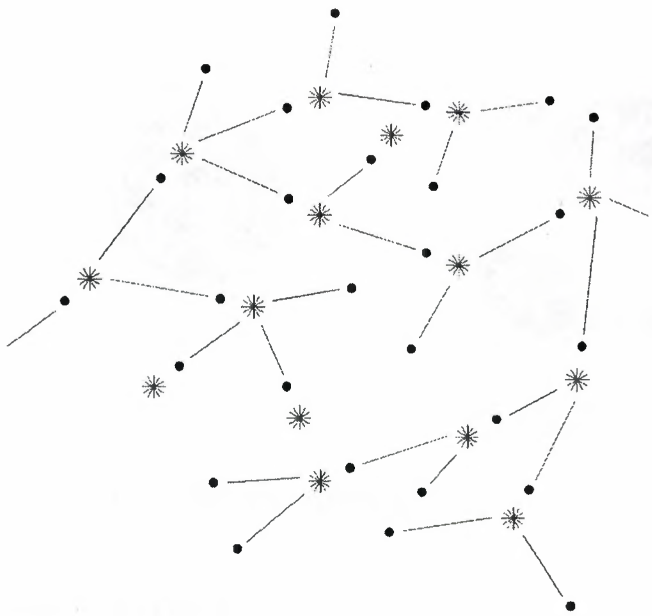

Figure 3.7 Fission Chain Reaction

3.5. Nuclear Fusion

We have seen that splitting the nucleus of a heavy element such as uranium results in a decrease in mass and a release of energy. We can also produce energy by combining the nuclei of two light elements in a process called nuclear fusion. For example, energy is released by the fusion of an atom of the deuterium with an atom of tritium. However, owing to the strong repulsive between the two nuclei, they only unite (fuse) when they approach each other at high speed. The required velocity is close to the speed of light and corresponds to a thermodynamic temperature of several million degrees. If both the atomic concentration and speed are high enough, a self-sustaining chain reaction will result.

We can, therefore, produce heat by the fusion of the two elements, and the hydrogen bomb is good example of this principle. Unfortunately, we run into almost insurmountable problems when we try to control the fusion reaction, as we must do in a nuclear reactor. Basically, scientists have not yet succeeded in confining the controlling high speed particles with out at the same time slowing them down.

A major worldwide research effort is being devoted to solve this problem. If scientists succeed in domesticating nuclear fusion, it could mean end to energy shortage because hydrogen is the most common element on earth.

Figure 3.8 Absorption and Fusion

3.6. Types of nuclear reactors

There are several types of reactors but following are the most important

3.6.1. Pressure water reactor (PWR)

Water is a coolant and it is kept under such high pressure that it cannot be boil off into steam. Ordinarily water, as in light-water reactors may be used or heavy water.

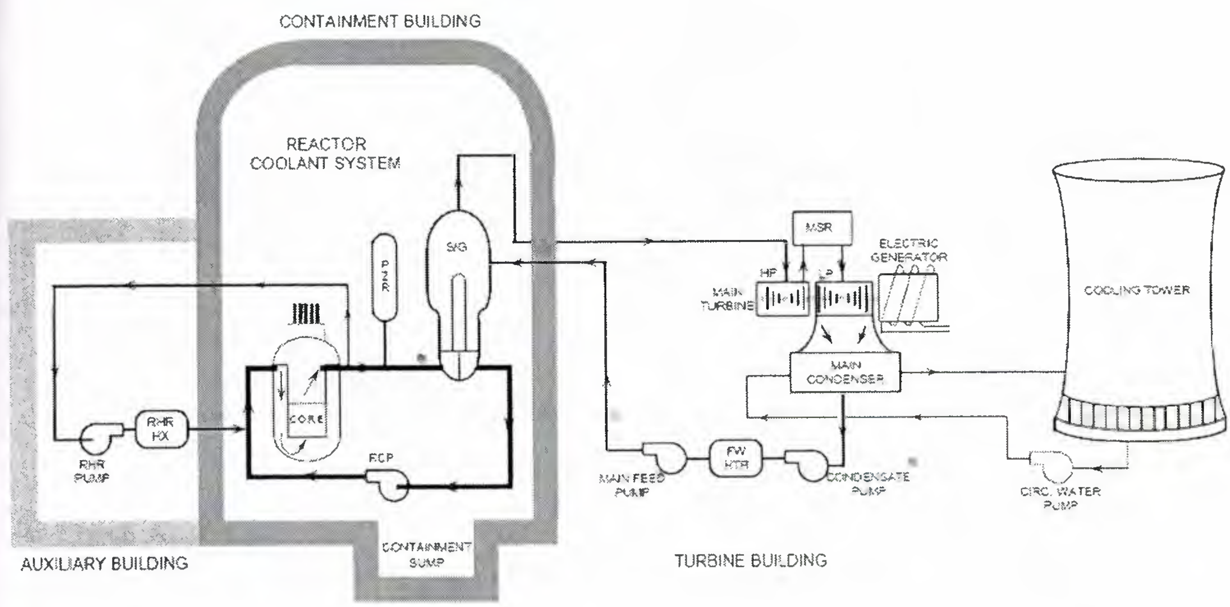

Figure 3.9

There are two major system utilized to convert the generated in the fuel into electrical power for industrial and residential use. The primary system transfers the heat from fuel to the steam generator, where the secondary system begins. The steam formed in the steam generator is transferred by the secondary system to the main turbine generator where it is converted into electricity. After passing through the low pressure turbine, the steam is routed to the main condenser. Cool water, flowing through the tubes in the condenser removes excess heat from the steam, which allows the steam to condense. The water is then pumped back to the steam generator for re use. In order for the primary and secondary systems to perform their functions, there are approximately one hundred support systems. In addition, for emergencies, there is dedicated system to mitigate the consequences of accidents.

3.6.2. Boiling water reactor (BWR)

The coolant in this reactor is ordinary water boiling under high pressure and releasing steam. This eliminates the need for a heat exchanger, because the steam circulates directly through turbines. However, as in all light water reactors, enriched uranium dioxide must be containing about 3 percent ^{235}U.

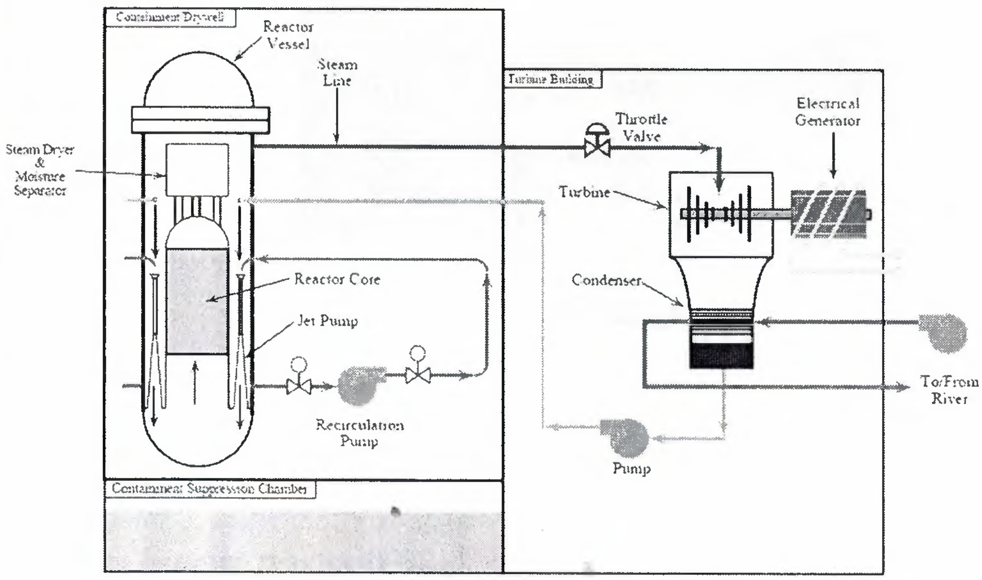

Figure 3.10 Boiling water reactor plant

Inside the boiling water (BWR) vessel, a steam water mixture is produced when very pure water (reactor coolant) moves upward through the core absorbing heat. The major difference in the operation of the BWR from other nuclear system is that steam void formation in the core. The steam-water mixture leaves the top of the core and enters the two stages of moisture separation, where water droplets are removed before the steam in allowed to enter the steam line. The steam line, in turn, directs the steam to the main turbine causing it to turn the turbine and attached electric generator. The unused steam is exhausted to the condenser where it's condensed into water. The resulting water is pumped out of the condenser with a series of pumps and back to the reactor vessel. The circulation pump and the jet pumps allow the operator to vary the coolant flow through the core and change the reactor power.

3.6.3. High temperature gas reactor

This reactor uses an inert gas as coolant such as helium or carbon dioxide. Due to high operating temperature (typically 750°C), graphite is used as a moderator. The steam created by the heat exchanger is as hot as that produced in a conventional coal-fired steam boiler. Consequently, the overall efficiency of HTGR station is about 40 percent.

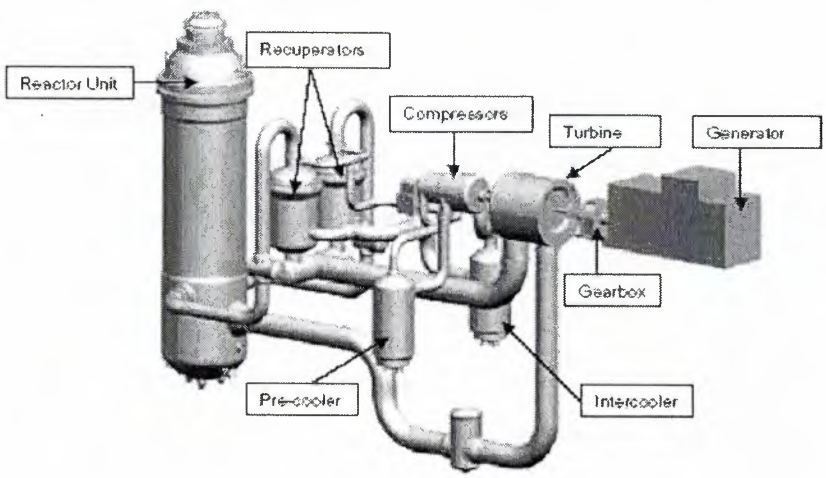

Figure 3.11 high temperature gas reactor

3.6.4. Fast breeder reactor (FBR)

This reactor has the remarkable ability to both generate heat and create additional nuclear fuel.

A fast breeder reactor differs from the other reactors because it can extract more of the variable energy in the nuclear fuel. It possesses a central core containing fissionable plutonium 239. The core is surrounded by a blanket composed of substances containing non fissionable uranium 238. No moderator is used; consequently the high speed neutrons generated by the fissioning ^{239}Pu bombard the non fissionable atoms of ^{238}U. This nuclear reaction produces two important results;

a. the heat released by the fissioning core can be used to drive a steam turbine.

b. some atoms of ^{238}U in the surrounding blanket capture the flying neutron, thereby becoming fissionable of ^{239}Pu. In other words, the passive atoms of uranium 238 are transmitted into fissionable atoms of plutonium 239.

As time goes by, the blanket of non fissionable U-238 is gradually transmitted to fissionable Pu-239 and waste product. The blanket is periodically removed and the materials are processed to recover the substance containing ^{239}Pu. The nuclear fuel recovered is placed in the central core to generate the heat and to produce still more fuel in a newly relined blanket of substances containing uranium 238. This process can be repeated until nearly 80 percent of the available energy in the uranium is extracted. This is much more efficient than the 2 percent extracted by conventional reactors.

The breeder reactor is particularly well adapted to complement existing light-weigh reactors. The reason is that great deal of ^{238}U is available as a by product in the manufacture of enriched ^{235}U. This otherwise useless material could be used to surround the core of the fast breeder reactor. By capturing fast neutrons, it could be rejuvenated, as explained above, until most of the potential energy is the uranium is used up.

3.6.5. Example of a Light-Water Reactor

Reactors that use light water as a moderator are similar to those using heavy water, but the uranium-dioxide fuel has to be enriched. Enrichment means that the fuel bundles contain between 2 and 4 percent of ^{235}U, the remainder being ^{238}U. This enable us to reduce the size of the reactor for a given power output. On the other hand, the reactor has to be shut down once a year to replace the expended fuel.

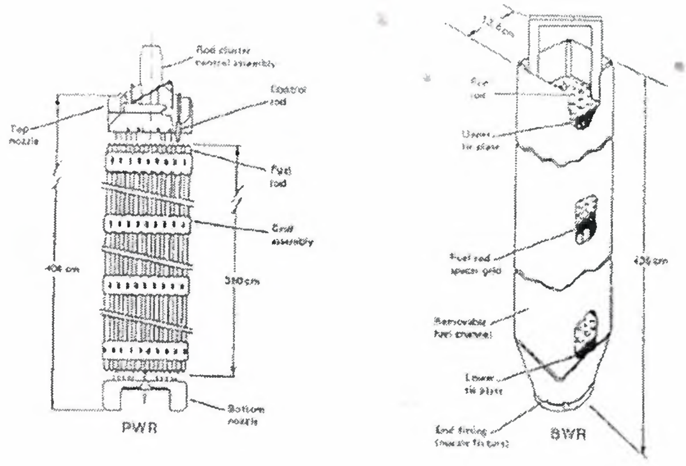

Figure 3.12 Typical light water reactor fuel assembly

The generated heat, created mainly by the fission of uranium 235, is carried away by the fission or uranium 235 is carried away by a coolant such as ordinary water, liquid sodium, gas or carbon dioxide. As it flows through the heat exchanger, the coolant creates the steam that drives the turbines.

A typical nuclear power station possesses a light-water reactor that is composed of massive vertical steel tank having an external diameter of 4.5 m and height of 12.5. The tank contains 157 vertical tubes, which can lodge 157 large fuel assemblies. Each assembly is 3 m long and groups 204 fuel rods containing a total of 477 kg of enriched UO_2. The nuclear reaction is kept under control by 45 special-alloy control rods. When these rods are generally lowered into the moderator, they absorb more and more neutrons. Consequently, they control the rate of nuclear reaction and, hence the amount of heat released by the reactor.

3.6.6. Example of heavy-water reactor

The candu reactor uses heavy water, both as moderator or coolant. It differs from all the other reactors in that it uses natural uranium dioxide as a fuel. One of the biggest installations of its kind is located at Pickering, a few kilometers east of Toronto, Canada. The nuclear station has 4 reactors. Each reactor is coupled to 12 heat exchangers that provide the interface between the heavy water coolant and the ordinary steam that drives the turbines.

Each reactor is enclosed in a large horizontal vessel (calandria) having a diameter of 8 m and a length of 8.25 m. the calandria possesses 390 horizontal tubes, each 12 fuel bundles containing 22.2 kg of UO_2.

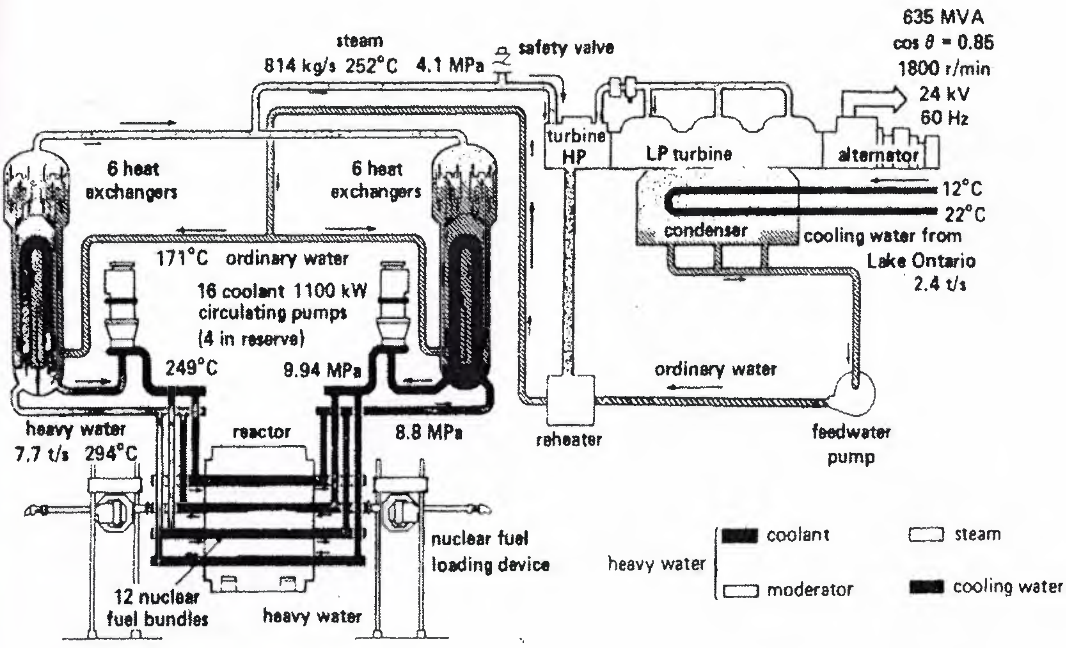

Figure 3.13 Simplified schematic diagram of candu nuclear generating unit composed of one heavy-reactor driving one alternator.

Each bundle releases about 372.5 kW while it is in operation. Because there is a total of 4680 bundles, the reactor develops 1740 MW of thermal power.

Twelve pumps, each driven by 110 kW motor, push the heavy water coolant through the reactor and the heat exchangers in the closed loop.

The heat exchangers produce the steam to drive the four turbines. The steam exhausts into a condenser that is cooled by the water drawn from Lake Ontario.

Each turbine drives a 3-phase 635 MVA 85 percent power factor, 24 kV, 1800 r/min, 60Hz alternator,The fuel bundles are inserted at one end of the Calandria and, after a 19-month stay in the tubes, they are withdrawn from other end. The bundles are inserted and removed on a continuous basis - an average of nine bundles per day.

Table below compares the typical characteristics of light-water and heavy water reactors.

Table 3.2 Typical characteristics of light-water and heavy-water reactor

	Light-Water Reactor	Heavy-Water Reactor
Reactor Vessel		
external diameter	4.5 m	8 m
length	12.5 m	8.25 m
vessel thickness	274 mm	25.4 mm
weight empty	416 t	604 t
position	vertical	horizontal
number of fuel canals	157	390
type of fuel	enriched UO_2 (3.3%)	natural UO_2
total mass of fuel	75 t	104 t
Moderator		
type	light-water	heavy-water
volume	13.3 m^3	242 m^3
Reactor Cooling		
heat produced in reactor	1825 MW	1661 MW
coolant	light-water	heavy-water
volume	249 m^3	130 m^3
flow rate	128 t/s	7.73 t/s
coolant temperature entering the reactor	285°C	249°C
coolant temperature leaving the reactor	306°C	294°C
coolant pumps	4	12
total pump power	12 MW	14 MW
Electrical Output		
3-phase, 1800 r/min, 60 Hz synchronous generator	600 MW	540 MW

4. CHAPTER FOUR

ALTERNATE SOURCES OF POWER GENERATION

4.1. Energy From Wind

Wind is simple air in motion. It is caused by the uneven heating of the earth's surface by the sun. Since the earth's surface is made of very different types of land and water, it absorbs the sun's heat at different rates. During the day, the air above the land heats up more quickly than the air over water. The warm air over the land expands and rises, and the heavier, cooler air rushes in to take its place, creating winds. At night, the winds are reversed because the air cools more rapidly over land than over water. In the same way, the large atmospheric winds that circle the earth are created because the land near the earth's equator is heated more by the sun than the land near the North and South Poles. Today, wind energy is mainly used to generate electricity. Wind is called a renewable energy source because the wind will blow as long as the sun shines.

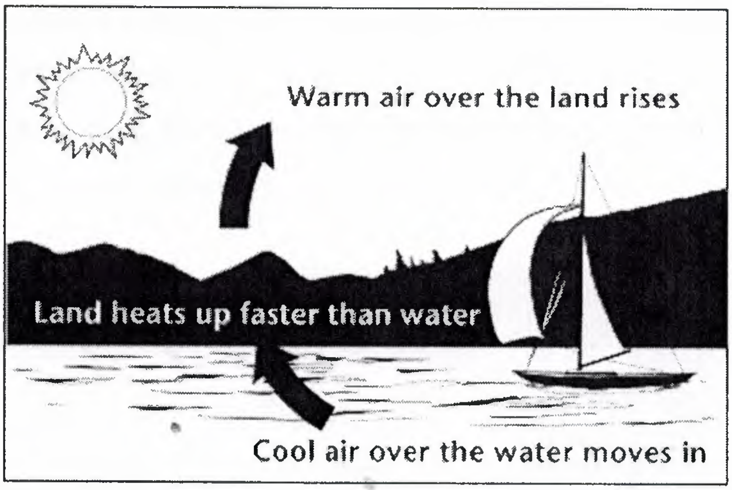

Figure 4.1. Air cycle

4.2. The History of Wind

Since ancient times, people have harnessed the winds energy. Over 5,000 years ago, the ancient Egyptians used wind to sail ships on the Nile River. Later, people built windmills to grind wheat and other grains. The earliest known windmills were in Persia (Iran). These early windmills looked like large paddle wheels. Centuries later, the people of Holland improved the basic design of the windmill. They gave it propeller-type blades, still made with sails. Holland is famous for its windmills. American colonists used windmills to grind wheat and corn, to pump water, and to cut wood at sawmills. As late as the 1920s, Americans used small windmills to generate electricity in rural areas without electric service. When power lines began to transport electricity to rural areas in the 1930s, local windmills were used less and less, though they can still be seen on some Western ranches. The oil shortages of the 1970s changed the energy picture for the country and the world. It created an interest in alternative energy sources, paving the way for the re-entry of the windmill to generate electricity. In the early 1980s wind energy really took off in California, partly because of state policies that encouraged renewable energy sources. Support for wind development has since spread to other states, but California still produces more than twice as much wind energy as any other state.

4.3. How Machines Work

Like old fashioned windmills, today's wind machines use blades to collect the wind's kinetic energy. Windmills work because they slow down the speed of the wind. The wind flows over the airfoil shaped blades causing lift, like the effect on airplane wings, causing them to turn. The blades are connected to a drive shaft that turns an electric generator to produce electricity.

Figure 4.2. Wind machines

When it comes to size, bigger is better – the bigger the wind turbine, the more wind it reaches and the more electricity it produces. With the new wind machines, there is still the problem of what to do when the wind isn't blowing. At those times, other types of power plants must be used to make electricity.

4.4. Types of Wind Machines

There are two types of wind machines used today: horizontal–axis wind machines and vertical-axis wind machines. Most windmills are the horizontal-axis type. One wind machine can produce 1.5 to 4.0 million kilowatt-hours (kWh) of electricity a year. That is enough electricity for to power 150-400 homes.

4.4.1. Horizontal-Axis

Horizontal-axis wind machines have blades like airplane propellers. A typical horizontal wind machine stands as tall as a 20-story building and has three blades that span 200 feet across. The largest wind machines in the world have blades longer than a football field! Wind machines stand tall and wide to capture more wind.

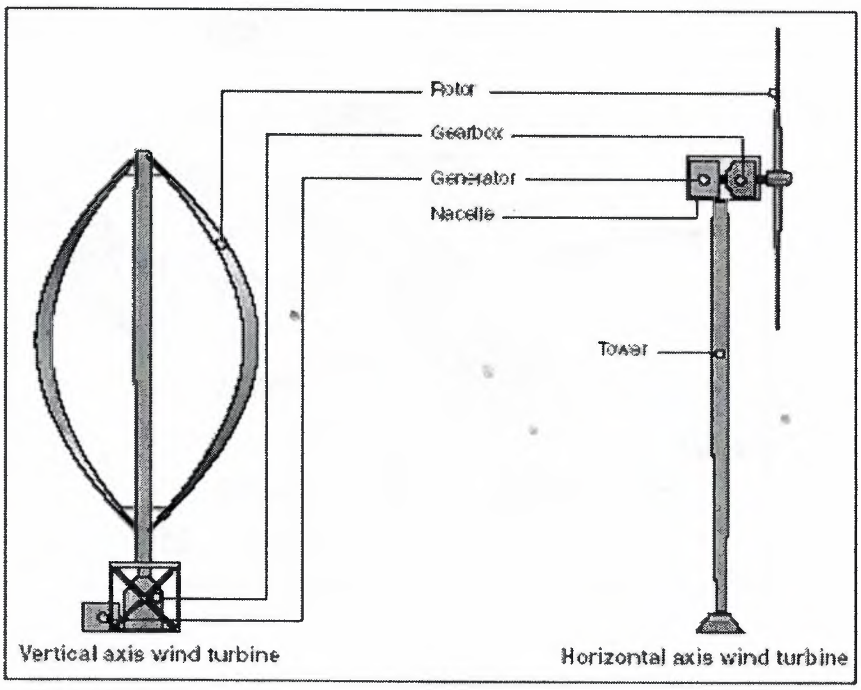

Figure 4.3 horizontal and vertical axis wind turbines

4.4.2. Vertical-axis

Vertical–axis winds machines have blades that go from top to bottom and look like giant egg beaters. The typical vertical wind machine stands 100 feet tall and 50 feet wide. Vertical-axis wind machines make up just five percent of the wind machines used today. The Wind Amplified Rotor Platform (WARP) is a different kind of wind system that is designed to be more efficient and use less land than wind machines in use today. The WARP does not use large blades; instead, it looks like a stack of wheel rims. Each module has a pair of small, high capacity turbines mounted to both of its concave wind amplifier module channel surfaces. The concave surfaces channel wind toward the turbines, amplifying wind speeds by 50 percent or more. Eneco, the company that designed WARP, plans to market the technology to power offshore oil platforms and wireless telecommunications systems.

4.5. How do wind turbines make electricity?

Simply stated, a wind turbine works the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity.

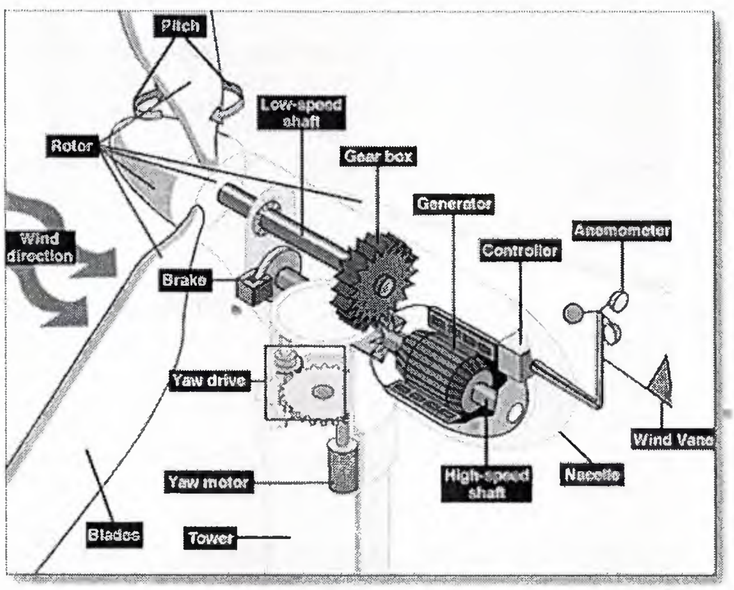

Figure 4.4 Look at the Wind Turbine Close Up

The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity. Utility-scale turbines range in size from 50 to 750 kilowatts. Single small turbines, below 50 kilowatts, are used for homes, telecommunications dishes, or water pumping.

4.6. Wind Turbine Glossary

Anemometer: Measures the wind speed and transmits wind speed data to the controller.

Blades: Most turbines have either two or three blades. Wind blowing over the blades causes the blades to "lift" and rotate.

Brake: A disc brake which can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies.

Controller: The controller starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 65 mph. Turbines cannot operate at wind speeds above about 65 mph because their generators could overheat.

Gear box: Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1200 to 1500 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.

Generator: Usually an off-the-shelf induction generator that produces 60-cycle AC electricity.

High-speed shaft: Drives the generator.

Low-speed shaft: The rotor turns the low-speed shaft at about 30 to 60 rotations per minute.

Nacelle: The rotor attaches to the nacelle, which sits atop the tower and includes the gear box, low- and high-speed shafts, generator, controller, and brake. A cover protects the components inside the nacelle. Some nacelles are large enough for a technician to stand inside while working.

Pitch: Blades are turned, or pitched, out of the wind to keep the rotor from turning in winds that are too high or too low to produce electricity.

Rotor: The blades and the hub together are called the rotor.

Tower: Towers are made from tubular steel (shown here) or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.

Wind direction: This is an "upwind" turbine, so-called because it operates facing into the wind. Other turbines are designed to run "downwind", facing away from the wind.

Wind vane: Measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.

Yaw drive: Upwind turbines face into the wind; the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive; the wind blows the rotor downwind.

Yaw motor: Powers the yaw drive.

4.7. Wind power plants

Wind power plants, or wind farms as they are sometimes called, are clusters of wind machines used to produce electricity. A wind farm usually has dozens of wind machines scattered over a large area. The Big Spring Wind Power Project in Texas has 46 wind turbines that generate enough electricity to power 7,300 homes. Unlike power plants, many wind plants are not owned by public utility companies. Instead they are owned and operated by business people who sell the electricity produced on the wind farm to electric utilities. These private companies are known as Independent Power Producers. Operating a wind power plant is not as simple as just building a windmill in a windy place. Wind plant owners must carefully plan where to locate their machines. One important thing to consider is how fast and how much the wind blows. As a rule, wind speed increases with altitude and over open areas with no windbreaks. Good sites for wind plants are the tops of smooth, rounded hills, open plains or shorelines, and mountain gaps that produce wind funneling.

Wind speed varies throughout the country. It also varies from season to season. In Tehachapi, California, the wind blows more from April through October than it does in the winter. This is because of the extreme heating of the Mojave Desert during the summer months. The hot air over the desert rises, and the cooler, denser air above the Pacific Ocean rushes through the Tehachapi mountain pass to take its place. In a state like Montana, on the other hand, the wind blows more during the winter. Fortunately, these seasonal variations are a good match for the electricity demands of the regions. In California, people use more electricity during the summer for air conditioners. In Montana, people use more electricity during the winter months for heating.

4.8. Wind production

All together, wind machines in the United States generate 17 billion kWh per year of electricity, enough to serve 1.6 million households. This is enough electricity to power a city the size of Chicago, but it is only a small fraction of the nation's total electricity production, about 0.4 percent. The amount of electricity generated from wind has been growing fast in recent years, tripling since 1998. New technologies have decreased the cost of producing electricity from wind, and growth in wind power has been encouraged by tax breaks for renewable energy and green pricing programs. Many utilities around the country offer green pricing options that allow customers the choice to pay more for electricity that comes from renewable sources. Wind machines generate electricity in 30 different states. The states with the most wind production are California, Texas, Minnesota, Iowa, and Wyoming.

The United States ranks third in the world in wind power capacity, behind Germany and Spain. Most of the wind power plants in the world are located in Europe and in the United States where government programs have helped support wind power development.

4.9. Wind and the environment

In the 1970s, oil shortages pushed the development of alternative energy sources. In the 1990s, the push came from a renewed concern for the environment in response to scientific studies indicating potential changes to the global climate if the use of fossil fuels continues to increase. Wind energy offers a viable, economical alternative to conventional power plants in many areas of the country. Wind is a clean fuel; wind farms produce no air or water pollution because no fuel is burned. The most serious environmental drawbacks to wind machines may be their negative effect on wild bird populations and the visual impact on the landscape. To some, the glistening blades of windmills on the horizon are an eyesore; to others, they're a beautiful alternative to conventional power plants.

4.10. The cost of wind power production in relationship to fossil fuels.

According to AWEA, the cost of electricity from utility-scale wind power projects was as high as 30 cents per kWh in the 1980s, far greater than the cost of electricity from alternative technologies using fossil fuels to generate power. 21 Various state and federal incentives helped overcome wind power's cost disadvantage in many locations, as did dramatic cost reductions due to improvements in wind turbine technology. At present, DOE estimates the cost of generating electricity from wind power ranges from 3 to 6 cents per kWh. Cost reductions also occurred in fossil-fuel power generation technologies, but recent increases in natural gas fuel costs may result in further market penetration by wind power. For example, if natural gas prices continue to be substantially higher than average levels in the 1990s, wind power is likely to be competitive in parts of the country with good wind resources and transmission access. However, wind power will continue to be too expensive to compete with fossil-fuel generation in parts of the country with poor wind resources. Although cost reductions due to technological improvements affect all segments of the electric industry, they tend to be particularly important for newer power generation technologies such as wind power in comparison to fossil-fuel generation technologies. Furthermore, continued federal and state actions that promote renewable energy power generation or raise the cost of emissions from fossil-fuel technologies could also play a significant role in improving the competitiveness of wind power.

4.11. Geothermal Energy

"Geothermal" comes from the Greek words geo (earth) and thermo (heat). So, geothermal means earth heat. In the earth's interior - like the sun - provides heat energy from nature. This heat - geothermal energy - yields warmth and power that can be used without polluting the environment. Geothermal heat originates from Earth's fiery consolidation of dust and gas over 4 billion years ago. At earth's core - 4,000 miles deep - temperatures may reach over 9,000 degrees F. Heat that flows from the Earth's hot interior due to crusted plate movements, zones of high heat flow may be located close to the surface where convective circulation plays a significant role in bringing heat close to surface. From the geothermal reservoirs, hot water is required to be brought to the surface. Then, once the hot water and/or steam travels up the wells to the surface, they can be used to generate electricity in geothermal power plants or for energy saving non-electrical purposes.

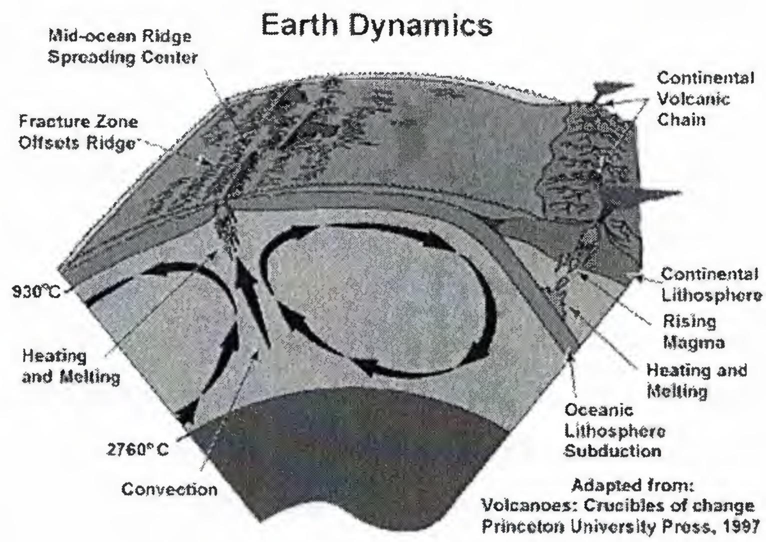

Figure 4.5 Geothermal energy is the heat from the Earth. It's clean and sustainable.

4.12. History of geothermal energy

Geothermal energy was used by ancient people for heating and bathing. Even today, hot springs are used worldwide for bathing, and many people believe that the hot mineral waters have natural healing powers. Using geothermal energy to produce electricity is a new industry. A group of Italian people first used it in 1904. The Italians used natural stream eruption from the earth to power a turbine generator. Geothermal resources can provide electricity for decades. The key to successful geothermal development lies in managing the resource. The geothermal field at The Geysers, established in 1960 in northern California, powered the first geothermal plant in the United States. Although the pressure of that resource has diminished, water injection techniques are helping to stabilize the pressure and the field now is expected to produce for many more years. Using geothermal energy to generate electricity for many years would require replacing aging power plant equipment and may require drilling new wells if the productivity of older ones diminishes over time. Recent technological advances such as improved turbine design allow developers to maximize resources and minimize drilling.

4.13. Where are geothermal resources located?

Generating electricity using geothermal energy requires high-temperature resources that range from the shallow ground to hot water and a few miles beneath the earths surface and down even deeper to the extremely high temperatures of molten rock called magma. Almost everywhere, the shallow ground or upper 10 feet of the Earth's surface maintains a nearly constant temperature between 50° and 60°F (10° and 16°C). Geothermal heat pumps can tap into this resource to heat and cool buildings. A geothermal heat pump system consists of a heat pump, an air delivery system (ductwork), and a heat exchanger-a system of pipes buried in the shallow ground near the building. In the winter, the heat pump removes heat from the heat exchanger and pumps it into the indoor air delivery system. In the summer, the process is reversed, and the heat pump moves heat from the indoor air into the heat exchanger. The heat removed from the indoor air during the summer can also be used to provide a free source of hot Advances in both drilling and power plant technologies could enable developers to more affordably tap geothermal resources in a larger portion of the country and expand the use of geothermal power. Geothermal heat pumps that simply transfer heat between the ground and buildings are practical nearly everywhere.

In the United States, most geothermal reservoirs of hot water are located in the western states, Alaska, and Hawaii. Wells can be drilled into underground reservoirs for the generation of electricity. Some geothermal power plants use the steam from a reservoir to power a turbine/generator, while others use the hot water to boil a working fluid that vaporizes and then turns a turbine. Hot water near the surface of Earth can be used directly for heat. Direct-use applications include heating buildings, growing plants in greenhouses, drying crops, heating water at fish farms, and several industrial processes such as pasteurizing milk. Hot dry rock resources occur at depths of 3 to 5 miles everywhere beneath the Earth's surface and at lesser depths in certain areas.

Figure 4.6 The Earth's heat-called geothermal energy-escapes as steam at a hot springs in Nevada.

Access to these resources involves injecting cold water down one well, circulating it through hot fractured rock, and drawing off the heated water from another well. Currently, there are no commercial applications of this technology. Existing technology also does not yet allow recovery of heat directly from magma, the very deep and most powerful resource of geothermal energy.

Many technologies have been developed to take advantage of geothermal energy - the heat from the earth. NREL performs research to develop and advance technologies for the following geothermal applications:

4.14. Formation of geothermal reservoir

In some regions of the world with high temperature gradients, there are deep subterranean faults and cracks that allow rainwater and snowmelt to seep underground - sometimes for miles. There the water is heated by the hot rock and circulates back up to the surface, to appear as hot springs, mud pots, geysers, or fumaroles. If the ascending hot water meets an impermeable rock layer, however, the water is trapped underground where it fills the pores and cracks comprising 2 to 5% of the volume of the surrounding rock, forming a geothermal reservoir.

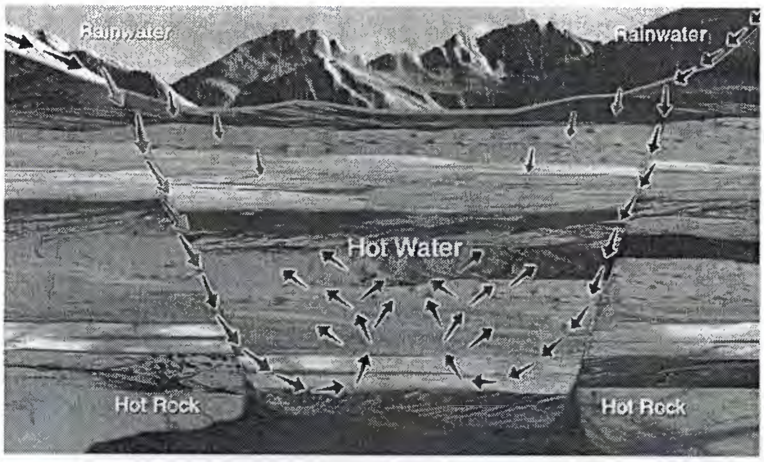

Figure 4.7 Much hotter than surface hot springs, geothermal reservoirs can reach temperatures of more than 350°C (700°F), and are powerful sources of energy.

4.15. Accessing geothermal energy

If geothermal reservoirs are close enough to the surface, it can be reached by drilling wells, sometimes over two miles deep. Scientists and engineers use geological, electrical, magnetic, geochemical and seismic surveys to help locate the reservoirs. Then, after an exploration well confirms a reservoir discovery, production wells are drilled. Hot water and steam shoot up the wells naturally (or are pumped to the surface) where – at temperatures between around 120-370°C (250-700°F) are used to generate electricity in geothermal power plants. Shallower reservoirs of lower temperature - 21-149°C (70- 300°F) are used directly in greenhouses, fish farms, and industry and in space heating systems for homes, schools and offices.

4.16. Geothermal power plant-electricity generation

In geothermal power plants, we use the natural hot water and steam from the earth to turn turbine generators to produce electricity. Unlike fossil fuel power plants, no fuel is burned. Geothermal power plants give off water vapor, but have no smoky emissions. Some types of power plans are given below.

4.17. Flashed Steam Plants

Most geothermal power plants operating today are "flashed steam" power plants. Hot water from production wells is passed through one or two separators where, released from the pressure of the deep reservoir, part of it flashes (explosively boils) to steam. The force of the steam is used to spin the turbine generator. To conserve the water and maintain reservoir pressure, the geothermal water and condensed steam are directed down an injection well back into the periphery of the reservoir, to be reheated and recycled.

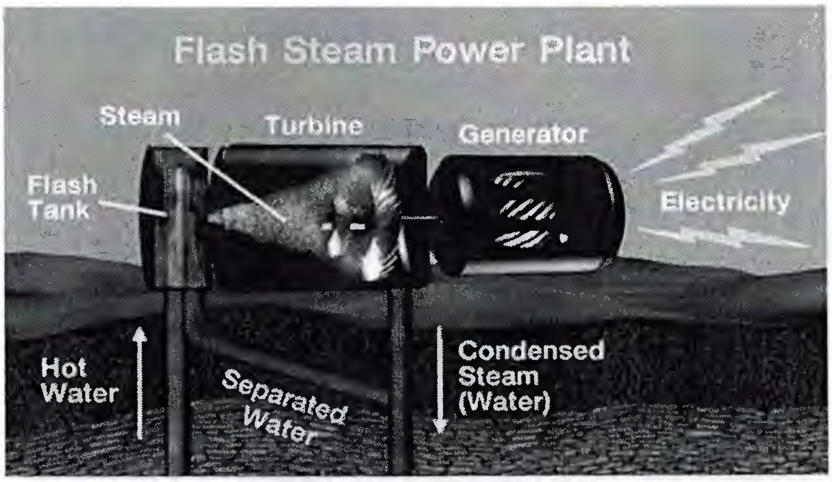

Figure 4.8 flash steam power plant

4.17.1. Dry Steam Plants:

A few geothermal reservoirs produce mostly steam and very little water. Here, the steam shoots directly through a rock-catcher and into the turbine.

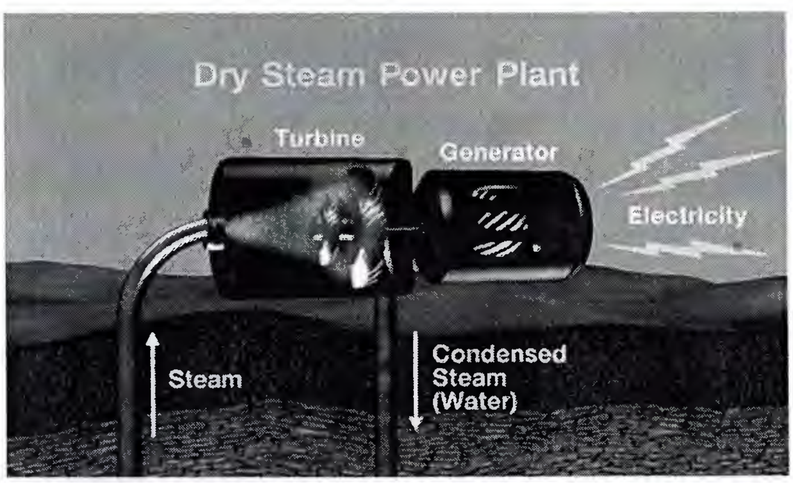

Figure 4.9 dry steam power plant

4.17.2. Binary Power Plants:

In a binary power plant, the geothermal water is passed through one side of a heat exchanger, where its heat is transferred to a second (binary) liquid, called a working fluid, in an adjacent separate pipe loop. The working fluid boils to vapor which, like steam, powers the turbine generator. It is then condensed back to a liquid and used over and over again. The geothermal water passes only through the heat exchanger and is immediately recycled back into the reservoir. Although binary power plants are generally more expensive to build than steam-driven plants, they have several advantages:

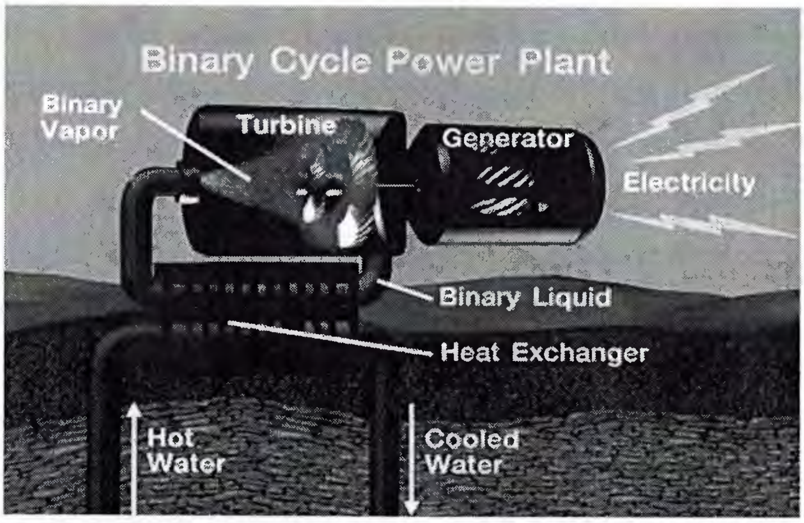

Figure 4.10 binary cycle water plant

- The working fluid (usually isobutene or isopentane) boils and flashes to a vapor at a lower temperature than what water does. So, electricity can be generated from reservoirs with lower temperatures. This increases the number of geothermal reservoirs in the world with electricity-generating potential.
- The binary system uses the reservoir water more efficiently. Since the hot water travels through an entirely closed system it results in less heat loss and almost no water loss.
- Binary power plants have virtually no emissions.

4.18. Hybrid Power Plants

In some power plants, flash and binary processes are combined. properly designed combined or hybrid systems achieve a synergistic advantage by having a higher overall efficiency compared with using the two systems or fuels(in the case of fossil-geothermal plants) in separate state of the art plants

4.19. Geothermal energy and environment

Geothermal energy does little damage to the environment. Another advantage is that geothermal plants don't have to transport fuel, like most power plants. Geothermal plants sit on top of their fuel source. Geothermal power plants have been built in deserts, in middle of desert and in mountain forest. Geothermal plants produce almost no emission because they don't burn any fuel to generate electricity.

Geothermal energy is considered a clean source of energy because geothermal power plants, depending on the technology, emit at most very small amounts of particulate matter, nitrogen oxides, sulfur dioxide and carbon dioxide. Geothermal plants also are compatible with agricultural and industrial land uses, can be designed to blend in with surrounding areas, and occupy small amounts of land. The agriculturally productive Imperial Valley in southern California is home to several geothermal power plants, and the Mammoth Lake power plant, near California's famous ski resort, is designed to blend into the scenery. The short-term effects of drilling include noise and the visual effects of the drilling equipment. In an operating power plant, noise is minimal under normal conditions. Finally, geothermal fluids contain dissolved minerals and sediments that are controlled to avoid contaminating local water resources. (For more detailed information see "Geothermal Power and the Environment"

4.20. Why is geothermal energy not more widely used?

The three main barriers to more widespread use of geothermal resources involve the location of resources, economics and permitting challenges. Geothermal resources that are suitable for generating power using today's technology are located mostly in western states, Alaska and Hawaii (USA). Resources that are practical for direct-use applications are more widespread, but also are located predominately in the west. Technology and public policy greatly influence the economics of geothermal energy. Locating geothermal resources is expensive and risky just as in oil and gas exploration. However, once a reservoir has been identified, the success ratio for developing commercial Resources increases to approximately 80 percent. The resource identification tools available to the petroleum industry are more effective than those available to the geothermal industry and geothermal systems are more complex.

Therefore, overall fossil fuels have a higher success rate for drilling discovery wells. The process of obtaining permits to lease land and build geothermal power plants can be lengthy and cumbersome and may increase the costs of developing geothermal resources.

4.21. How much does electricity from geothermal energy cost?

The price of electricity generated at new geothermal power plants currently ranges between $0.05 and $0.08 per kilowatt-hour (kWh). Once capital costs for the projects are recovered, the price of power can decrease to below $0.05 per kWh. Recent federal legislation qualifies new geothermal power plants for a production tax credit of $0.018 per kilowatt hour for each of the first five years of service. This credit has been a major factor in the growth of the domestic wind industry in recent years. If applied to geothermal energy, this incentive would decrease the price of electricity generated at geothermal power plants. Most of the costs associated with geothermal development are related to exploring and defining the resource and plant construction. Drilling for resources can account for as much as one-third to one-half of the total cost of a project. Geothermal power plants also have ongoing operating costs such as royalties paid for using the geothermal resource, property taxes and plant personnel.

4.22. SOLAR ENERGY

The sun has produced energy for billions of years. Solar energy is the solar radiation that reaches the earth (this radiation is produced by nuclear fusion reactions deep in the sun's core). Solar energy travels to earth through space in discrete packets of energy called photons. In the 1830s, the British astronomer John Herschel used a solar collector box to cook food during an expedition to Africa. Now, people are trying to use the sun's energy for lots of things. Out of the 14 known solar electric generating units operating in the US at the end of 2004, 10 of these are in California and 4 in Arizona. No statistics are being collected on solar plants that produce less than 1 megawatt of electricity, so there may be smaller solar plants in a number of other states.

4.23. The Solar Energy Conversion System

There are many different types of solar energy systems that will convert the solar resource into a useful form of energy. A block diagram showing three of the most basic system types is shown as Figure 1.3. In the first diagram , the solar resource is captured and converted into heat which is then supplied to a demand for thermal energy (thermal load) such as house heating, hot water heating or heat for industrial processes. This type of system may or may not include thermal storage, and usually include an auxiliary source of energy so that the demand may be met during long periods with no sunshine.

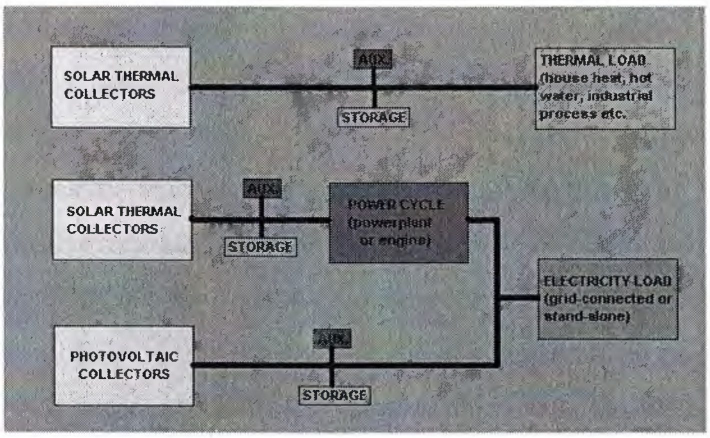

Figure 4.11 Diagram of a basic solar energy conversion systems. The AUX. box represents some auxiliary source of thermal or electrical energy.

If the demand (load) to be met is electricity (an electrical load) rather than heat, there are two common methods of converting solar energy into electricity. One method is by collecting solar energy as heat and converting it into electricity using a typical power plant or engine; the other method is by using photovoltaic cells to convert solar energy directly into electricity. In general, if solar energy conversion systems are connected to a large electrical transmission grid, no storage or auxiliary energy supply is needed. If the solar energy conversion system is to be the only source of electricity, storage and auxiliary energy supply are usually both incorporated. If the thermal route is chosen, storage of heat rather than electricity may be used to extend the operating time of the system. Auxiliary energy may either be supplied either as heat before the power conversion system, or as electricity after it. If the photovoltaic route is chosen, extra electricity may be stored, usually in storage batteries, thereby extending the operating time of the system. For auxiliary power, an external electricity source is the only choice for photovoltaic systems.

4.24. Photovoltaic energy

Photovoltaic energy is the conversion of sunlight into electricity through a photovoltaic (PVs) cell, commonly called a solar cell. A photovoltaic cell is a non mechanical device usually made from silicon alloys. Sunlight is composed of photons, or particles of solar energy. These photons contain various amounts of energy corresponding to the different wavelengths of the solar spectrum. When photons strike a photovoltaic cell, they may be reflected, pass right through, or be absorbed. Only the absorbed photons provide energy to generate electricity. When enough sunlight (energy) is absorbed by the material (a semiconductor), electrons are dislodged from the material's atoms. Special treatment of the material surface during manufacturing makes the front surface of the cell more receptive to free electrons, so the electrons naturally migrate to the surface. When the electrons leave their position, holes are formed. When many electrons, each carrying a negative charge, travel toward the front surface of the cell, the resulting imbalance of charge between the cell's front and back surfaces creates a voltage potential like the negative and positive terminals of a battery. When the two surfaces are connected through an external load, electricity flows.

The photovoltaic cell is the basic building block of a PV system. Individual cells can vary in size from about 1 cm (1/2 inch) to about 10 cm (4 inches) across. However, one cell only produces 1 or 2 watts, which isn't enough power for most applications. To increase power output, cells are electrically connected into a packaged weather-tight module. Modules can be further connected to form an array. The term array refers to the entire generating plant, whether it is made up of one or several thousand modules. As many modules as needed can be connected to form the array size (power output) needed. The performance of a photovoltaic array is dependent upon sunlight. Climate conditions (e.g., clouds, fog) have a significant effect on the amount of solar energy received by a PV array and, in turn, its performance. Most current technology photovoltaic modules are about 10 percent efficient in converting sunlight with further research being conducted to raise this efficiency to 20 percent.

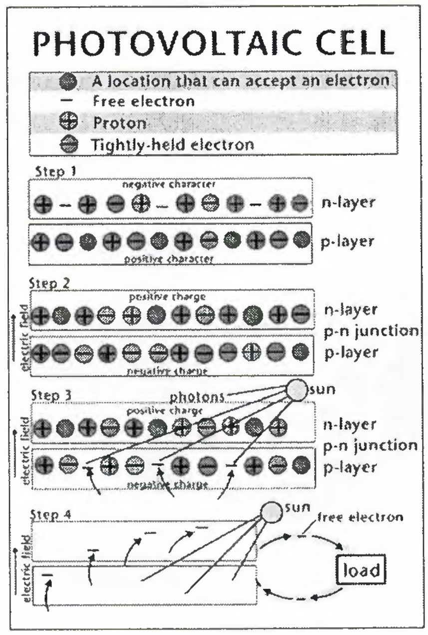

Figure 4.12 photovoltaic cell

The Pv cell was discovered in 1954 by Bell Telephone researchers examining the sensitivity of a properly prepared silicon wafer to sunlight. Beginning in the late 1950s, pvs were used to power U.S. space satellites. The success of PVs in space generated commercial applications for pv technology. The simplest photovoltaic systems power many of the small calculators and wrist watches used everyday. More complicated systems provide electricity to pump water, power communications equipment, and even provide electricity to our homes. Photovoltaic conversion is useful for several reasons. Conversion from sunlight to electricity is direct, so that bulky mechanical generator systems are unnecessary. The modular characteristic of photovoltaic energy allows arrays to be installed quickly and in any size required or allowed. Also, the environmental impact of a photovoltaic system is minimal, requiring no water for system cooling and generating no by-products. Photovoltaic cells, like batteries, generate direct current (DC) which is generally used for small loads (electronic equipment). When DC from photovoltaic cells is used for commercial applications or sold to electric utilities using the electric grid, it must be converted to alternating current (AC) using inverters, solid state devices that convert DC power to AC. Historically, pvs have been used at remote sites to provide electricity. However, a market for distributed generation from PVs may be developing with the unbundling of transmission and distribution costs due to electric deregulation. The siting of numerous small-scale generators in electric distribution feeders could improve the economics and reliability of the distribution system.

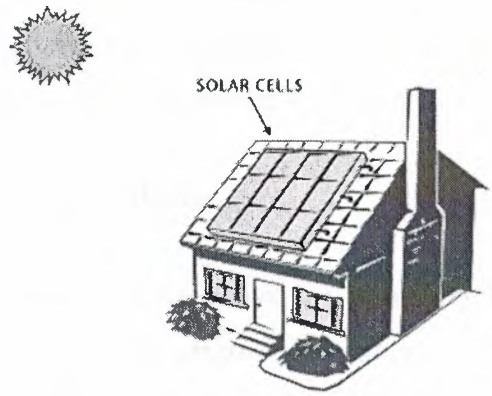

Figure 4.13 solar energy

4.25. Solar thermal heat

The major applications of solar thermal energy at present are heating swimming pools, heating water for domestic use, and space heating of buildings. For these purposes, the general practice is to use flat-plate solar-energy collectors with a fixed orientation (position).

Where space heating is the main consideration, the highest efficiency with a fixed flat-plate collector is obtained if it faces approximately south and slopes at an angle to the horizon equal to the latitude plus about 15 degrees. Solar collectors fall into two general categories: non concentrating and concentrating. In the non concentrating type, the collector area (i.e. the area that intercepts the solar radiation) is the same as the absorber area (i.e., the area absorbing the radiation). In concentrating collectors, the area intercepting the solar radiation is greater, sometimes hundreds of times greater, than the absorber area. Where temperatures below about 200o F are sufficient, such as for space heating, flat-plate collectors of the non concentrating type are generally used. There are many flat-plate collector designs but generally all consist of (1) a flat-plate absorber, which intercepts and absorbs the solar energy, (2) a transparent cover(s) that allows solar energy to pass through but reduces heat loss from the absorber, (3) a heat-transport fluid (air or water) flowing through tubes to remove heat from the absorber, and (4) a heat insulating backing.

Solar space heating systems can be classified as passive or active. In passive heating systems, the air is circulated past a solar heat surface(s) and through the building by convection (i.e. less dense warm air tends to rise while more dense cooler air moves downward) without the use of mechanical equipment. In active heating systems, fans and pumps are used to circulate the air or the heat absorbing fluid.

4.26. Solar thermal power plants

Solar thermal power plants use the sun's rays to heat a fluid, from which heat transfer systems may be used to produce steam. The steam, in turn, is converted into mechanical energy in a turbine and into electricity from a conventional generator coupled to the turbine. Solar thermal power generation is essentially the same as conventional technologies except that in conventional technologies the energy source is from the stored energy in fossil fuels released by combustion. Solar thermal technologies use concentrator systems due to the high temperatures needed for the working fluid. The three types of solar-thermal power systems in use or under development are: parabolic trough, solar dish, and solar power tower.

4.27. Parabolic trough

The parabolic trough is used in the largest solar power facility in the world located in the Mojave Desert at Kramer Junction, California. This facility has operated since the 1980's and accounted for the majority of solar electricity produced by the electric power sector in 2004.

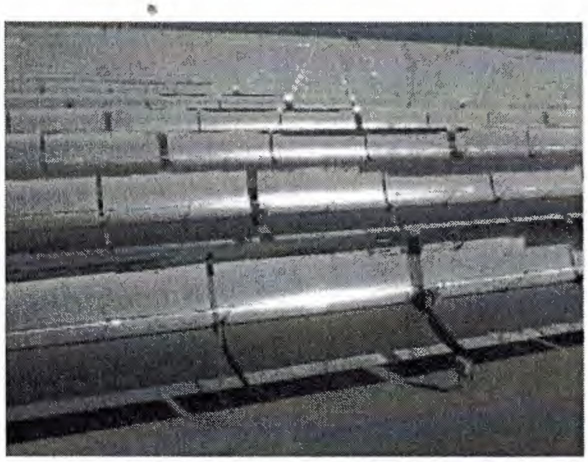

Figure 4.14 Parabolic trough

A parabolic trough collector has a linear parabolic-shaped reflector that focuses the sun's radiation on a linear receiver located at the focus of the parabola. The collector tracks the sun along one axis from east to west during the day to ensure that the sun is continuously focused on the receiver. Because of its parabolic shape, a trough can focus the sun at 30 to 100 times its normal intensity (concentration ratio) on a receiver pipe located along the focal line of the trough, achieving operating temperatures over 400 degrees Celsius. A collector field consists of a large field of single-axis tracking parabolic trough collectors. The solar field is modular in nature and is composed of many parallel rows of solar collectors aligned on a north-south horizontal axis. A working (heat transfer) fluid is heated as it circulates through the receivers and returns to a series of heat exchangers at a central location where the fluid is used to generate high-pressure superheated steam. The steam is then fed to a conventional steam turbine/generator to produce electricity. After the working fluid passes through the heat exchangers, the cooled fluid is recirculated through the solar field. The plant is usually designed to operate at full rated power using solar energy alone, given sufficient solar energy. However, all plants are hybrid solar/fossil plants that have a fossil-fired capability that can be used to supplement the solar output during periods of low solar energy. The Luz plant is a natural gas hybrid.

4.28. Solar Dish

A solar dish/engine system utilizes concentrating solar collectors that track the sun on two axes, concentrating the energy at the focal point of the dish because it is always pointed at the sun. The solar dish's concentration ratio is much higher that the solar trough, typically over 2,000, with a working fluid temperature over 750 °C. The power-generating equipment used with a solar dish can be mounted at the focal point of the dish, making it well suited for remote operations or, as with the solar trough, the energy may be collected from a number of installations and converted to electricity at a central point. The engine in a solar dish/engine system converts heat to mechanical power by compressing the working fluid when it is cold, heating the compressed working fluid, and then expanding the fluid through a turbine or with a piston to produce work. The engine is coupled to an electric generator to convert the mechanical power to electric power.

4.29. Solar Power Tower

A solar power tower or central receiver generates electricity from sunlight by focusing concentrated solar energy on a tower-mounted heat exchanger (receiver). This system uses hundreds to thousands of flat sun-tracking mirrors called heliostats to reflect and concentrate the sun's energy onto a central receiver tower. The energy can be concentrated as much as 1,500 times that of the energy coming in from the sun. Energy losses from thermal-energy transport are minimized as solar energy is being directly transferred by reflection from the heliostats to a single receiver, rather than being moved through a transfer medium to one central location, as with parabolic troughs. Power towers must be large to be economical. This is a promising technology for large-scale grid-connected power plants. Though power towers are in the early stages of development compared with parabolic trough technology, a number of test facilities have been constructed around the world.

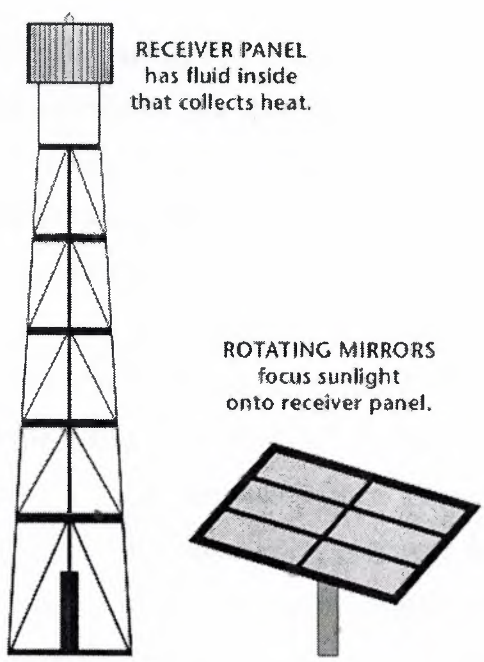

Figure 4.15 Solar power tower

The U.S. Department of Energy along with a number of electric utilities built and operated a demonstration solar power tower near Barstow, California, during the 1980's and 1990's.

Figure 4.16 A 2-MW utility-scale photovoltaic power system co-located with a defunct nuclear power plant near Sacramento, California. (Photo courtesy of DOE/NREL, Warren Gretz)

4.30. The Solar Resource

The basic resource for all solar energy systems is the sun. Knowledge of the quantity and quality of solar energy available at a specific location is of prime importance for the design of any solar energy system. Although the solar radiation is relatively constant outside the earth's atmosphere, local climate influences can cause wide variations in available insulation on the earth's surface from site to site. In addition, the relative motion of the sun with respect to the earth will allow surfaces with different orientations to intercept different amounts of solar energy. However, solar energy is available over the entire globe, and only the size of the collector field needs to be increased to provide the same amount of heat or electricity as in the shaded areas. It is the primary task of the solar energy system designer to determine the amount, quality and timing of the solar energy available at the site selected for installing a solar energy conversion system. Just outside the earth's atmosphere, the sun's energy is continuously available at the rate of 1,367 Watts on every square meter facing the sun. Due to the earth's rotation, asymmetric orbit about the sun, and the contents of its atmosphere, a large fraction of this energy does not reach the ground.

In addition to estimating the amount of energy coming from the sun, the solar designer must also be able to predict the position of the sun. By using only four parameters (latitude, longitude, date and local time), equations are derived to determine the location of the sun in the sky. A characteristic fundamental to the capture of solar energy is that the amount of energy incident on a collector is reduced by a fraction equal to the cosine of the angle between the collector surface and the sun's rays. Knowing the position of the collector (or any other surface for that matter) and the position of the sun equations can be used to predict the fraction of incoming solar energy that falls on the collector. These include situations where the collector is fixed or is tracked about a single axis, no matter what the orientation.

Appropriate regions include the southwest United States, northern Mexico, the north African desert, the Arabian peninsula, major portions of India, central and western Australia, the high plateaus of the Andean states, and northeastern Brazil. Promising site locations in Europe are found in southern Spain and several Mediterranean islands. Solar electricity generation costs and feasibility of the project highly depend on the project site itself.

4.31. Solar Collectors

The solar collector is the key element in a solar energy system. It is also the novel technology area that requires new understandings in order to make captured solar energy a viable energy source for the future. The function of a solar collector is simple; it intercepts incoming insolation and changes it into a useable form of energy that can be applied to meet a specific demand. In the following text, we will develop analytical understandings of flat-plate and concentrating collectors, as used to provide heat or electricity. Each type is introduced below. Flat-plate thermal solar collectors are the most commonly used type of solar collector. Their construction and operation are simple. A large plate of blackened material is oriented in such a manner that the solar energy that falls on the plate is absorbed and converted to thermal energy thereby heating the plate. Tubes or ducting are provided to remove heat from the plate, transferring it to a liquid or gas, and carrying it away to the load. One (or more) transparent (glass or plastic) plates are often placed in front of the absorber plate to reduce heat loss to the atmosphere. Likewise, opaque insulation is placed around the backside of the absorber plate for the same purpose. Operating temperatures up to 125 ^{o}C are typical.

Flat plate collectors have the advantage of absorbing not only the energy coming directly from the disc of the sun (beam normal insolation) but also the solar energy that has been diffused into the sky and that is reflected from the ground. Flat plate thermal collectors are seldom tracked to follow the sun's daily path across the sky; however their fixed mounting usually provides a tilt toward the south to minimize the angle between the sun's rays and the surface at noontime. Tilting flat-plate collectors toward the south provides a higher rate of energy at noontime and more total energy over the entire day.

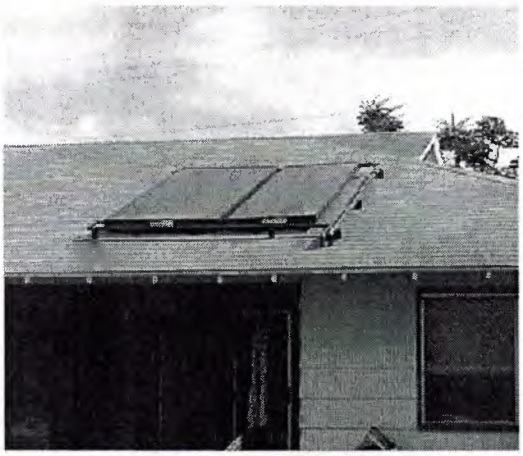

Figure 4.17 Flat-plate thermal solar collectors for providing hot water.(photo courtesy of DOE/NREL, Warren Gretz)

Flat-plate photovoltaic collectors contain an array of individual photovoltaic cells, connected in a series/parallel circuit, and encapsulated within a sandwich structure with the front surface being glass or plastic. Solar energy falls directly upon the photovoltaic cell front surface and produces a small direct current voltage, providing electrical energy to a load. Unlike thermal collectors however, the backside of the panel is not insulated. Photovoltaic panels need to loose as much heat as possible to the atmosphere to optimize their performance. Like flat-plate thermal collectors, flat-plate photovoltaic collectors (panels) absorb both energy coming directly from the sun's disc, and diffuse and reflected energy coming from other directions. In general, flat-plate photovoltaic panels are mounted in a fixed position and tilted toward the south to optimize noontime and daily energy production. However, it is common to see flat-plate photovoltaic panels mounted on mechanisms that track the sun about one tilted axis, thereby increasing the daily output of the panels.

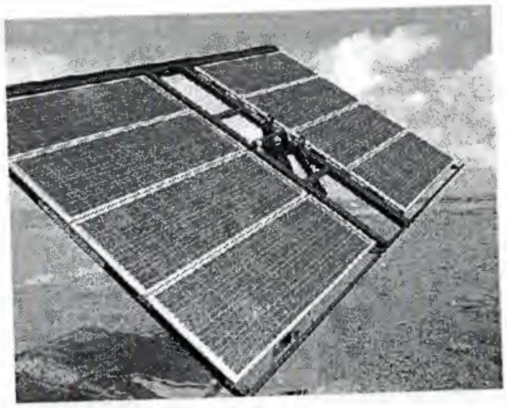

Figure 4.18 flat plate collector

Figure 4.19 Flat-plate photovoltaic collector applications. (Photos courtesy of DOE/NREL, Warren Gretz)

When higher temperatures are required, concentrating solar collectors are used. Solar energy falling on a large reflective surface is reflected onto a smaller area before it is converted into heat. This is done so that the surface absorbing the concentrated energy is smaller than the surface capturing the energy and therefore can attain higher temperatures before heat loss due to radiation and convection wastes the energy that has been collected. Most concentrating collectors can only concentrate the parallel insolation coming directly from the sun's disk (beam normal insolation), and must follow (track) the sun's path across the sky. Four types of solar concentrators are in common use; parabolic troughs (as used in the Kramer Junction, California solar energy electricity generating plant), parabolic dishes, central receivers and Fresnel lenses. Figure 1.9 shows these concepts schematically. A parabolic trough concentrates incoming solar radiation onto a line running the length of the trough. A tube (receiver) carrying heat transfer fluid is placed along this line, absorbing concentrated solar radiation and heating the fluid inside. The trough must be tracked about one axis. Because the surface area of the receiver tube is small compared to the trough capture area (aperture), temperatures up to 400°C can be reached without major heat loss.

A parabolic dish concentrates the incoming solar radiation to a point. An insulated cavity containing tubes or some other heat transfer device is placed at this point absorbing the concentrated radiation and transferring it to a gas. Parabolic dishes must be tracked about two axes. Figure 1.10b shows six 9kWe parabolic dish concentrators with Stirling engines attached to the receiver at the focus. A central receiver system consists of a large field of independently movable flat mirrors (heliostats) and a receiver located at the top of a tower. Each heliostat moves about two axes, throughout the day, to keep the sun's image reflected onto the receiver at the top of the tower. The receiver, typically a vertical bundle of tubes, is heated by the reflected insolation, thereby heating the heat transfer fluid passing through the tubes. Figure 1.10a shows the 10 MWe Solar One central receiver generating plant at Daggett, California with its adjoining steam power plant. A Fresnel lens concentrator, such as shown in Figure 1.10d uses refraction rather than reflection to concentrate the solar energy incident on the lens surface to a point. Usually molded out of inexpensive plastic, these lenses are used in photovoltaic concentrators. Their use is not to increase the temperature, but to enable the use of smaller, higher efficiency photovoltaic cells. As with parabolic dishes, point-focus Fresnel lenses must track the sun about two axes.

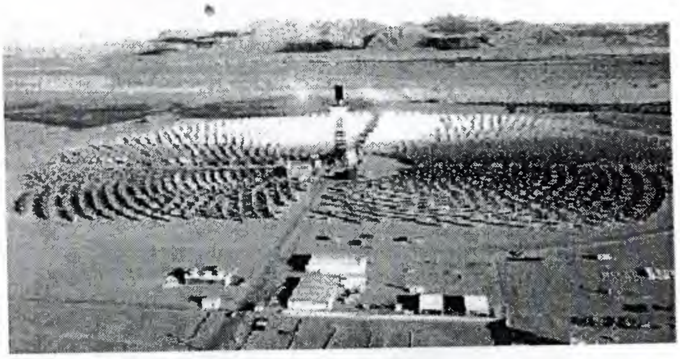

Figure 4.20 A central receiver system. (Courtesy of Sandia National Laboratories, Albuquerque)

Figure 4.21. (d) Two-axis tracking parabolic dish collectors. (Courtesy of Schlaich, Bergermann und Partner)

Figure 4.22 A single-axis tracking parabolic trough collector. (Courtesy of Kramer Junction Operating Company)

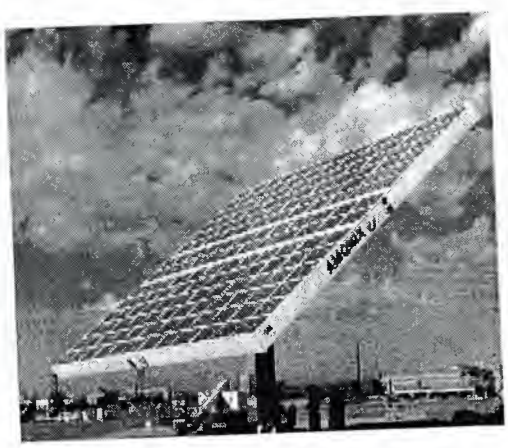

Figure 4.23 A concentrating photovoltaic collector using Fresnel lenses. (Courtesy of Amonix Corp.)

4.32. Need for Storage

Like with any other power plant, solar power plant output must satisfy the demands of the utility market. During peak demand periods, kilowatt-hour prices are high and financial incentives are high for guaranteed supply. Solar plant input is limited by diurnal, seasonal and weather-related insolation changes. In order to cope with these fluctuations, the solar plant input may be backed up by fossil fuels, or the solar changes may be mitigated by a buffering storage system. The choice depends on demands, system and site conditions.

In thermal solar power plants, thermal storage and/or fossil backup act as:

- an output management tool to prolong operation after sunset, to shift energy sales from low revenue off-peak hours to high revenue peak demand hours, and to contribute to guaranteed output
- An internal plant buffer, smoothing out insolation charges for steadying cycle operation, and for operational requirements such as blanketing steam production, component pre-heating and freeze protection.

Photovoltaic plants in general need no internal buffer, and output management can be achieved with battery or other electrochemical storage, pumped hydroelectric storage, or with diesel-generator backup.

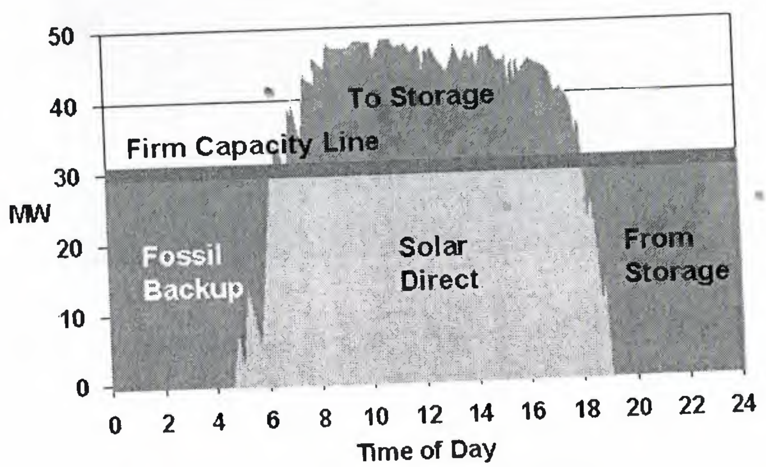

Figure 4.24 Stored solar energy provides a firm capacity of 31MW until midnight at which time fossil fuel backup us used.

4.33. Integration with Power Cycles

Because of their thermal nature, all the solar thermal technologies can be hybridized, or operated with fossil fuel as well as solar energy. Hybridization has the potential to increase the value of concentrating solar thermal technology by increasing its availability and dispatch ability, decreasing its cost (by making more effective use of power generation equipment), and reducing technological risk by allowing conventional fuel use when needed.

Although an interconnected field of solar thermal collectors and thermal energy storage may be sufficient for providing high temperature heat directly to a thermal demand, a power generation subsystem must be incorporated into the system design if mechanical work or electrical power is to be an output from the system. Chapter 11 reviews the technology for power generation with particular emphasis on power generation units suitable for interfacing with solar thermal energy collection subsystems. The inclusion of power generation in a solar thermal energy design presents a challenge in selecting the appropriate design conditions. The efficiency of a power generation unit usually increases with the operating temperature of the power generation cycle, where as the efficiency of solar collectors decreases with temperature. A tradeoff must be performed to determine the best system design point.

Figure 4.25 One of the steam cycle power cycles at the Kramer Junction solar energy generating system. (Photo courtesy of DOE/NREL, Warren Gretz)

4.34. Economic and Environmental Considerations

The most important factor driving the solar energy system design process is whether the energy it produces is economical. Although there are factors other than economics that enter into a decision of when to use solar energy; i.e. no pollution, no greenhouse gas generation, security of the energy resource etc., design decisions are almost exclusively dominated by the 'levelized energy cost'. This or some similar economic parameter, gives the expected cost of the energy produced by the solar energy system, averaged over the lifetime of the system. Commercial applications from a few kilowatts to hundreds of megawatts are now feasible, and plants totaling 354 MW have been in operation in California since the 1980s. Plants can function in dispatch able, grid-connected markets or in distributed, stand-alone applications. They are suitable for fossil-hybrid operation or can include cost-effective storage to meet dispatch ability requirements. They can operate worldwide in regions having high beam-normal insolation, including large areas of the southwestern United States, and Central and South America, Africa, Australia, China, India, the Mediterranean region, and the Middle East, . Commercial solar plants have achieved levelized energy costs of about 12-15¢/kWh, and the potential for cost reduction are expected to ultimately lead to costs as low as 5¢/kWh.

CONCLUSION

Energy is the necessity of life. Every physical process that occurs in the universe involves energy and energy transformations. power generation from resources like hydro, thermal, nuclear, wind, solar and geothermal with appropriate figure, examples, contruction and working of electrical devices used for this purpose have been explained. But these resources are not permanent. They are fading out with the passage of time. New research says that the resources of coal, oil and gas would expire in the end of present century. Similarly, solar energy is not available mostly in winters in northern region of the world. Likewise, wind and geothermal are available only at specific locations and the resources for uranium are already very limited. So what would be the alternate (new) resource of power generation? This question is a challenge to today's world.

Nowadays, developed nations are spending a lot of money on research and are giving incentives to scientists to discover new energy resources. The newly discovered resources should be good for environment as we are already suffering from extensive environmental pollution in the same way cost factor should be considered because in power industry consumers are mainly concerned about financial relaxation. Secondly power gained from present resources should be saved and preserved for later usage. For example in peak summers solar energy can be saved on long term basis and in winter when that energy can be utilized, this would lead to save other resources which were previously been used in winter.

There is a hope that significant technological growth, highly funded research and mainly devoted human efforts would result in the discovery of new resources. As these new resources would appear, the life would be much secure, comfortable and safe. One of the example, in Brazil, they burn sugar cane to move their vehicles.

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