NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronics Engineering

SOLAR ENERGY IN CIVIL APPLICATIONS

Graduation Project
EE – 400

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ABSTRACT

As whole world is trying to save energy for future or for coming rainy days, so world is going toward finding out the way to protect the resources we have and use alternative resources and get from them maximum outcome. Talking about energy first of all sun comes first. Sun is the great source of energy that is producing energy for human when this world came into being. In olden days sun light was used for limited purposes as science developed and entered in the world of modernism and humans start generating electric energy then comes the turn of the world to find out the renewable energy sources therefore sun became the major source of renewable energy sources. Now solar is used to generate electric energy in many countries along with heating process.

The project aims to provide thorough grounding in theory and application solar energy generation. And the method to convert solar energy into electric and later how could it used in proper way to get maximum benefit. Also it is discussed in project what problems we can face while solar energy conversion is under process. More over economic factors are also considered in this project. Later on advantages and disadvantages are discussed briefly in this project.

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INTODUCTION

Solar Energy, radiation produced by nuclear fusion reactions deep in the Sun's core. The Sun provides almost all the heat and light Earth receives and therefore sustains every living being. Solar energy travels to Earth through space in discrete packets of energy called photons. On the side of Earth facing the Sun, a square kilometer at the outer edge of our atmosphere receives 1,400 megawatts of solar power every minute, which is about the capacity of the largest electric-generating plant in Nevada. Only half of that amount, however, reaches Earth's surface. The atmosphere and clouds absorb or scatter the other half of the incoming sunlight. The amount of light that reaches any particular point on the ground depends on the time of day, the day of the year, the amount of cloud cover, and the latitude at that point. The solar intensity varies with the time of day, peaking at solar noon and declining to a minimum at sunset. The total radiation power (1.4 kilowatts per square meter, called the solar constant) varies only slightly, about 0.2 percent every 30 years. Any substantial change would alter or end life on Earth.

People have devised two main types of artificial collectors to directly capture and utilize solar energy: flat plate collectors and concentrating collectors. Both require large surface areas exposed to the Sun since so little of the Sun's energy reaches Earth's surface. Even in areas of the United States that receive a lot of sunshine, a collector surface as big as a two-car garage floor is needed to gather the energy that one person typically uses during a single day.

For applications such as air conditioning, central power generation, and many industrial heat requirements, flat plate collectors cannot provide carrier fluids at high enough temperatures to be effective. They may be used as first-stage heat input devices; the temperature of the carrier fluid is then boosted by other conventional heating means. Alternatively, more complex and expensive concentrating collectors can be used. These devices reflect the Sun's rays from a large area and focus it onto a small, blackened receiving area. The light intensity is concentrated to produce temperatures of several hundred or even several thousand degrees Celsius. The concentrators move to track the Sun using devices called heliostats. Concentrators use curved mirrors with aluminum or silver reflecting surfaces that coat the front or back surfaces of glass or plastic. Researchers are developing cheap polymer films to replace the more expensive glass. One new technique uses a pliable membrane stretched across the front of a cylinder and another across the back with a partial vacuum between. The vacuum causes the membranes to form a spherical shape ideal for concentrating sunlight. Concentrating solar energy is the least expensive way to generate large-scale electrical power from the Sun's energy and therefore has the potential to make solar power available at a competitive rate. Consequently, government, industry, and utilities have formed partnerships to reduce the manufacturing costs of concentrators. One important high-temperature application of concentrators is solar furnaces. Such furnaces are ideal for research requiring high temperatures and contaminant-free environments—for example, materials research to determine how substances will react when exposed to extremely high temperatures. Other methods of reaching such temperatures usually require chemical reactants that would also react with the substances to be studied, skewing the results. Another type of concentrator called a central receiver, or "power tower," uses an array of sun-tracking reflectors mounted on computer-controlled heliostats to reflect and focus the Sun's rays onto a water boiler mounted on a tower.

CHAPTER ONE

INTRODUCTION TO SOLAR CELL

1.1 Overview

Solar energy is natural energy source which is very essential for human life. As in modern world when human start to understand the importance for electric energy and how it can make our life easy. We human start to find out the ways to generate electricity by different ways. Some time we use water, steam and nuclear energy to generate electricity. But all of these resources are limited and need high cost to generate electricity so then world move toward renewable energy sources. Solar energy is all so a kind of renewable energy source that is converted from solar energy to electrical energy using solar cell. In this whole chapter it is explained that how the solar cell works and what are types of solar energy. And how the new developments are going to done in order to improve efficiency and solar cell and conversion of solar energy.

1.2 Energy from Sun

The continuous fusion of hydrogen into helium keeps the core of the Sun cooking at 27,000,000 degrees Fahrenheit. The surface of the Sun, also known as the photosphere, is relatively cool, only 10,000 degrees Fahrenheit. This fusion process produces the Sun's light. This sunlight travels at the speed of 186,282 miles per second or 299,792, 458 meters per second. This means that light from the Sun takes 8.4 minutes to travel 93 million miles to Earth. Sunlight is easy to collect without generating dangerous waste, and it can be converted into electricity or heat in many ways:

1.3 History

The development of the solar cell stems from the work of the French experimental physicist Antoine-César Becquerel back in the 19th century. In 1839, Becquerel discovered (although he could not fully explain) the photovoltaic effect while experimenting with an electrolytic cell containing two metal electrodes. The then nineteen year old found that certain metals and solutions would produce small amounts of electric current when exposed to light. In 1877, Charles Fritts constructed the first true solar cells (at least, the first resembling modern cells in that it was made from only solid materials) by using junctions formed by coating the semiconductor selenium with an ultra thin, nearly transparent layer of gold. Fritts's devices were very inefficient, transforming less than 1 percent of the absorbed light into electrical energy, but they were a start. Substantial improvements in solar cell efficiency had to wait for a better understanding of the physical principles involved in their design, provided by Einstein in 1905 and Schottky in 1930. By 1927 another metal semiconductor-junction solar cell, in this case made of copper and the semiconductor copper oxide, had been demonstrated. By the 1930s both the selenium cell and the copper oxide cell were being employed in light-sensitive devices, such as photometers, for use in photography. These early solar cells, however, still had energy conversion efficiencies of less than 1 percent (so they made fine light sensors, but lousy energy converters). Solar cell efficiency finally saw substantial progress with the development of the first silicon cell by Russell Ohl in 1941. In 1954, three other American researchers, G.L. Pearson, Daryl Chapin, and Calvin Fuller, demonstrated a further-refined silicon solar cell capable of 6% energy conversion efficiency (in direct sunlight). By the late 1980s silicon cells, as well as those made of gallium arsenide, with efficiencies of more than 20% had been fabricated. In 1989 a concentrator solar cell, a type of device in which sunlight is concentrated onto the cell surface by means of lenses, achieved an efficiency of 37% thanks to the increased intensity of the collected energy.

1.4 Some Semiconductor Physics

The solar cell operation is based on the ability of semiconductors to convert sunlight directly into electricity by exploiting the photovoltaic effect. In the conversion process, the incident energy of light creates mobile charged particles in the semiconductor which are then separated by the device structure and produce electrical current. The characteristic distribution of electron energies within the semiconductor; How the electrical properties of semiconductors can be controlled by the addition of impurities; How illumination creates mobile charged particles called electrons and holes at the semiconductor junction Band structure and Doping The principles of semiconductor physics are best illustrated using the example of silicon, a group 4 elemental semiconductor. The silicon crystal forms the so called diamond lattice where each atom has four nearest neighbors at the vertices of a tetrahedron. The four-fold tetrahedral co-ordination is the result of the bonding arrangement which uses the four outer (valence) electrons of each silicon atom. Each bond contains two electrons, and can easily see that all the valence electrons are taken up by the bonds. Most other industrially important semiconductors crystallize in this or closely related lattices, and have a similar arrangement of the bonding orbital.

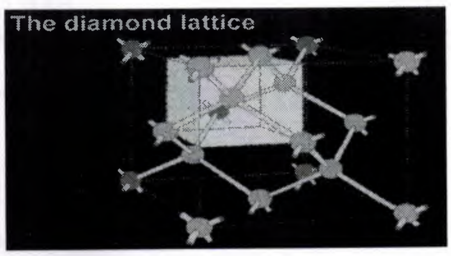

Figure1.1 Arrangement of the bonding orbital

This crystal structure has a profound effect on the electronic and optical properties of the semiconductor. According to the quantum theory, the energy of an electron in the crystal must fall within well-defined *bands*. The energies of valence orbital which form bonds between the atoms represent just such a band of states, the *valence band*. The next higher band is the *conduction band* which is separated from the valence band by the *energy gap*, or *band gap*. The width of the band gap E_c - E_v is a very important characteristic of the semiconductor and is usually denoted by E_g. This table gives the band gaps of the most important semiconductors for solar-cell applications

Table 1.1 Different materials with respect to their energy gap and type of gap

Material	Energy gap (eV)	Type of gap
crystalline Si	1.12	indirect
amorphous Si	1.75	direct
$CuInSe_2$	1.05	direct
CdTe	1.45	direct
GaAs	1.42	direct
InP	1.34	direct

A pure semiconductor (which is called *intrinsic*) contains just the right number of electrons to fill the valence band, and the conduction band is therefore empty. Electrons in the full valence band cannot move - just as, for example, marbles in a full box with a lid on top. For practical purposes, a pure semiconductor is therefore an insulator.

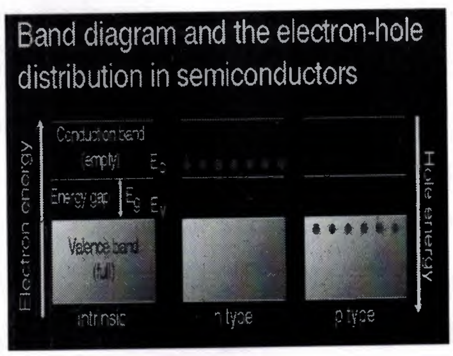

Figure 1.2 Band and electron hole distribution in semiconductors

Semiconductors can only conduct electricity if carriers are introduced into the conduction band or removed from the valence band. One way of doing this is by alloying the semiconductor with an impurity. This process is called *doping*. Doping makes it possible to exert a great deal of control over the electronic properties of a semiconductor, and lies in the heart of the manufacturing process of all semiconductor devices. some group 5 impurity atoms (for example, phosphorus) are added to the silicon melt from which the crystal is grown. Four of the five outer electrons are used to fill the valence band and the one extra electron from each impurity atom is therefore promoted to the conduction band. For this reason, these impurity atoms are called *donors*. The electrons in the conduction band are mobile, and the crystal becomes a conductor. Since the current is carried by negatively charged electrons, this type of semiconductor is called *N type*. A similar situation occurs when silicon is doped with group 3 impurity atoms (for example, boron) which are called *acceptors*. Since four electrons per atoms are needed to fill the valence band completely, this doping creates electron deficiency in this band. The missing electrons - called *holes* - behave as positively charged particles which are mobile, and carry current. A semiconductor where the electric current is carried predominantly by holes is called *p-type*

1.5 Semiconductor Junctions

The operation of solar cells is based on the formation of a *junction*. The important feature of all junctions is that they contain a strong electric field. To illustrate how this field comes about, let us imagine the hypothetical situation where the p-n junction is formed by joining together two pieces of semiconductor, one p-type and the other n-type. In separation, there is electron surplus in the n-type material and hole surplus in the p-type. When the two pieces are brought into contact, electrons from the n region near the interface diffuse into the p side, leaving behind a layer which is positively charged by the donors. Similarly, holes diffuse in the opposite direction, leaving behind a negatively charged layer stripped of holes. The resulting junction region then contains practically no mobile charge carriers, and the fixed charges of the dopant atoms create potential barrier acting against a further flow of electrons and holes. Note that the electric field in the junction pulls the electrons and holes in opposite directions.

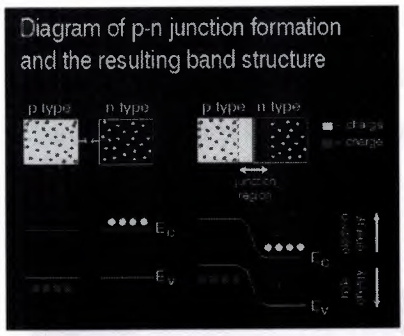

Figure 1.3 P-N junction formation and resulting band structure

The potential barrier of a junction permits the flow of electric current in only one direction - the junction acts as a rectifier, or diode. This can be seen in our example where electrons can only flow from the p region to the n region, and holes can only flow in the opposite direction. Electric current, which is the sum of the two, can therefore flow only from the p-side to the n-side of the junction (remember that it is defined as the direction of flow of the positive carriers!). The *I-V* characteristic of a diode

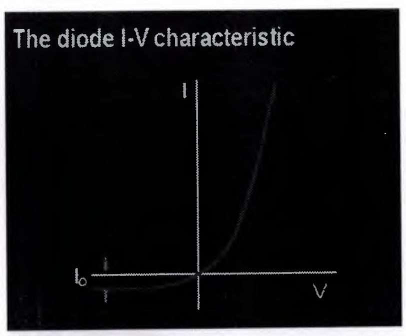

Figure.1.4 Light absorption by a semiconductor = generation

Photovoltaic energy conversion relies on the quantum nature of light whereby we perceive light as a flux of particles called photons. On a clear day, about 4.4 x 10^{17} photons strike a square centimeter of the Earth's surface every second. Only some of these photons - those with energy in excess of the band gap - can be converted into electricity by the solar cell. When such photon enters the semiconductor, it may be absorbed and promote an electron from the valence to the conduction band. Since a hole is left behind in the valence band, the absorption process generates *electron-hole pairs*.

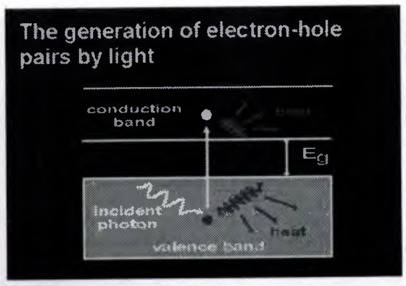

Figure 1.5 Generation of electron hole pairs by light

Each semiconductor is restricted to converting only a part of the solar spectrum. The spectrum is plotted here in terms of the incident photon flux as a function of photon energy. The shaded area represents the photon flux that can be converted by a silicon cell - about two-thirds of the total flux.

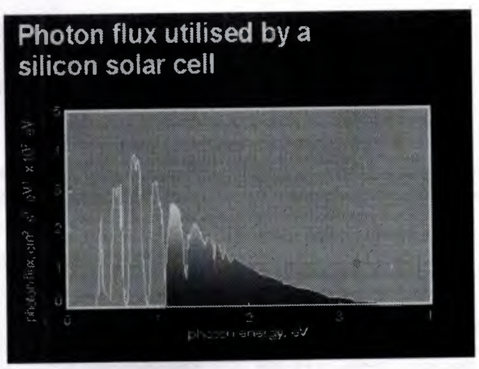

Figure 1.6 Photon flux used by Solar Cell

The nature of the absorption process also indicates how a part of the incident photon energy is lost in the event. Indeed, it is seen that practically all the generated electron-hole pairs have energy in excess of the band gap. Immediately after their creation, the electron and hole decay to states near the edges of their respective bands. The excess energy is lost as heat and cannot be converted into useful power. This represents one of the fundamental loss mechanisms in a solar cell. A solar cell is a device that transforms this electron traffic across the band gap into electric current.

1.6 How Solar Cells Work

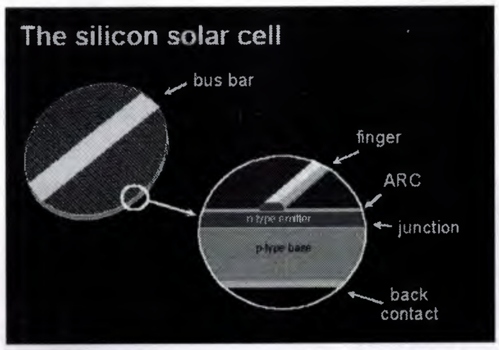

Figure 1.7 Solar Cell internal structure

This diagram shows a typical crystalline silicon solar cell. The electrical current generated in the semiconductor is extracted by contacts to the front and rear of the cell. The top contact structure which must allow light to pass through is made in the form of widely-spaced thin metal strips (usually called *fingers*) that supply current to a larger bus bar. The cell is covered with a thin layer of dielectric material - the *anti-reflection coating*, ARC - to minimize light reflection from the top surface.

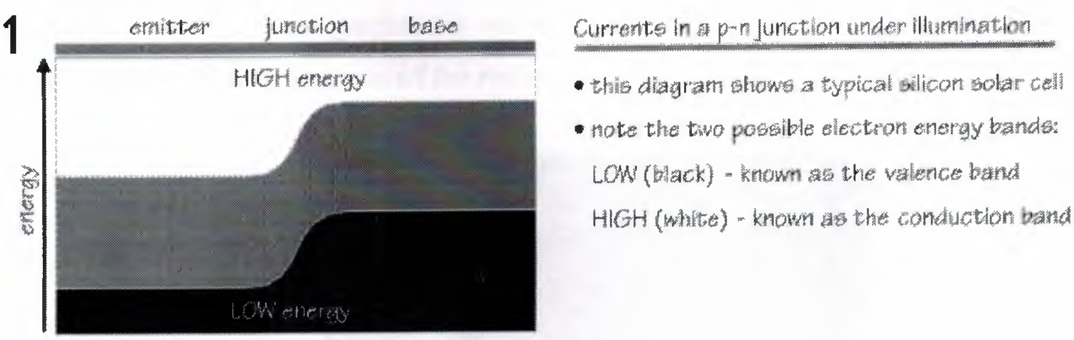

Figure 1.8 Current in Solar Cell under illumination

Solar cells are essentially semiconductor junctions under illumination. Light generates electron-hole pairs on both sides of the junction, in the n-type emitter and in the p-type base. The generated electrons (from the base) and holes (from the emitter) then diffuse to the junction and are swept away by the electric field, thus producing electric current across the device. Note how the electric currents of the electrons and holes reinforce each other since these particles carry opposite charges. The p-n junction therefore separates the carriers with opposite charge, and transforms the generation current between the bands into an electric current across the p-n junction. A more detailed consideration makes it possible to draw an equivalent circuit of a solar cell in terms of a current generator and a diode. This equivalent circuit has a current-voltage relationship.

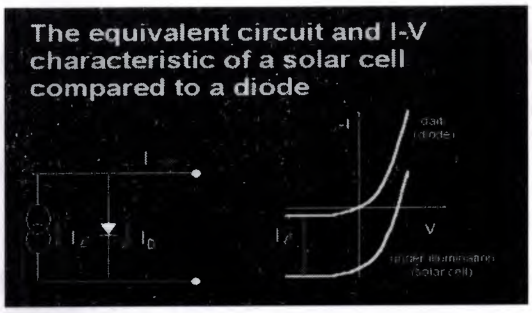

Figure 1.9 Comparison of Solar Cells with pn junction diode

In solar cell applications this characteristic is usually drawn inverted about the voltage axis, as shown below. The cell generates no power in short-circuit (when current I_{sc} is produced) or open-circuit (when cell generates voltage V_{oc}). The cell delivers maximum power P_{max} when operating at a point on the characteristic where the product IV is maximum. This is shown graphically below where the position of the maximum power point represents the largest area of the rectangle shown.

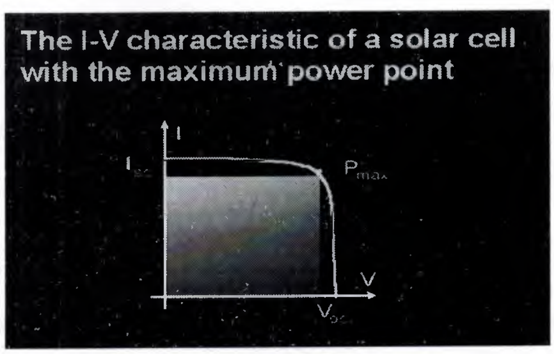

Figure 1.10 Characteristics of solar cell

The efficiency (n) of a solar cell is defined as the power P_{max} supplied by the cell at the maximum power point under standard test conditions, divided by the power of the radiation incident upon it. Most frequent conditions are: irradiance 100 mW/cm^2 , standard reference spectrum, and temperature 25 ^{0} C. The use of this standard irradiance value is particularly convenient since the cell efficiency in percent is then numerically equal to the power output from the cell in mW/cm^2

1.7 Modern Solar Cell

Modern solar cells are basically just P-N junction photodiodes with a very large light-sensitive area. So let's move along to get a bit of background on the semiconductor here solar energy is the most important form of energy for this planet. This is because all life on this planet depends on the energy received from the sun. Our coal-fired power stations would not exist today were it not for the sun. The plants that became coal stored the sun's energy, which is burnt to produce electricity. The most common way solar energy is used in Queensland is in solar hot water systems. These are large flat plates that directly heat the water, which is stored in an insulated tank until it is used.

1.8 Electricity Produced from Photovoltaic Cells is used in:

i. Calculators,
ii. Wristwatches and similar equipment water pumps
iii. Lighthouses
iv. Satellites

Unfortunately photovoltaic cells are too expensive at this time to be a viable alternative to produce enough electricity to satisfy the needs of a city. The two ways in which electricity can be produced from the sun are:

1. solar collectors which convert solar energy to thermal or heat energy;
2. Photovoltaic cells which convert solar energy directly to electric energy.

1.9 General Solar collectors

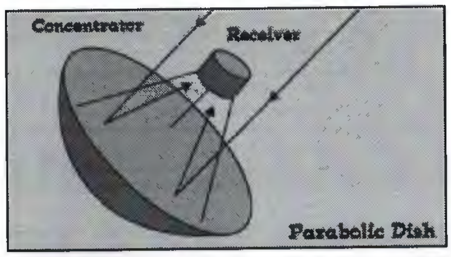

Figure 1.11 Parabolic Solar Collectors

Large reflectors concentrate or focus the sun's light onto a boiler. This heats water to produce steam that is used to drive a heat engine, which in turn drives a generator. Sometimes molten salt is used instead of water. To generate electricity in sufficient quantities, an array of solar collectors is necessary. An array is a bank of solar collectors.

1.9.1 Parabolic Dish

The parabolic dish is made of a highly reflective material. The dish reflects the sun's light to the focal point. Because the sun's light is concentrated at one point, high temperatures are achieved. The receiver is situated at the focal point of the parabolic dish where the heat of the sun's light is concentrated. A boiler is placed in this position water is

Latitude	Angle (degrees)
0' to 15	15
15 to 25	angle = latitude
25 to 30	latitude + 5
30 to 35	latitude + 10
35 to 40	latitude + 15
40 +	latitude + 20

Figure 1.12 Parabolic collector and its suitable angels

Converted to steam. This steam can then be used to generate electricity. The Australian National University (ANU) in Canberra has constructed a parabolic collector, which is capable of producing 80 kW of electricity.

1.10 Setting up a Solar Panel

The efficiency of a solar panel depends on the angle it is positioned. This is because the sun's light strikes the Earth's surface at an angle. Another factor to consider is that the sun tracks across the sky during the day. One way to counter these conditions is to use a "solar tracker" which allows the solar panel to follow the sun as it moves across the sky. The other alternative is to set up a solar panel so that the midday sunlight strikes it at an angle roughly equal to the latitude of your position. For example, if you were to set up a solar panel in Brisbane which is longitude 150° E and latitude 30° S, then your solar panel should be set at an angle of about 40° (using the table).

1.11 Available Types of Solar Cells -- Materials and Packaging

Three key elements in a solar cell form the basis of their manufacturing technology. The first is the semiconductor, which absorbs light and converts it into electron-hole pairs. The second is the semiconductor junction, which separates the photo-generated carriers (electrons and holes), and the third is the contacts on the front and back of the cell that allow the current to flow to the external circuit. The two main categories of technology are defined by the choice of the semiconductor: either crystalline silicon in a wafer form or thin films of other materials.

1.11.1 Crystalline Silicon Solar Cells

Figure 1.13 Crystalline Solar Cells

Historically, crystalline silicon (c-Si) has been used as the light-absorbing semiconductor in most solar cells, even though it is a relatively poor absorber of light and requires a considerable thickness (several hundred microns) of material. Nevertheless, it has proved convenient because it yields stable solar cells with good efficiencies (11-16%, half to two-thirds of the theoretical maximum) and uses process technology developed from the huge knowledge base of the microelectronics industry. Two types of crystalline silicon are used in the industry. The first is monocrystalline, produced by slicing wafers (up to 150mm diameter and 350 microns thick) from a high-purity single crystal boule. The second is multicrystalline silicon, made by sawing a cast block of silicon first into bars and then wafers. The main trend in crystalline silicon cell manufacture is toward multicrystalline technology. For both mono- and multicrystalline Si, a semiconductor homojunction is formed by diffusing phosphorus (an n-type dopant) into the top surface of the boron doped (p-type) Si wafer. Screen-printed contacts are applied to the front and rear of the cell, with the front contact pattern specially designed to allow maximum light exposure of the Si material with minimum electrical (resistive) losses in the cell. The most efficient production cells use monocrystalline c-Si with laser grooved, buried grid contacts for maximum light absorption and current collection. Some companies are product ionizing technologies that by-pass some of the inefficiencies of the crystal growth/casting and wafer sawing route. One route is to grow a ribbon of silicon, either as a plain two-dimensional strip or as an octagonal column, by pulling it from a silicon melt. Another is to melt silicon powder on a cheap conducting substrate. These processes may bring with them other issues of lower growth/pulling rates and poorer uniformity and surface roughness. Each c-Si cell generates about 0.5V, so 36 cells are usually soldered together in series to produce a module with an output to charge a 12V battery. The cells are hermetically sealed under toughened, high transmission glass to produce highly reliable, weather resistant modules that may be warranted for up to 25 years.

1.11.2 Developing Technology: Concentrators

Solar cells usually operate more efficiently under concentrated light. This has led to the development of a range of approaches using mirrors or lenses to focus light on to specially designed cells and use heat sinks, or active cooling of the cells, to dissipate the large amount of heat that is generated. Unlike conventional flat plate PV arrays, concentrator systems require direct sunlight (clear skies) and will not operate under cloudy conditions. They generally follow the sun's path through the sky during the day using single-axis tracking. To adjust to the sun's varying height in the sky through the seasons, two-axis tracking is sometimes used. Concentrators have not yet achieved widespread application in photovoltaic, but solar concentration has been widely used in solar thermal electricity generation technology where the generated heat is used to power a turbine

1.11.3 Developing Technology: Electrochemical PV cells

Unlike the crystalline and thin film solar cells that have solid-state light absorbing layers, electrochemical solar cells have their active component in a liquid phase. They use a dye sensitizer to absorb the light and create electron-hole pairs in a nanocrystalline titanium dioxide semiconductor layer. This is sandwiched in between a tin oxide coated glass sheet (the front contact of the cell) and a rear carbon contact layer, with a glass or foil backing sheet. Some consider that these cells will offer lower manufacturing costs in the future because of their simplicity and use of cheap materials. The challenges of scaling up manufacturing and demonstrating reliable field operation of products lie ahead. However, prototypes of small devices powered by dye-sensitized nanocrystalline electrochemical PV cells are now appearing (120cm2 cells with an efficiency of 7%).

1.11.4 Thin film Solar Cells

Figure 1.14 Thin Film Solar Cells

The high cost of crystalline silicon wafers (they make up 40-50% of the cost of a finished module) has led the industry to look at cheaper materials to make solar cells. The selected materials are all strong light absorbers and only need to be about 1micron thick, so materials costs are significantly reduced. The most common materials are amorphous silicon (a-Si, still silicon, but in a different form), or the polycrystalline materials: cadmium telluride (CdTe) and copper indium (gallium) diselenide (CIS or CIGS). Each of these three is amenable to large area deposition (on to substrates of about 1 meter dimensions) and hence high volume manufacturing. The thin film semiconductor layers are deposited on to either coated glass or stainless steel sheet. The semiconductor junctions are formed in different ways, either as a p-i-n device in amorphous silicon, or as a hetero-junction (e.g. with a thin cadmium sulphide layer) for CdTe and CIS. A transparent conducting oxide layer (such as tin oxide) forms the front electrical contact of the cell, and a metal layer forms the rear contact. Thin film technologies are all complex. They have taken at least twenty years, supported in some cases by major corporations, to get from the stage of promising research (about 8% efficiency at 1cm2 scale) to the first manufacturing plants producing early product. Amorphous silicon is the most well developed of the thin film technologies. In its simplest form, the cell structure has a single sequence of p-i-n layers. Such cells suffer from significant degradation in their power output (around 30% generally) when exposed to the sun. The mechanism of degradation is called the Staebler-Wronski Effect, after its discoverers. Better stability requires the use of thinner layers in order to increase the electric field strength across the material. However, this reduces light absorption and hence cell efficiency. This has led the industry to develop tandem and even triple layer devices that contain p-i-n cells stacked one on top of the other. In the cell at the base of the structure, the a-Si is sometimes alloyed with germanium to reduce its band gap and further improve light absorption. All this added complexity has a downside though; the processes are more complex and process yields are likely to be lower. In order to build up a practically useful voltage from thin film cells, their manufacture usually includes a laser scribing sequence that enables the front and back of adjacent cells to be directly interconnected in series, with no need for Further solder connection between cells. As before, thin film cells are laminated to produce a weather resistant and environmentally robust module. Although they are less efficient (production modules range from 5 to 8%), thin films are potentially cheaper than c-Si because of their lower materials costs and larger substrate size. However, some thin film materials have shown degradation of performance over time and stabilized efficiencies can be 20-30% lower than initial values. Many thin film technologies have demonstrated best cell efficiencies at research scale above 13%, and best prototype module efficiencies above 10%. The technology that is most successful in achieving low manufacturing costs in the long run is likely to be the one that can deliver the highest stable efficiencies (probably at least 10%) with the highest process yields. Amorphous silicon is the most well-developed thin film technology to-date and has an interesting avenue of further development through the use of "microcrystalline" silicon which seeks to combine the stable high efficiencies of crystalline Si technology with the simpler and cheaper large area deposition technology of amorphous silicon. However, conventional c-Si manufacturing technology has continued its steady improvement Year by year and its production costs are still falling too. The emerging thin film technologies have yet to make significant in-roads into the dominant position held by the relatively mature c-Si technology. However, they do hold a niche position in low power (<50W) and consumer electronics applications, and may offer particular design options for building integrated applications.

1.12 Cell Packaging

Solar cells also are available in a variety of packages. Most common are "raw cells," often with some cover sheet attached. One popular line of cells, the Panasonic Sunbeams, consist of amorphous silicon cells, deposited on the back of a glass substrate (in this case, the glass functions as both substrate and cover sheet). These are durable and cost-effective cells, if a bit heavy due to the thickness of the glass. Encapsulated solar cells are also sold -- as the name implies, an enclosure (often plastic, often with some sort of concentrator lenses built into the cover sheet) contains a regular (generally multicellular) solar cell or cells. These are extremely durable, if heavy and none too efficient. Recently, flexible solar cells have become available. These are amorphous cells on a thin plastic substrate -- low efficiency, fairly high cost, but light and a very useful package for some applications.

1.13 Battery Power for Your Residential

Solar Electric System

A battery bank stores electricity produce by a solar electric system. If your house is not connected to the utility grid, or if you anticipate long power outages from the grid, you will need a battery bank. This fact sheet provides an overview of battery basics, including information to help you select and maintain your battery bank.

1.13.1 Types of Batteries

There are many types of batteries available, and each type is designed for specific applications. Lead-acid batteries have been used for residential solar electric systems for many years and are still the best choice for this application because of their low maintenance requirements and cost. You may remember the flooded version, which used to be widely used in automobiles. The sealed version is used in most types of portable equipment. Other names for sealed batteries are absorbed glass mat, valve regulated lead acid, and gel. Lithium and nickel which are commonly used in cell phones, laptop computers, and camcorders because of their energy-to weight ratios, are very expensive and may be difficult to use in residential solar applications. The best kinds of batteries power system are deep-discharge Lead-acid batteries specially designed for stationary batteries may be a less expensive alternative. Car and marine batteries are not recommended for solar electric system use because they are designed to give a large burst of energy when starting a vehicle and are not made for deep discharges. Although they are sometimes used in situations in which deep discharge batteries are not available, car and marine batteries will quickly fail if used in a solar electric application.

1.13.2 The Battery Bank

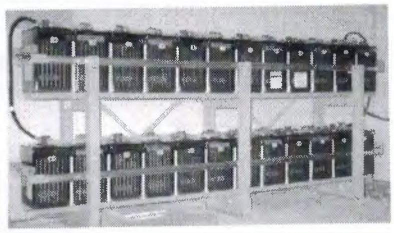

Figure 1.15 Solar Battery Banks

The basic building block of a lead-acid battery is a 2-volt cell. A battery bank is a collection of connected 2-, 6-, or 12-volt batteries that supply power to the household in case of outages or low production from renewable energy sources. The batteries are wired together in series to produce 12-, 24-, or 48-volt strings. These strings are then connected together in parallel to make up the entire battery bank. The battery bank supplies DC power to an inverter, which produces AC power that can be used to run appliances. The decision to select a 12-, 24-, or 48-volt battery bank will be determined by the inverter's input, the type of battery you select, and the amount of energy storage you require.

1.13.3 Sizes and Costs

To determine the number of batteries you need, you must first determine how much energy storage you need in kilowatt-hours (kWh). If you are connected to the utility grid, you can use your monthly utility bill to calculate past energy usage for your household. (Keep in mind that implementing energy-efficiency measures in your home is a preliminary step to installing a solar electric system. Reducing energy consumption and installing energy-efficient appliances are far cheaper than purchasing larger solar electric systems.) A second way to determine your required kWh of energy storage is to multiply the wattage of your appliances by the number of hours you use them in a day. Because watts = amps x volts, if you require 1,000 watt-hours (or 1 kWh) per day, and if you have a 24-volt battery bank, then you need 42 amp-hours of useful storage. Because you cannot fully discharge lead-acid this 24-volt battery bank, used at a remote home powered by a solar-electric system, consists of 2-volt, lead-acid batteries. The batteries are flooded and have clear cases for easy maintenance and quick visual Inspection of the plates and the electrolyte levels.

1.14 Summary

This whole chapter explains the solar cell function and the way solar cell convert the solar energy into electric energy further more all facts and figure that explain solar cell are concerned in this chapter. The different types of batteries and collectors that are use to do same function also are concerned in this chapter.

CHAPTER TWO

TRANSFORMATION FROM SOLAR TO ELECTRICAL ENERGY

2.1 Overview

Method is described in the thesis to investigate the production potential of photo-voltaic (PV) installations. The method considers the latitude and the horizon profile of a specific site to predict the amount of available energy. The horizon profile is especially important for high-latitude locations like Sweden where the sun spends a large fraction of time close to the horizon. A related problem is shading due to nearby objects. Due to the connection of the solar panels, the percentage reduction in energy production is much more than the percentage of the panel that is shaded. Decentralized PV inverters are proposed to limit the effect of Shading on the energy production.

2.2 Conversion from DC to AC

Solar cells produce electrical energy at a voltage of about 0.5 Volt. This is a dc voltage which has to be converted to the utilization voltage of 230 Volt, 50 Hz (in Europe). A number of Conversion methods are compared in the thesis, with the emphasis of the description being on the two methods which had clear advantages over the other methods. These two methods use a two-step conversion process with an intermediate voltage level. For one method a number of small dc/dc converters are connected to one larger dc/ac converter. For the other method a Number of small dc/ac converters is connected to one (normal) ac/ac transformer.

The two Configurations are shown in Figure 2.1.

230 Vac 230 Vac

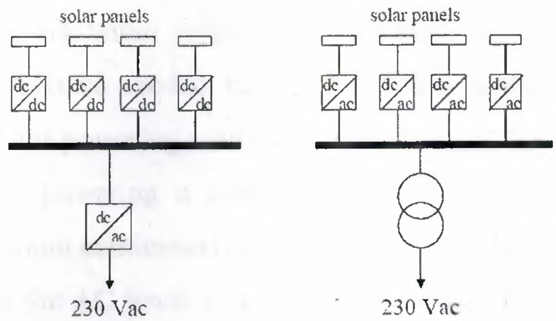

Figure 2.1 Connection of solar panels to the public low-voltage system with a dc (left) and a (right) intermediate voltage level.

A 110 Watt dc/ac converter has been designed and built for use in the configuration on the Right-hand side of Figure 2.1. This converter uses a PWM-based controller together with four Mosfet transistors.

2.3 Inverters for Grid-Tied System

An inverter converts direct current (DC) into alternating current (AC) by mechanical or electronic means and makes renewable resources and energy-storage systems utility interactive. Inverters are basic components on most small and large energy systems that convert low-voltage DC power generated from a renewable energy source into higher-voltage AC power required for many residential, commercial, and industrial applications. Grid-tied inverters are required in energy systems that produce or store electric energy in DC form and transfer that energy to or from an AC power system. Typical energy systems include solar photovoltaic (PV), wind turbines, batteries, and fuel cells. Stand-alone inverters can be used to convert DC from a battery to AC to run electronic equipment, motors, appliances, etc. Intertie Inverters are used to convert the DC output of a photovoltaic module, a wind generator or a fuel cell to AC power to be sold to the utility grid. Multifunction inverters perform both functions.

2.3.1 Stand-Alone Inverters

Stand-alone inverters convert DC power stored in batteries to AC power that can be used as needed. Selecting an inverter for your power system based on the maximum load you will be powering, the maximum surge required, output voltage required, input battery voltage and optional features needed. High quality stand-alone inverters are available in sizes from 100 watts, for powering notebook computers and fax machines from your car, to 500,000 watts, for powering a commercial operation. The size of an inverter is measured by its maximum continuous output in watts. This rating must be larger than the total wattage of all of the AC loads you plan to run at one time. The size of the inverter can be minimized if the number and size of the AC loads is kept under control. Wattage of most AC loads can be determined from a tag or label on the appliance, usually located near where the power cord enters, or from the owner's manual. If the inverter is expected to run induction motors, like the ones found in automatic washers, dryers, dishwashers and large power tools, it must be designed to surge, or deliver power many times its rating for short periods of time while these motors start. Stand-alone inverters are available with three basic power output waveforms: square wave, modified square wave (often called modified sine wave) and sine wave. Intertie inverters and utility companies deliver a sine wave. Square wave inverters have the lowest cost and efficiency and are not sold in this catalog. The price of the better quality inverters is low enough to make square wave inverters an unattractive choice. Trace UX series, DR series, U series inverters and Genius inverters have modified square wave output with harmonic distortion of around 40%. They are an economical choice in power systems where waveform is not critical. Their high surge capacity allows them to start large motors while their high efficiency makes them economical with power when running small loads like a stereo or a small light. They can power most lighting, televisions, appliances and computers very well. We do not recommend them for computer systems with laser printers. -Unfortunately, this type of inverter may destroy some low cost rechargeable tools and flashlights, and their waveform will not allow many laser printers, copiers, light dimmers and some variable speed tools to operate. Equipment with silicon controlled rectifiers or SCRs will not operate. Some audio equipment will have a background buzz that may be annoying to music connoisseurs. Sine wave inverters have a slightly higher cost, but they can operate almost anything that can be operated on utility power. Trace Sine wave inverters are available in sizes from 2500 watts to 5500 watts, and a pair of them can be synchronized to deliver up to 11,000 watts. They are an excellent choice for a 'whole house" inverter. Exeltech sine wave inverters, available in sizes from 150 watts to 5000 watts, are an excellent choice for power systems running audio or telecommunications equipment and other electronics that are waveform-sensitive. Larger Sine wave inverters are available in sizes up to 500,000 watts that can run a small village.

2.3.2 Intertie Inverters

Intertie inverters change DC power into AC power to be fed into the utility grid. A power system with this type of inverter uses the utility company as a storage battery. When the sun is shining, your electricity comes from the PV array, via the inverter. If the PV array is making more power than you are using, the excess is sold to the utility (Power Company) through an electric meter. If you use more power than the PV array can supply, the utility makes up the difference. This type of system makes the most sense if you have utility power, because there are no batteries to maintain or replace, but it has a very long payback period and may not be cost-effective at today's electric rates. The Trace SWPV, UT and micro sine, AEI GC and Omnion 2400 inverters are examples of an intertie inverter. Using a multifunction inverter allows you to sell excess power to the utility, and also maintain a battery bank for standby power in the event of a utility power failure.

2.3.3 Multifunction Inverters

Trace Engineering Company produces a line of sine wave inverters called the SW line that can operate as a stand-alone inverter and as an intertie inverter at the same time. In a typical installation, the Trace SW inverter is connected to a battery bank, the utility power lines, a standby generator and the house load center. When batteries are in a charged condition, the SW inverter supplies AC power to the house from the batteries. If the batteries become discharged, the inverter supplies the house loads from the utility lines, while charging the batteries. If the batteries become fully charged by another power source, such as photovoltaic modules or a wind or hydroelectric generator, excess power may be sold back to the utility. If utility power fails, the inverter can still operate, supplying critical loads. If a standby generator is started, it can also supply power to loads. The inverter will synchronize to the generator and allow loads to be powered that are too large for either the generator or inverter to supply alone. Multifunction inverters are not the most efficient intertie inverters because the system must have a battery, but they allow system flexibility that intertie inverters do not.

2.3.4 Output Voltage

Inverters that supply standard 120 Volt 60 HZ AC power, such as one gets from utility companies and fuel-powered generators. Most of them can be special ordered with other output voltages and frequencies for use anywhere in the world.

2.3.5 Interference

The electronic circuitry in inverters may, in some cases, cause problems with radio and television reception, noise on telephones and buzz in audio equipment. Sine wave inverters cause the least amount of interference. Interference can be minimized by locating the inverter very close to the batteries, twisting together the cables that connect the inverter to the battery, running AC lines separate from other wiring (such as telephone wires) and locating the inverter away from appliances that are susceptible to interference. All inverters cause interference on AM radio!

2.3.6 Reduction of Pollutants

The reduction of CO^2 emission and other pollution resulting from energy conversions is becoming more and more important. The direct conversion of solar radiation to electric energy (Photovoltaic) will play a substantial role in this essential matter. One way that consumers can help to avoid an energy crisis is to engage in net metering. Net metering is the process by which excess solar electricity generated in a home is sent back through their electric meter and into the utility electric power grid. Net metering provides a simplified, easily administered, and inexpensive approach for interconnecting and metering customer-sited, small-scale renewable generating facilities. Net metering requires a grid-tied system

2.4 Powers-System Integration

Large amounts of solar power integrated in the electrical power system may deteriorate the quality of the supply voltage. Two integration issues are discussed in this thesis: the injection of harmonic currents by the inverters; the rise in voltage during low-load high-isolation periods. Measurements show that the even-harmonic and high-frequency harmonic current distortion of individual inverters is on the high side. However the harmonic components from different inverters have independent phase angles resulting in their cancellation when many inverters are connected close to the same location in the system. Simulations show that the combined distortion of 10 inverters is well within acceptable limits. This has been confirmed by Measurements. A control algorithm has been developed to limit the voltage rise due to the injection of active Power. The inverter produces or consumes reactive power depending on the voltage at the Inverter terminals. Mathematical models and simulations have shown that this control method significantly reduces the voltage variations and the risk of over voltage.

2.5 Energy Loss

Why does our solar cell absorb only about 15 percents of the sunlight's energy? Visible light is only part of the electromagnetic spectrum. Electromagnetic radiation is not monochromatic -- it is made up of a range of different wavelengths, and therefore energy levels. Light can be separated into different wavelengths, and we can see them in the form of a rainbow. Since the light that hits our cell has photons of a wide range of energies, it turns out that some of them won't have enough energy to form an electron-hole pair. They'll simply pass through the cell as if it were transparent. Still other photons have too much energy. Only a certain amount of energy, measured in electron volts (eV) and defined by our cell material (about 1.1 eV for crystalline silicon), is required to knock an electron loose. We call this the band gap energy of a material. If a photon has more energy than the required amount, then the extra energy is lost (unless a photon has twice the required energy, and can create more than one electron-hole pair, but this effect is not significant). These two effects alone account for the loss of around 70 percent of the radiation energy incident on our cell. Why can't choose a material with a really low band gap, so we can use more of the photons? Unfortunately, our band gap also determines the strength (voltage) of our electric field, and if it's too low, then what we make up in extra current (by absorbing more photons), we lose by having a small voltage. Remember that power is voltage times current. The optimal band gap, balancing these two effects, is around 1.4 eV for a cell made from a single material. We have other losses as well. Our electrons have to flow from one side of the cell to the other through an external circuit. We can cover the bottom with a metal, allowing for good conduction, but if we completely cover the top, then photons can't get through the opaque conductor and we lose all of our current (in some cells, transparent conductors are used on the top surface, but not in all). If we put our contacts only at the sides of our cell, then the electrons have to travel an extremely long distance (for an electron) to reach the contacts. Remember, silicon is a semiconductor -- it's not nearly as good as a metal for transporting current. Its internal resistance (called series resistance) is fairly high, and high resistance means high losses. To minimize these losses, our cell is covered by a metallic contact grid that shortens the distance that electrons have to travel while covering only a small part of the cell surface. Even so, some photons are blocked by the grid, which can't be too small or else its own resistance will be too high.

2.6 Finishing the Cell

There are a few more steps left before we can really use our cell. Silicon happens to be a very shiny material, which means that it is very reflective. Photons that are reflected can't be used by the cell. For that reason, an antireflective coating is applied to the top of the cell to reduce reflection losses to less than 5 percent the final step is the glass cover plate that protects the cell from the elements. PV modules are made by connecting several cells (usually 36) in series and parallel to achieve useful levels of voltage and current, and putting them in a sturdy frame complete with a glass cover and positive and negative terminals on the back.

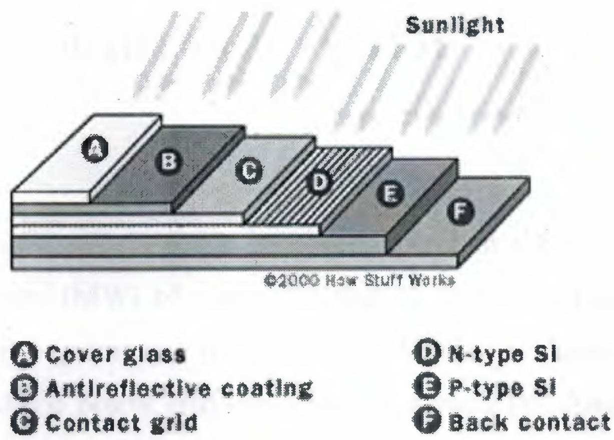

Figure 2.2 Basic structure of a generic silicon PV cell

More than one electric field Single crystal silicon isn't the only material used in PV cells. Polycrystalline silicon is also used in an attempt to cut manufacturing costs, although resulting cells aren't as efficient as single crystal silicon. Amorphous silicon, which has no crystalline structure, is also used, again in an attempt to reduce production costs. Other materials used include gallium arsenide, copper indium dieseline and cadmium telluride. Since different materials have different band gaps, they seem to be "tuned" to different wavelengths, or photons of different energies. One way efficiency has been improved is to use two or more layers of different materials with different band gaps. The higher band gap material is on the surface, absorbing high-energy photons while allowing lower-energy photons to be absorbed by the lower band gap material beneath. This technique can result in much higher efficiencies. Such cells, called multi-junction cells,

2.7 Summary

In this chapter we learned the transformation of solar energy to electrical energy. We used different kind of inverters. At the end we applied an antireflective coating to the cell to reduce the reflection losses in the finishing of cell.

CHAPTER THREE

SOLAR ENRGY SYSTEM

3.1 Overview

Designing the largest solar electric generating plant in the world produces a maximum of 354 megawatts (MW) of electricity and is located at Kramer Junction, California. This solar energy generating facility, shown below, produces electricity for the Southern California Edison power grid supplying the greater Los Angeles area. The authors' goal is to provide the necessary information to design such systems. The solar collectors concentrate sunlight to heat a heat transfer fluid to a high temperature. The hot heat transfer fluid is then used to generate steam that drives the power conversion subsystem, producing electricity. Thermal energy storage provides heat for operation during periods without adequate sunshine.

3.2 Designing and arranging the solar power station

Figure 3.1 One of nine solar electric energy generating systems at Kramer Junction, California, with a total output of 354 MWe.

Another way to generate electricity from solar energy is to use photovoltaic cells; magic slivers of silicon that converts the solar energy falling on them directly into electricity. Large scale applications of photovoltaic for power generation, either on the rooftops of houses or in large fields connected to the utility grid are promising as well to provide clean, safe and strategically sound alternatives to current methods of electricity generation.

Figure 3.2 A 2-MW utility-scale photovoltaic power system co-located with a defunct nuclear power plant near Sacramento, California.

The following chapter examines basic principles underlying the design and operation of solar energy conversion systems such as shown in Figure 3.1 and 3.2. This includes collection of solar energy, either by a thermal or photovoltaic process, and integration with energy storage and thermal-to-electric energy conversion to meet a predefined load. Study of the interaction of these subsystems yields the important guidelines for the design of optimal solar energy systems. System design tools are provided to produce optimal sizing of both collector field and storage so that optimum system designs can be produced. Emphasis is on the design of entire solar energy conversion systems rather than design of its individual components; both thermal and photovoltaic systems are included. This novel approach results from recognition of the commonality of most system design considerations for both types of solar energy systems. We will not dwell on the intricacies of individual component design, but instead encourage the designer to take experimental (or predicted) component input/output information and incorporate this into an overall system design The system shown in Figure 3.1 employs parabolic trough line-focus collectors. We will cover this and other types of collectors for capturing the sun's energy including flat plate, parabolic dish, central receiver and photovoltaic collectors. The purpose of a solar collector is to intercept and convert a reasonably large fraction of the available solar radiation. For solar thermal systems this energy is converted into thermal energy at some desired temperature and then, maybe, into electricity. For photovoltaic systems as shown in Figure 3.2, intercepted solar energy is converted directly into low voltage direct current electricity. The engineering tradeoff between cost and performance of the components necessary to perform these processes has led to a wide variety of collector and system designs. Reviews of solar collector designs representative of the different concepts that have been built and tested are presented here. The following sections serve as an overview of the solar energy system design process. They follow in a general manner, the flow of logic leading from the basic solar resource to the definition of an operating solar energy conversion system that meets a specified demand for either thermal or electrical energy. *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 3.3. 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.

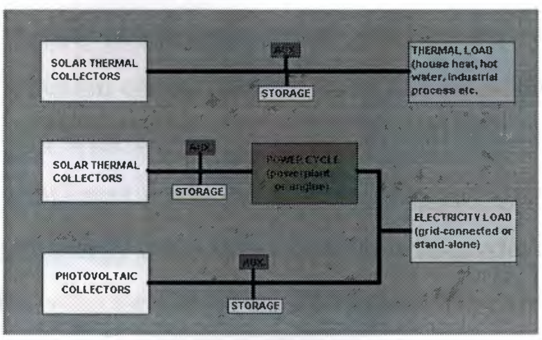

Figure 3.3 Diagram of a basic solar energy conversion system. The AUX. box represents some auxiliary source of thermal or electrical energy.

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. Both methods are shown schematically in Figure 3.3. 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.

3.3 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 (isolation) is relatively constant outside the earth's atmosphere, local climate influences can cause wide variations in available isolation 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. Figure 3.4 shows regions of high isolation where solar energy conversion systems will produce the maximum amount of energy from a specific collector field size. 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.

Figure 3.4 Areas of the world with high isolation.

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. Figure 3.5 shows the variation of isolation over a full, clear day in March at Daggett, California, a meteorological measurement site close to the Kramer Junction solar power plant described previously. The outer curve, representing the greatest rate of incident energy, shows the energy coming directly from the sun (*beam normal isolation*) and falling on a square meter of surface area which is pointed toward the sun. The peak rate of incident solar energy occurs around 12:00 noon and is 1,030 Watts per square meter. Over the full day, 10.6 kilowatt-hours of energy has fallen on every square meter of surface area as represented by the area under this curve.

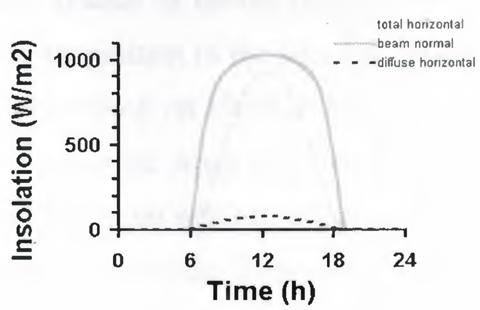

Figure 3.5 Isolation data from Daggett, California on a clear March day.

The middle curve represents the rate of solar energy falling on a horizontal surface at the same location. This curve includes both the energy coming directly from the sun's disc, and also that scattered by the molecules and particles in the atmosphere (*total horizontal isolation*). This scattered energy is shown as the bottom curve (*diffuse isolation*). Over the entire day, 6.7 kilowatt-hours of solar energy fall on every square meter of horizontal surface, of which 0.7 kilowatt-hours comes from all directions other than directly from the sun. An example of a complete set of beam normal isolation data for a given location is shown in Figure 3.6. Here we see hourly isolation data, summarized over a day, for each month of a year. With this type of data for a specific site, it is possible to predict accurately the output of a solar energy conversion system, whether it is a low temperature thermal system, a high temperature thermal system or a photovoltaic system.

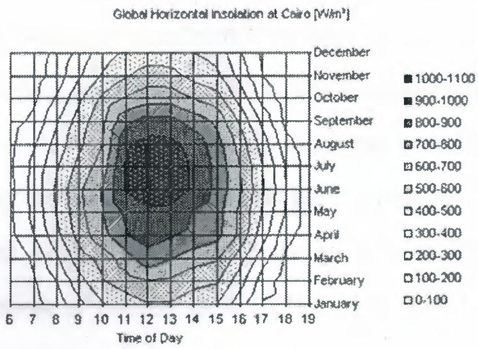

Figure 3.6 Time and date description of the global, horizontal isolation solar resource for Cairo India.

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. The sun's position must be known to predict the amount of energy falling on tilted surfaces, and to determine the direction toward which a tracking mechanism must point a collector. Discussion includes the computation of the position of the sun with respect to any given point on the face of the earth. 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 may 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.

3.4 Solar Collectors used in solar power stations

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 isolation 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°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 isolation) 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 3.7 shows an installation of flat-plate thermal collectors.

Figure 3.7 Flat-plate thermal solar collectors for providing hot water

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.

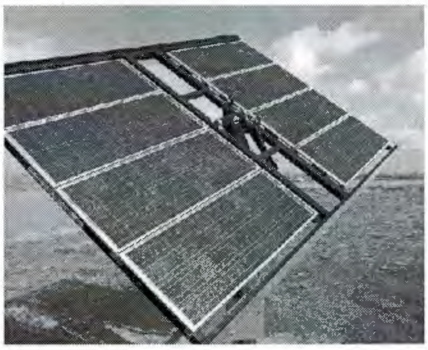

Figure 3.8 Solar panel

Figure 3.9 Flat-plate photovoltaic collector applications

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 isolation coming directly from the sun's disk (beam normal isolation), 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 shown in Figure 3.1), parabolic dishes, central receivers and Fresnel lenses. Figure 3.10 shows these concepts schematically.

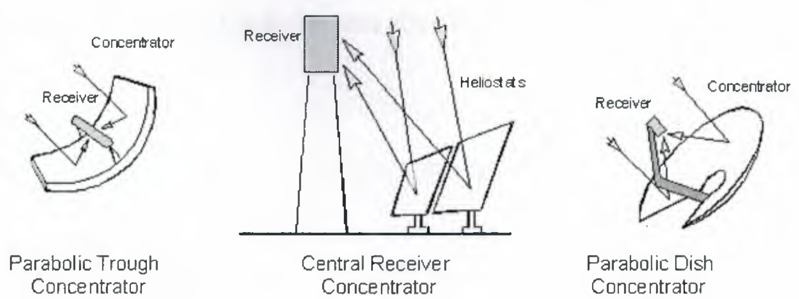

Figure 3.10 Three commonly used reflecting schemes for concentrating solar energy to attain high temperatures.

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. Figure 3.10shows one parabolic trough from the Kramer Junction, California field shown in Figure 3.12 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 3.13 shows six 9kWe parabolic dish concentrators with Stirring 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 isolation, thereby heating the heat transfer fluid passing through the tubes. Figure 3.11 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 3.10 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 3.11 A central receiver system.

Figure 3.12 Two-axis tracking parabolic dishes collectors

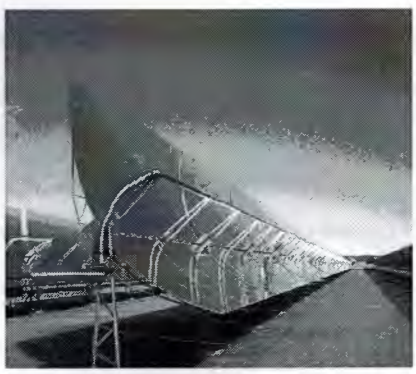

Figure 3.13 A single-axis tracking parabolic trough collector.

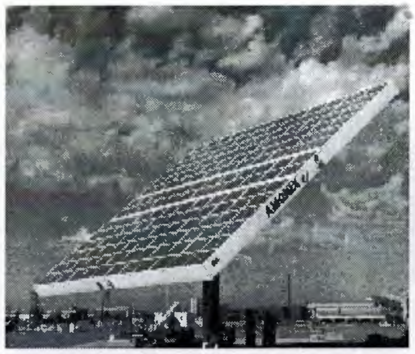

Figure 3.14 A concentrating photovoltaic collector using Fresnel lenses.

3.5 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 isolation 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 isolation 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.

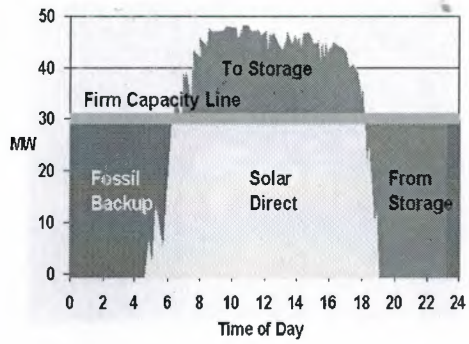

Figure 3.15 Stored solar energy provides a firm capacity of 31MW until midnight at which time fossil fuel backup us used.

3.6 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. 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, whereas the efficiency of solar collectors decreases with temperature. A tradeoff must be performed to determine the best system design point.

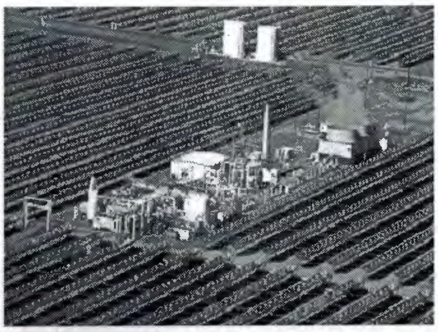

Figure 3.16 One of the steam cycle power cycles at the Kramer Junction solar energy generating system.

3.7 Site Qualification

Solar technologies using concentrating systems for electrical production require sufficient beam normal radiation, which is the beam radiation which comes from the sun and passes through the planet's atmosphere without deviation and refraction. Consequently, appropriate site locations are normally situated in arid to semi-arid regions. On a global scale, the solar resource in such regions is very high. More exactly, acceptable production costs of solar electricity typically occur where radiation levels exceed about 1,700 kWh/m^2-yr, a radiation level found in many areas as illustrated in Figure 3.4. 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.

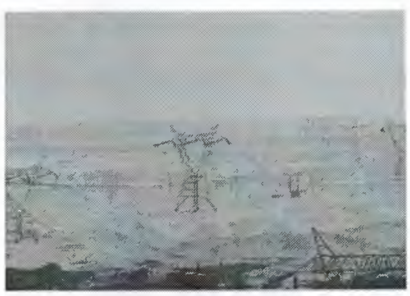

Figure 3.17 A View of Kuraymat (Egypt), the envisaged site for a solar thermal power plant in the Egyptian desert with cooling water from the Nile and connections to the national high voltage grid.

Solar electricity generation costs and feasibility of the project highly depend on the project site itself. A good site has to have a high annual beam isolation to obtain maximum solar electricity output. It must be reasonably flat to accommodate the solar field without prohibitive expensive earth works. It must also be close to the grid and a substation to avoid the need to build expensive electricity lines for evacuating the power. It needs sufficient water supply to cover the demand for cooling water of its steam cycle. A backup fuel must be available for granting firm power during the times when no solar energy is available. Access roads must be suitable for transporting the heavy equipment like turbine generators to the site. Skilled personnel must be available to construct and operate the plants.

3.8 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 isolation, 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.

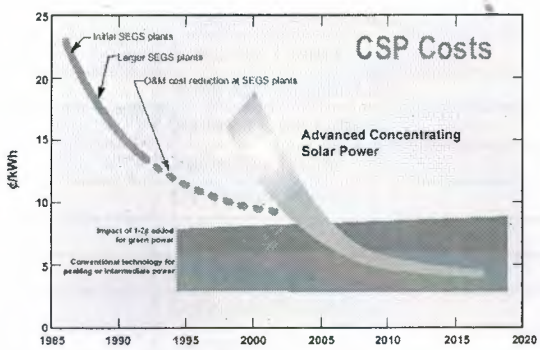

Figure 3.18 Projections of levelized electricity cost predictions for large scale solar thermal power plants. Current costs are shown in blue with a 1-2 cent/kWh addition for 'green' power shown in green.

3.9 Solar Power Plants, Worldwide

100kW+
(as of 3/15/2004)

Locale	Description	Size
Australia		
Sydney	Olympic Village Housing	630 kW
Singleton, Upper Hunter Valley	Hybrid Power Plant	400 kW
Wilpena Pound, South Australia	Hybrid Power Plant	100 kW
Canberra	ANU Tech large dish test facility	600 kW
Austria		
Bions	**Biospharenpark**	**420 kW**
Werfenweng	**PV Plant**	**235 kW**
St. Veit	**GreenOneTec, RM**	**180 kW**
Belize		
Ambergris Cay	**Essene Way Hybrid PV System**	**100 kW**
China		
Shenzhen Province	VanMelli PV System	114 kW
Denmark		
Kolding	**Solgarden Installation**	**106 kW**
Germany		
Hemau	Solarpark Hemau	4 MW
Munich	Munich Trade Fair	2.1 MW
Neustadt	Solarpark Neustadt	2 MW
Passau	Solarpark Sonnen	1.75 MW
Passau	Solarpark Oberotzdorf-Untergriesbach	1.7 MW

Markstetten/Oberpfalz	Solarpark Markstetten	1.6 MW
Relzow	Logistics Center	1.5 MW
Saarbrucken	Solarpark Saarbrucken	1.4 MW
Meerane	Solarpark Meerane	1.1 MW
Furth	Solarpark Furth	1 MW
Herne	PV Power Plant	1 MW
Biebesheim (Sudhessen)	Warehouse	951 kW
Pellworm Island	PV Power Plant	600 kW
Sochtenau/Rosenheim	Solarpark Sochtenau	599 kW
Neuenmarkt	Burgersolarkraftwerk	584 kW
Ichenhausen-Autenried	Creaton Company	583 kW
Freising (Munich)	Motorway Noise Barrier	499 kW
Tauberbischofsheim	VS Vereinigte Spezialmobelfabriken	494 kW
Morbach/Hunsruck, Rheinland-Pfalz	GroBanlage Morcacher Energielandschaft	490 kW
Miltenberg	Kompostieranlage Guggenberg	454 kW
Munich	Munich Airport	450 kW
Freiburg	Messe Freiburg	440 kW
Bad Cannstatt	Mercedes Benz Plant	435 kW
Bochingen	Mulldeponie	378 kW
Neurather See	PV Plant	360 kW
Dortmund	Eissportzentrum der Westfallenhallen	345 kW

Kobern-Gondorf	RWE Utility	340 kW
Bad Oeynhausen	Innovation Center	302 kW
Hannover	Uestra Public Transportation Company	250 kW
Korkwitz	City power plant	250 kW
Freiburg	Solarsiedlung am Schlierberg	245 kW
Gelsenkirchen	Office Building	225 kW
Bremen	Terrace House PV Systems (80)	200 kW
Berlin	Heinrich-Boll Siedlung Residential	145 kW
Fehmarn	PV Power Plant	140 kW
Berlin	Paul-Loebe-Haus, German Parliament	123 kW
Offenburg	Hans Grohe Ltd.	100 kW
Berlin	Federal Ministry of Economic Affairs	100 kW
Freiburg	Stadion SC Freiburg	100 kW
Gelsenkirchen	Shell Solar Production Hall	100 kW
Greece		
Kythnos Island	Greek Public Power Corporation Hybrid Plant	160 kW
Crete	SolarGen fixed dish test facility	900 kW
India		
Coimbatore, Tamil Nadu	NEPC, Chennai	100 kW
Lonavala, Maharashtra	Tata BP Solar and Tata Electric	100 kW
Kalyanpura, Uttar Pradesh	NEDA, Uttar Pradesh	100 kW
Gosi, Uttar Pradesh	NEDA, Uttar Pradesh	100 kW

Israel		
Rehovot	**Weizmann Institute Power Tower**	**3MW**
Italy		
Serre	ENEL Research Center	3.3 MW
Vasto	Vasto Power Plant	1 MW
Foggia	Delphos Power Plant	680 kW
Carloforte	Hybrid Power Plant	600 kW
Lamezia Terme	Hybrid Power Plant	600 kW
Salve	Hybrid Power Plant	600 kW
Mandatoriccio	City Plant	216 kW
Eolie Islands	**PV Plant**	200 kW
Casaccia	**Building PV System**	100 kW
Rome	Lenori	100 kW
Alta Nurra	ENEL	100 kW
Reggio Emilia	PV Plant	100 kW
Portici	ENEA	100 kW
Lipari	Water Desalination Plant	100 kW
Nettuno	Water Desalination Plant	100 kW
Lampedusa	Water Desalination Plant	100 kW
Japan		
Miyakojima Island, Okinawa	Hybrid PV System	780 kW
Gifu	Sanyo Plant	630 kW
Osaka	Rokko PV Test Plant	500 kW
Odaiba, Tokyo	AIST Waterfront Center	300 kW
Sakata	Tohoku Koeki University	250 kW
Kiyomino, Tokyo	Municipal Housing (79 Systems)	237 kW
Kyoto	Kyocera Headquarters	214 kW
Nagoya	Nagoya Municipal Housing	200 kW
Isikawa	Industry Inspection Center	200 kW
Kagoshima	High School PV System	150 kW
Fukuoka	Kyushu Electric (Island Power)	100 kW
Wakayama (40 m. so. of Kansai)	PV System	100 kW
Korea		
Ho Island	KEPCO	100 kW
Luxemburg		
Grevenmacher	Supermarket	300 kW
Malaysia		
Kuala Lumpur	Technology Park	362 kW

(name of town not given)	Communications Ministry-Sabah/Borneo Plant	100 kW
Netherlands		
Vijfhuizen	Floriade Exhibition Hall	2.3 MW
Amersfoort-Nieuwland	500 Roof Systems	1 MW
Apeidoorn	Municipal Housing	750 kW
Rotterdam	Blijdorp Zoo	500 kW
Zutphen	Recreation Park	431 kW
Wageningen	Sports Center	281 kW
Amsterdam	New Sloten Municipal Housing	250 kW
Annen	Essent Power Plant	188 kW
Petten	Laboratory and Office Building	110 kW
Saudi Arabia		
Solar Village (50 km NW of Riyadh)	**Power Plant for 3 Remote Villages**	**350 kW**
Spain		
Tudela	PV Power Plant	1.18 MW
Toledo	PV Power Plant	1.1 MW
Tenerife, Canarian Islands	Euclides Plant	480 kW
Jaen	Universidad Verde	200 kW
Almeria	Central Fotovoltaica de Sierra Maria	160 kW
Madrid	Fotovoltaica de San Agustin	100 kW
Almeria	CESA Uno power tower	1 MW
Almeria	DISS parabolic trough test facility	2.5 MW
Switzerland		
Mont Soleil	Mont Soleil Power Plant	560 kW
Zurich	Zurich Airport	290 kW
Basel	Basel Fair	240 kW
Bern	Grain Warehouse	200 kW
Manno	Union Bank, Suglio	180 kW
Zurich	ETH Honggerberg University	130 kW
Domat-Ems (N13)	Federal Office for Energy pilot plant	106 kW
Bellinzona-Locarno	Federal Office for Energy pilot plant	103 kW
Lago Maggiore	Magadino PV Plant	103 kW
Caischavedra	NOK Power Facility	100 kW
Giebenach, Basel Canton	Federal Office for Energy pilot plant	100 kW
Disentis	PV Plant	100 kW
United Kingdom		
Ipswich (Suffolk)	TXU Europe Power Headquarters	200 kW
Bridgend, Wales	Ford Motor Jaguar engine plant	102 kW

United States		
Boron, CA (Harper Lake)	SEGS parabolic trough	160 MW
Kramer Junction, CA	SEGS KJC plants	184 MW
Daggett, CA	SunRay Energy/SEGS parabolic trough	44 MW
Albuquerque, NM	National Solar Thermal Power Tower	5 MW
Rancho Seco, CA	SMUD/PV Plant	3.9 MW
Springerville, AZ	TEP Springerville Generating Station	3.78 MW
Prescott, AZ	APS Prescott Airport Power Plant	2 MW
Twenty-Nine Palms, CA	29 Palms Marine Corp Combat Center	1.3 MW
Santa Rita, CA	Santa Rita Jail	1.18 MW
Hayward, CA	Cal State University	1.05 MW
Farmingdale, NY	FALA Direct Marketing	1.01 MW
Davis, CA	PVUSA Davis Power Plant	1 MW
San Diego, CA	Del Mar Fair	1 MW
San Diego, CA	Coronado Naval Base	924 kW
Santa Rosa, CA	Rodney Strong Vineyards	766 kW
Los Angeles, CA	Loyola Marymount University	724 kW
San Francisco, CA	Moscone Convention Center	675 kW
Tempe, AZ	APS STAR Solar Center	560 kW
Los Angeles, CA	J & J Neutrogena Main Building	546 kW
Sacramento, CA	Cal Expo	540 kW
Los Angeles, CA	Toyota Motor Sales	536 kW
Oroville, CA	Wastewater Treatment Plant	520 kW
Kohala Coast, Island of Hawaii, HI	Mauna Lani Resort Hotel	520 kW
Titusville, NJ	Janssen Pharmaceutical	500 kW
Sacramento, CA	SMUD Hedge Substation	500 kW
Kerman, CA	PG&E Substation	500 kW
Sacramento, CA	SMUD Training Center Plant	500 kW
Bakersfield, CA	Texaco Solarmine	500 kW
Sacramento, CA	California State Franchise Tax Board	469 kW
Yuma, AZ	Yuma Proving Ground	440 kW
Sacramento, CA	Cal Expo Barns (26)	400 kW
Los Angeles, CA	Lowes West Hills Store	370 kW
China Lake, CA	Superior Valley Naval Facility	344 kW
Atlanta, GA	Olympic Natatorium	342 kW
San Jose, CA	Cypress Semiconductor	335 kW
Martinez, CA	Contra Costa County	309 kW

Washington, DC	Georgetown University	300 kW
Bronx, NY	Gun Hill Bus Depot	289 kW
Pencader, DE	AstroPower Factory	286 kW
Paulsboro, NJ	BP Solar Power Plant	276 kW
Austin, TX	Decker Power Plant	272 kW
Scottsdale, AZ	Scottsdale Water Campus	256 kW
Vallejo, CA	Columbus Parkway Solar Power Plant	256 kW
Phoenix, AZ	Salt River Project	250 kW
Camarillo, CA	Shell Solar Facility	245 kW
San Mateo, CA	County Forensics Laboratory	234 kW
Fresno, CA	OK Produce's Distribution Facility	231 kW
Prescott, AZ	APS System at Emery Riddle Aeronautical Univ.	228 kW
Kamuela, Island of Hawaii, HI	Parker Ranch	219 kW
San Mateo, CA	San Mateo County	209 kW
Frederick, MD	Solarex' PV Factory	200 kW
Ithaca, NY	Tomkins County Library	179 kW
Lake Powell, UT	Dangling Rope Marina	161 kW
Marina del Rey, CA	US Postal Service Processing Center	159 kW
Gilbert, AZ	APS System at Gilbert Nature Center	144 kW
Hopland, CA	Real Goods Center	138 kW
Fountain Valley, CA	Fountain Valley Building 1	138 kW
Fountain Valley, CA	Fountain Valley Building 2	138 kW
Santa Cruz Island, CA	Communication Site	138 kW
Brooklyn, NY	Greenpoint Manufacturing and Design Center	134 kW
Research Triangle Park, NC	EPA National Computer Center	130 kW
Riverside, CA	Utility Operations Center	130 kW
Sacramento, CA	SMUD Carport	128 kW
Carlsbad, CA	Carlsbad Building	125 kW
Anaheim, CA	Anaheim Convention Center	125 kW
Berkeley, CA	First Energy Solar Factory	125 kW
Phoenix, AZ	APS System at Arizona Dept. of Environ. Quality	121 kW
Yuma, AZ	Wide Area Munitions Facility	121 kW
Ft. Davis, TX	Central & SW Utilities Solar Plant	120 kW
Santa Maria, CA	Hayward Lumber	110 kW
City of Industry, CA	Bentley Prince Street Carpet Facility	109 kW
Beverly, MA	Beverly High School	100 kW
Dallas-Ft. Worth, TX	Texas Utilities Electric Plant	100 kW
Suitland, MD	Suitland Federal Facility	100 kW

Table 3.1 world wide solar power station

3.10 Summary

The overall objective is to illustrate the design of solar energy systems, both thermal and photovoltaic types. To do this, examine the solar resource and the ability of various types of solar collectors to capture it effectively. Design tools are developed which integrate performance of isolated solar collectors, along with energy storage, into a larger system that delivers either electrical or thermal energy to a demand. We show as many examples as possible, both graphic and photographic of these systems and their components. It is our hope that once the simplicity of solar energy system design is understood, engineers and manufacturers will provide new system designs that will expand the solar market worldwide and permit all to benefit from this clean, sustainable and distributed source of energy.

CHAPTER FOUR

APPLICATIONS OF SOLAR CELL

4.1 Overview

Alongside a variety of consumer products - electronic watches, calculators, power for leisure equipment and tourism - there is an extensive range of applications where solar cells are already viewed as the best option for electricity supply. These applications are usually stand-alone, and exploit the following advantages of photovoltaic electricity:

- There are no fuel costs or fuel supply problems
- The equipment can usually operate unattended
- Solar cells are very reliable and require little maintenance

At the other end of the scale are grid-connected systems which are now being seriously considered to supplement the conventional power generation in many industrialized countries. Although they have yet to become viable on economic grounds, the participation of PV in large-scale power generation is viewed with increasing prominence as a means of halting the adverse environmental effects of conventional energy sources

4.2 Rural Electrification

The provision of electricity to rural areas derives important social and economic benefits to remote communities throughout the world. Power supply to remote houses or villages, electrification of the health care facilities, irrigation and water supply and treatment are just few examples of such applications. The potential for PV powered rural applications is enormous. The UN estimates that two million villages within 20 of the equator have neither grid electricity nor easy access to fossil fuel. It is also estimated that 80% of all people worldwide do not have electricity, with a large number of these people living in climates ideally suited to PV applications. Even in Europe, several hundred thousand houses in permanent occupation (and yet more holiday homes) do not have access to grid electricity. The economics of PV systems compares favorably with the usual alternative forms of rural electricity supply, grid extension and diesel generators.

The extension and subsequent maintenance of transmission lines over long distances of often a difficult terrain is expensive, particularly if the loads are relatively small. Regular fuel supply to diesel generators, on the other hand, often present problems in rural areas, in addition to the maintenance of the generating equipment.

4.3 Water pumping

Figure 4.1 Deep well solar pump in Arizona

More than 10,000 PV powered water pumps are known to be successfully operating throughout the world. Solar pumps are used principally for two applications: village water supply (including livestock watering), and irrigation. Since villages need a steady supply of water, provision has to be made for water storage for periods of low insulation. In contrast, crops have variable water requirements during the year which can often be met by supplying water directly to produce without the need for a storage tank

4.4 Domestic supply

Figure 4.2 Solar-powered houses in Main, USA.

Stand-alone PV domestic supply systems are commonly encountered in developing countries and remote locations in industrialized countries. The size range varies from 50 Wp to 5 kWp depending on the existing standard of living. Typically larger systems are used in remote locations or island communities of developed countries where household appliances include refrigeration, washing machine, television and lighting. In developing regions large systems (5 kWp) are typically found for village supply while small systems (20-200 Wp) are used for lighting, radio and television in individual houses.

4.5 Health care

Figure 4.3 vaccine cold chains

Extensive vaccination programmers are in progress throughout the developing world in the fight against common diseases. To be effective, these programmers must provide immunization services to rural areas. All vaccines have to be kept within a strict temperature range throughout transportation and storage. The provision of refrigeration for this aim is known as the vaccine cold chain.

4.6 Lighting

Figure 4.4 Tunnel light application

In terms of the number of installations, lighting is presently the biggest application of photovoltaic, with tens of thousands of units installed world-wide. They are mainly used to provide lighting for domestic or community buildings, such as schools or health centers. PV is also being increasingly used for lighting streets and tunnels, and for security lighting.

Figure 4.5 traffic light applications

Visitors wait for a green light to walk into the Tiananmen Square in Beijing August 2 2004. To ensure the safety of pedestrians and save energy, the city authorities have installed the first solar energy traffic light at a pedestrian walk to the square of the road at the east side of the square, and pedestrians could push the button for a green light. This solar light system could store electricity for 24 hours.

4.7 Professional application

For some time, photovoltaic modules have proved to be a good source of power for high-reliability remote industrial use in inaccessible locations, or where the small amount of power required is more economically met from a stand-alone PV system than from mains electricity. Examples of these applications include:

Figure 4.6 Ocean navigation aids: many lighthouses and most buoys are now powered by solar cells.

Figure 4.7 PV powered navigation aid in Saint Lawrence River

4.8 Telecommunication systems: radio transceivers on mountain tops or telephone boxes in the country can often be solar powered

Figure 4.8 Communication application

4.9 Remote monitoring and control: scientific research stations, seismic recording, weather stations, etc. use very little power which, in combination with a dependable battery, is provided reliably by a small PV module. *Solar-powered weather station.*

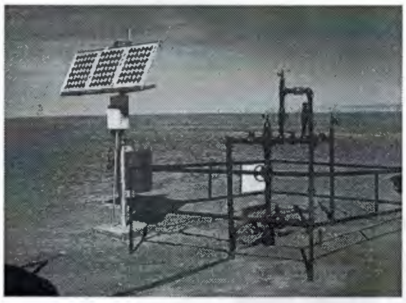

Figure 4.9 Research station applications

4.10 Cathodic protection

This is a method for shielding metalwork from corrosion, for example, pipelines and other metal structures. A PV system is well suited to this application since a DC source of power is required in remote locations along the path of a pipeline.

4.11 Electric power generation in space

Photovoltaic solar generators have been and will remain the best choice for providing electrical power to satellites in an orbit around the Earth. Indeed, the use of solar cells on the U.S. satellite Vanguard I in 1958 demonstrated beyond doubt the first practical application of photovoltaic. Since then, the satellite power requirements have evolved from few Watts to several kilowatts, with arrays approaching 100 kW being planned for a future space station. A space solar array must be extremely reliable in the adverse conditions of space environment. Since it is very expensive to lift every kilogram of weight into the orbit, the space array should also have a high power-to-weight ratio.

Figure 4.10 solar power station in space

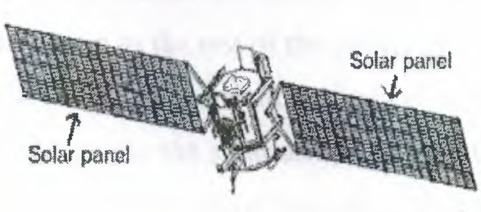

Figure 4.11 solar panel in space

4.11.1 Solar panels in space

Crystalline silicon and gallium arsenide are typical choices of materials for solar panels for deep-space missions. Gallium arsenide crystals are grown especially for photovoltaic use, but silicon crystals are available in less-expensive standard ingots, which are produced mainly for consumption in the microelectronics industry. When exposed to direct sunlight at 1 AU, a 6-centimeter diameter silicon cell can produce a current of about 0.5 ampere at 0.5 volt. Gallium arsenide is more efficient. Crystalline ingots are sliced into wafer-thin disks, polished to remove slicing damage, dopants are introduced into the wafers, and metallic conductors are deposited onto each surface: a thin grid on the sun-facing side and usually a flat sheet on the other. Spacecraft solar panels are constructed of these cells cut into appropriate shapes, protected from radiation and handling damage on the front surface by bonding on a cover glass, and cemented onto a substrate (either a rigid panel or a flexible blanket), and electrical connections are made in series-parallel to determine total output voltage. The cement and the substrate must be thermally conductive, because in flight the cells tend to heat up from absorbing infrared energy that is not converted to electricity. Since cell heating reduces the operating efficiency it is desirable to minimize the heating. The substrate is supported on a deployable structural framework. The resulting assemblies are called solar panels or solar arrays. A solar panel is a collection of solar cells. Although each solar cell provides a relatively small amount of power, many solar cells spread over a large area can provide enough power to be useful. To get the most power, solar panels have to be pointed directly at the Sun. Spacecraft are built so that the solar panels can be pivoted as the spacecraft moves. Thus, they can always stay in the direct path of the light rays no matter how the spacecraft is pointed. Spacecraft are usually designed with solar panels that can always be pointed at the Sun, even as the rest of the body of the spacecraft moves around, much as a tank turret can be aimed independently of where the tank is going. A tracking mechanism is often incorporated into the solar arrays to keep the array pointed towards the sun. Solar panels need to have a lot of surface area that can be pointed towards the Sun as the spacecraft moves. More exposed surface area means more electricity can be converted from light energy from the Sun. Sometimes, satellite scientists purposefully orient the solar panels to "off point," or out of direct alignment from the Sun. This happens if the batteries are completely charged and the amount of electricity needed is lower than the amount of electricity made. The extra power will just be vented by a shunt into space as heat. Solar panels are very hardy. Compared to alternative power sources, they wear out very slowly. The principal factor affecting the loss in power with time is the Space radiation environment. For low radiation environments, such as low Earth orbiting, their effectiveness decreases around 1 to 2 percent a year. This means after a five year mission the solar panels will still be making more than 90% of what they made at the beginning of the mission (as long as they haven't gotten farther away from the Sun). In contrast, for missions in higher radiation environments, such as mid altitude Earth orbit (2000 to 10000 kilometers), arrays can lose half their power within 1 year. That is one reason few missions fly in this orbital range. Photovoltaic concentrator solar arrays for primary spacecraft power are devices, which intensify the sunlight on the photovoltaic. This design uses lenses, called Fresnel lenses, which take a large area of sunlight and direct it towards a specific spot by bending the rays of light and focusing them. Some people use the same principle when they use a magnifying lens to focus the Sun's rays on a pile of kindling or paper to start fires. Solar concentrators put one of these lenses over every solar cell. This focuses light from the large concentrator area down to the smaller cell area. This allows the quantity of expensive solar cells to be reduced by the amount of concentration. Concentrators work best when there is a single source of light and the concentrator can be pointed right at it. This is ideal in space, where the Sun is a single light source. Solar cells are the most expensive part of solar arrays, and arrays are often a very expensive part of the spacecraft. This technology allows costs to be cut significantly due to the utilization of less material. *Fresnel lenses have been around since Augustine Jean Fresnel invented them in 1822. Theaters use them for spotlights and lighthouses use them to make their lights visible at greater distances.

4.12 Grid-connected systems

Two types of grid-connected installations are usually distinguished, centralized PV power stations, and distributed generation in units located directly at the customer's premises (PV in buildings).

4.13 PV in buildings

Figure 4.12 Scheidegger Building with photo*voltaic* facade near Bern in Switzerland

PV arrays mounted on roof tops or facades offer the possibility of large-scale power generation in decentralized medium-sized grid-connected units. Studies in Germany, Switzerland and the UK have shown that the roof and facade area technically suitable for PV installations is large enough to supply the country's electricity demand. The size envisaged for each decentralized residential PV system is typically 1- 5kW, with systems up to a hundred kW or so suitable for commercial and industrial buildings.

Figure 4.13 Atlantis Solar System AG has recently introduced Sun slates that can be fitted to existing roofs easily and unobtrusively.

The main advantages of these distributed systems over large PV plants are as follows:

- There is no cost in buying the land and preparing the site.
- The transmission losses are much lower because the load is on the same site as the supply.
- The value of the PV electricity is also higher because it is equal to the selling price of the grid electricity which has been replaced, rather that to the cost of generating it.

However, it should also be noted that the price paid by utility companies for electricity exported from a decentralized source is a fraction of the utility sale price. The optimum economic benefit is therefore derived by consuming all PV produced electricity, with direct reduction of the energy imported from the utility. Thus grid connected PV systems are ideal for loads which vary in proportion to the irradiation. Typical loads are air-conditioning, refrigeration and pumping. Other significant loads can be timed to operate when PV power is likely to be available. Examples include washing machines and clothes dryers which can operate on timing clocks.

4.14 Summary

In this chapter it is described that what are the solar energy applications and how it is beneficial for human life. There are different ways to use solar energy in usual life and solar energy is clean and durable energy that can be use to alternate all other electric sources and over all theme of this chapter is that the world is going toward usage of renewable energy sources.

CHAPTER FIVE

The Economics of Solar Energy

5.1 Overview

Solar power systems can be a much less expensive way to develop power on your remote property. In some cases, it can cost over $20,000 to run in public utility power lines. Some of the best recreational property available is not necessarily near public utility power. If you are considering the purchase of a remote property, solar energy can help you get the property you want without the inconvenience and expense of trying to figure out how to connect to the public utility power grid. All of a sudden, that remote island in the middle of the lake is now a possibility! Plus, the advantage of the sun's endless fuel supply and a peaceful, silent power source.

5.2 Daily Solar Energy Costs

so, where do solar energy costs rank on the scale of daily expenditures? It's useful to have some perspective.

Example:

Let's say you spend $4,000 to purchase a medium sized cabin system for your recreational property. Since the system has no moving parts, you'll use the system for at least ten years. You'll have some additional maintenance costs—maybe replace the batteries, upgrade your power delivery system, and so on. Let's say those maintenance costs are $2000. The total is $6000. So, over a ten year period, you'd be spending the following $6000 / 3650 days = $1.64 per day. Of course, utility supplied power will be less expensive... About 40 to 50 cents per day. Where do these energy expenditures sit on the scale?

Table.5.1 Comparison of different costs with solar energy

Automobile Insurance	**$4.00 per day**
Gasoline costs to keep a mini-van running	**$3.50 per day**
Smoke a pack of cigarettes	**$3.50 per day**
Daily tall latte coffee drink and muffin	**$3.50 per day**
Solar Energy System capital and operating costs	**$1.64 per day**
Utility supplied power	**$0.45 per day**

In reality solar energy actually doesn't cost all that much. Create the following benefits with solar power, which are extremely valuable:

- Reduce global warming
- Reduce acid rain
- Reduce the costs associated with the storage of radioactive waste

Cost estimate Using figures derived from the US Energy Information Administration statistics, the cabin system described above will have the power generating capability to eliminate over 2,000 pounds of air pollutants every year on average for the American family for each of these three consequences are in the billions of dollars!

5.3 Cost Benefits

Costs of PV systems have come down 25 fold over the last 20 years and are now often the most cost effective in remote energy applications such as cabins and resorts. In remote locations, connecting to the grid is prohibitively expensive, making an alternative power system a necessity. A renewable energy system requiring an inverter application is economically viable in most situations, as the cost of extending grid wiring to a remote location can cost anywhere from $20,000 to $80,000 per mile. A full-scale renewable energy system with an inverter to supply AC power to the house is a cost-effective solution to this problem.

5.4 Utilities, too, are looking at the cost benefits of solar power.

The trouble with these times is that the future isn't what it used to be. With electrical restructuring occurring in the US, and most likely evolving in Canada in the next five years, the electrical utilities are looking for new revenue streams, a better, nature-friendly image with consumers, and a more stable cost structure. Renewable energy provides all three. People are willing to pay a premium for renewable energy. Several market research studies have confirmed this, and early market experience has confirmed this. The Sacramento Municipal Utility District (SMUD), which has more PV's installed than any other utility, charges customers $4.00 more per month for their electricity if the customer allows SMUD to install PVs on their roofs

5.5 Cost effective, even in more northern locations

A typical active solar thermal system will have about 35% efficiency, and solar photovoltaic is about 12% efficiency. Solar photovoltaic energy generation (PV) has a very bright future. Photovoltaic are economical today, especially if you take into consideration the cost of fossil fuel pollution and global warming. Using an analysis that takes into account the solar energy available with utility seasonal demand patterns, effective load caring capacity and costs show that solar can be cost effective even in northern areas.

5.6 Environmental Benefits

Natural disaster costs soar to another world record. Violent weather cost the world a record $130 Billion in the first eleven months of 1998- more money than was lost from weather related disasters from 1980 to 1990 ($82 Billion). Researchers from the World watch Institute and Munich Re blame deforestation and climate change from Earth warming for much of the loss. The previous one year record was $90 Billion in 1996.

5.7 Save Money with Energy Efficiency

Regardless of the power generation source is going to use, reducing consumption with energy-efficient appliances and lights will save money. Even if it is decide not to use solar energy, still enjoy the financial benefits of energy efficiency and reduce wear and tear on the environment. Purchasing energy efficient appliances for home or cabin often pays it back immediately on larger solar energy system costs.

5.7.1 Switching incandescent lighting (i.e. bulbs)

Switching to compact fluorescent lights reduces energy consumption by up to 75%. Compact fluorescent bulbs also last up to eight times longer than conventional incandescent bulbs.

5.7.2 Turn off big lights at nighttime

By turning off large outdoor floodlights and main interior lights can significantly reduce daily power consumption. In a small cabin, switching off two 100-watt outdoor floodlights before going to bed could reduce total daily consumption by 25%! Motion sensors for outdoor lighting are also a good idea.

5.7.3 Switch to energy efficient refrigeration

Refrigeration typically uses the most amount of power in a cabin residence on a daily basis. Switching to a more energy efficient fridge or considering electric models specifically designed for independent power systems are usually worth the investment. Propane refrigerators are commonly used in cabins, and should be seriously considered. Solar Sense can provide advice on the types of fridges and options in this area.

5.7.4 More sun in the summer, less in the winter

For most North American residences, there's one unavoidable fact: it's generally a lot sunnier in the summertime. In fact, solar radiation can be as much as three times greater in the summertime than in the wintertime. Even in sunny locations like San Diego, the amount of wintertime solar radiation is roughly 70% of the summertime amount. Relying completely on solar energy to satisfy wintertime requirements can result in a massive surplus of power in the summertime, as well as an expensive solar energy system that is oversized for much of the year.

5.8 Solar Resources & Economics

The cost of solar power depends largely on the amount of sunlight in region and the type and cost of equipment needed for a solar system. There are many other factors that affect cost, such as financing options, the expected lifetime of the solar equipment, and for systems connected to the utility grid, the rules utility has in place for buying and selling electricity to the grid.

5.8.1 Costs of Solar Electricity Generation—Photovoltaic Technologies

Depending on what kind of system is installed, you will need not only the electricity-generating PV modules, but also what is called balance-of-system (BOS) equipment, such as: inverters (which transform direct electricity current to alternating current), batteries, battery charge controllers, and other components. Grid-connected systems are generally cheaper to install than non-grid connected systems the cost of electricity from PV cells depends on the solar isolation, or amount of energy from sunlight that reaches your area on average each day. PVWATTS determines what the solar resource is in community, and will tell, based on an average cost of electricity in state, the cost savings that can be expected from a grid-connected PV system. That is, the tool will calculate the difference between buying electricity from a traditional source and generating it yourself with a PV system. To get an idea of the cost of solar energy, you can subtract the PVWATTS cost savings number from the average cost of electricity in area. Though, that many states offer rebate programs, which can greatly reduce the initial cost, and therefore the cost of energy, over the lifetime of the system. Finally, if it is desired to perform more detailed calculations on the cost of energy from photovoltaic Concentrating solar power technologies currently offer the lowest-cost solar electricity for large-scale power generation (10 megawatt-electric and above). Current technologies cost \$2–\$3 per watt. This results in a cost of solar power of 9¢–12¢ per kilowatt-hour. New innovative hybrid systems that combine large concentrating solar power plants with conventional natural gas combined cycle or coal plants can reduce costs to \$1.5 per watt and drive the cost of solar power to below 8¢ per kilowatt hour. Advancements in the technology and the use of low-cost thermal storage will allow future concentrating solar power plants to operate for more hours during the day and shift solar power generation to evening hours. Future advances are expected to allow solar power to be generated for 4¢–5¢ per kilowatt-hour in the next few decades. For comparison, electricity can be generated by new scrubbed coal power plants at a rate of about 3.5–4.5¢ per kWh, and by gas combined cycle plants at a rate of 2.5–4.5¢ per kWh depending on assumptions about fuel prices and financing costs. In coal and gas plants, fuel costs three to five times as much as capital costs, and it is the most important variable in projecting costs. Energy generated from renewable sources like the sun does not rely on fuel inputs, and therefore prices will not reflect rising fuel costs, or be subject to constraints on the fuel supply or fluctuations in the market.

5.8.2 Costs of Solar Hot Water

of fuel sources, the solar water heater can be more economical over the lifetime of the system than heating water with electricity, fuel oil, propane, or even natural gas because the fuel (sunshine) is free. Many home builders choose electric water heaters because they are easy to install and relatively inexpensive to purchase. However, research shows that an average household with an electric water heater spends about 25% of its home energy costs on heating water. It makes economic sense to think beyond the initial purchase price and consider lifetime energy costs, or how much you will spend on energy to use the appliance over its lifetime. The Florida Solar Energy Center studied the potential savings to Florida homeowners of common water-heating systems compared with electric water heaters. It found that solar water heaters offered the largest potential savings, with solar water-heater owners saving as much as 50% to 85% annually on their utility bills over the cost of electric water heating. The FSEC analysis illustrates that the initial installed cost of the solar water heater ($1,500 to $3,000) is higher than that of a gas water heater ($350 to $450) or an electric water heater ($150 to $350). The costs vary from region to region, so check locally for costs in your area. Depending on the price

5.8.3 Run Times with Batteries

Some examples of approximate appliance running times with inverter using different battery banks. We've included both 12 and 24V battery banks, at an average temperature of 50 degrees Fahrenheit (10°C) and a planned depth of discharge of 50%.

Table 5.2 Solar batteries run time

12V battery bank run time in hours:							
Appliance wattage	Sample Application	100Ah	200Ah	400Ah	800Ah	1200Ah	1600Ah
100	19" Color TV	5.0	10.1	20.2	40.3	60.5	80.6
200	Refrigerator	2.5	5.0	10.1	20.2	30.2	40.3
300	Computer System	1.7	3.4	6.7	13.4	20.2	26.9
400	4 100W Incandescent Lights	1.3	2.5	5.0	10.1	15.1	20.2
800	Small Microwave	0.6	1.3	2.5	5.0	7.6	10.1
1000	Toaster	0.5	1.0	2.0	4.0	6.0	8.1
1500	Full-size Microwave	0.3	0.7	1.3	2.7	4.0	5.4

24V battery bank run time in hours:							
Appliance wattage	Sample Application	100Ah	200Ah	400Ah	800Ah	1200Ah	1600Ah
100	19" Color TV	10.1	20.2	40.3	80.6	121.0	161.3
200	Refrigerator	5.0	10.1	20.2	40.3	60.5	80.6
300	Computer System	3.4	6.7	13.4	26.9	40.3	53.8
400	4 100W Incandescent Lights	2.5	5.0	10.1	20.2	30.2	40.3
800	Small Microwave	1.3	2.5	5.0	10.1	15.1	20.2
1000	Toaster	1.0	2.0	4.0	8.1	12.1	16.1
1500	Full-size Microwave	0.7	1.3	2.7	5.4	8.1	10.8

5.9 Summary

In this chapter it is viewed that how solar energy can be compared with other energy sources on economic point of view. This chapter shows that solar energy is safer and less expensive than other energy sources. This chapter shows the calculation of solar energy usage related to home appliance and other applications further more it is considered that which factor effect the cost per unit charges of solar energy.

CHAPTER SIX

SOLAR ENERGY CASE STUDY

6.1 Overview

Solar energy decision is made by different calculations and depending on area also the sun lighting time is very important factor in order to make decision of solar energy plant or small scale solar energy apparatus even for home appliance. Case study is very important factor before starting any project because it gives us approach to analyze the facts and figures.

6.2 Solar power in urban NSW – Case study 1

Living in the Sydney suburb of Matraville, Deo wanted to do his bit to help the environment while renovating his home. To install 9 solar panels on his roof to create a grid connected solar power system with a capacity of 1.35 kW. "I wanted to put the principles of living more sustainable into practice. Buying a solar power system to provide environmentally-friendly electricity to my home was one easy way for me to do this," said Deo. Deo chose to install Pacific Solar's Plug and Power solar panels, highlighting the need for architectural integration of solar system as part of the building design. The system produces enough solar power to supply about 40% of his 4-bedroom, 2-storey house; any excess electricity generated is bought by the electricity supplier and fed back into the grid. Minimizing the energy use in the building through passive solar design and using low energy appliances as a first step also meant less demand on the system and further cost savings. According to Deo, there was little problem in getting the system installed. The system also carries a 20-year warranty, and Pacific Solar provides regular maintenance checks on the system. The entire system cost $18,695 to purchase and set-up, leaving Deo eligible for a $6,750 government rebate. Installing the system has considerably reduced Doe's greenhouse gas production and will mean savings annually on electricity bills. Deo also points out that the system can only make their house more attractive if he ever decides to sell. "It makes economic and environmental sense. Making my home more sustainable could add between 5% and 15% to the property value, which basically pays for the system in one day!" And Doe's advice to anyone thinking of going solar? "Just do it – it works. If 2 million households in Sydney did it, the impact to greenhouse gas emission reductions and industry development would be considerable."

6.2.1 Vital Statistics:

- Product Plug and Power Solar Panels
- Supplier Pacific Solar Pty Ltd
- Installer Pacific Solar
- Installation date May 2003
- System Capacity/size 1.35 kW
- No. solar panels/tiles 9
- Cost of system $18,695
- $$ saved through government rebate $6,750
- Greenhouse gas savings (per year) 1.8 tonnes CO_2 reductions/yr

6.3 Solar power in urban NSW – Case study 2

Environmental considerations were top of mind when Sydney resident and architect John considered solar power for his newly built home in Paddington. "Making the house more environmentally sustainable was the major motivating factor for having the system installed, "John explained. Having decided to design his own 2-storey, 3-bedroom terrace house, John felt this was the ideal time to install a solar power system, along with other design initiatives to reduce energy consumption. John points out: "It is important to consider the system as early as possible in the design process to ensure the best fit with the overall building." John chose PV Solar Tiles as that are integrates into the building fabric, making them an appealing aesthetic feature to his home. PV Solar Energy provided a 20-year warranty on installation, and handled paperwork for grid connection and government rebates. The 16 solar tiles cost close to $19,000, and John was able to take advantage of a $6,000 government rebate from the Australian Greenhouse Office and Sustainable Energy Development Authority. "The price of the system was relatively small compared to the overall building costs. It also made sense to make my home more energy efficient so I'd need fewer solar tiles, making the system even more affordable", said John. The solar tiles are connected to the mains electricity grid and any excess solar power will be sold to the electricity supplier. John expects annual savings of around $250 on his energy bills while preventing emissions of nearly 2 tonnes of greenhouse gas emissions annually.

6.3.1 Vital Statistics:

- Product PV Solar Tile
- Supplier PV Solar Energy Pty Ltd
- Installer PV Solar Energy Pty Ltd
- Installation date April 2004
- System Capacity/size 1.2 kW
- No. solar panels/tiles 16
- Cost of system $18,870
- $$ saved through government rebate $6,000
- Greenhouse gas savings (per year) 1.6 tonnes CO2 reductions/yr

6.4 Case study 3
Chanterelle Inn, Nova Scotia, benefits from a commercial solar water heating system.

Chanterelle Inn is a large country inn located in North River, Nova Scotia, approximately 50 kilometers north of Baddeck on the Cabot Trail. Although the inn operates year-round, most of the inn's guests, who come from around the world, visit during the spring, summer and fall. The two-storey inn, shown in the photo with the Cape Breton Highlands in the background, was constructed in 2000. The wood-frame building measures 15 meters by 15 meters and has a full basement. It features eight suites on the upper floor, as well as a kitchen, a dining room, a lounge and another large suite on the main floor. The building consumes no fossil fuels on site and depends upon solar energy with electricity backup for space and water heating. An in-floor radiant heating system also provides space heating for the inn.

6.4.1 The Solar Decision

Earlene Busch, owner of the inn, had three key environmental objectives in mind when she decided to construct the inn in 2000: The inn would provide a healthy environment for her guests, with no fossil fuels consumed on site. The inn would fit in with environmental concerns about the depletion of fossil fuels. The owner would consider power self-generation at the site in the future. According to Busch, "Solar hot water seemed a natural fit with my three environmental objectives." One factor that helped her choose solar is Natural Resources Canada's Renewable Energy Deployment Initiative (REDI), which contributed 25 percent of the purchase and installation costs of the solar hot water system.

6.4.2 The System

Thermo Dynamics Ltd. of Dartmouth, Nova Scotia, designed and supplied the solar hot water system. Sun Ross Energy Systems Ltd. of Port Hawkesbury, Nova Scotia, installed it. Table 1 provides technical information and design parameters for the system, which includes 16 flat-plate and two 12-volt solar electric (photovoltaic) collectors. They are located on the south roof and are mounted at a 35° slope with an azimuth of 10° west of south. The two photovoltaic collectors supply power to the system's water pump. The panels are mounted on Unistrut channels lagged to the roof and sealed with silicone to prevent leaks. Extra trusses were installed to ensure that the roof could support the additional load of the solar panels. The glycol piping runs down to the basement through the roof and walls. A rubber boot was installed around the piping on the roof to prevent water leaks. The mechanical equipment is located in the basement next to the in-floor radiant heating equipment. Diagram 1 shows the schematic of the solar hot water system. The system is designed to meet the domestic water heating needs of the complex first. The solar-heated water flows into four 455-litre tanks and is then fed through four 27 litre backup electric water heaters, connected in series.

Application: Preheat Domestic Hot Water and Provide In-Floor Radiant Heat	
Collector Information	
Type	Flat-plate, metal absorber
Number	16
Size 2	Total gross area: 47.5 m
Mounting Location	Rooftop
Slope	35.0°
Azimuth 10.0° west of south	10.0° west of south
Storage Information	
Type	Water
Volume	1.82 m
Location	Basement
Loss Coefficient	10.8 watts/°C
Antifreeze	Glycol
Hot Water Data	
Consumption	468 m3/year
Total Annual Load	92 GJ (25 600 kWh)
Solar Contribution	
Energy Displaced/Year	46 GJ (12 800 kWh)
Solar Fraction	50%
Type of Energy	Electric

System Type: Liquid Closed-Loop	
Space-Heating Data	
Total Annual Load	184 GJ (51 100 kWh)
Solar Contribution Energy	
Mounting Location	Displaced/Year 46 GJ (12 800 kWh)
Solar Fraction	25%
Type of Energy Displaced	Electric
Cost of System	
Total Without Incentive	$36,700
Total With Incentive	$27,600
O & M Costs	$100/year
Energy Savings	$2,660/year
Price of Electricity	$0.0959/kWh
Simple Payback Without Incentive (years)	13.9
Simple Payback With Incentive (years)	10.5
CO2 Emission Factor	802 g/kWh
CO2 Displacement	20 500 kg/yr

Table 6.1 Technical Information, Solar Hot Water System Chanterelle Inn, and North River, Nova Scotia

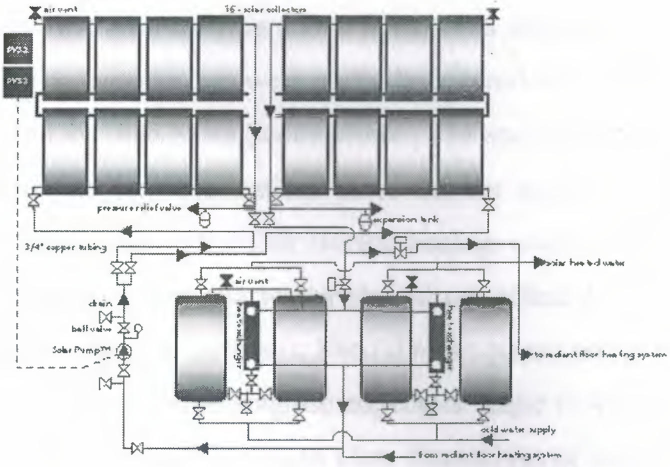

Figure 6.1 Schematic diagram of the Chanterelle Inn's
solar hot water system Courtesy of Thermo Dynamics Ltd., Nova Scotia

Any surplus solar-heated water is used to supplement the load of the in-floor radiant heating system. Water is fed into a 40-kilowatt electric boiler, which provides most of the inn's space heating, before flowing through the floor loop. After these needs have been met, any remaining energy is used to heat the domestic hot water tanks above their set-point. The electrical code requires each electric water heater to have a fusible disconnect switch. This lets the owner shut off power to the tanks when they are not required, and thus manage demand to the complex. The solar system is designed to displace 20 500 kilograms of carbon dioxide ($CO2$) per year. The solar fraction (proportion of the load met by solar energy) for the domestic hot water is estimated to be 50 percent, based on an annual consumption of 468 cubic meters of water. The solar fraction for the space heating system is 25 percent, based on an annual electric heating load of 51 100 kilowatt hours (kWh). Because the system was installed only in 2000, operating data are not available.

6.4.3 Project Cost

The total project cost was $36,700. With REDI's 25-percent contribution, the cost was reduced by approximately $9,100 for a net total of $27,600.

6.4.4 Operating and Maintenance Experience

The system is in its first year of operation. Busch has encountered no maintenance problems to date. The solar collectors were partially covered with snow in January 2001, which is unusual for an average Nova Scotia winter. The snow cover made the collectors less effective, but this had few implications since the inn operates at minimal capacity during the winter, and only one of the four electric backup water heaters was being used. The reduced solar capacity during the winter should not affect the overall performance during the prime season (April to October). Should more guests arrive in the winter, then Busch may have to investigate increasing the collectors' angle to 45° to reduce the snow cover. Usually, flat-plate solar collectors can clear themselves of snow once a small part of the glass is exposed to sunlight. Still, the 35° angle for the collectors is close to ideal for summer operations, so changing the angle is fundamentally an operating decision. Since Busch is concerned about the snow cover during much of the winter, she is examining the best way to keep the panels clear.

6.5 Summary

The aim of this chapter is give the idea about the solar power decision and which factors are considered before making this decision. In this chapter case study of different companies is described and showed that how they approach the solution and which vital statistics has to consider in order to make decision more over project cost and place where project is going to start is important. This chapter brief discussion of different countries case studies.

CHAPTER SEVEN

LATEST RESEARCH TO IMPROVE EFFICENCY OF SOLAR CELL

7.1 Overview

Since the 1950s, the uses for solar power have exploded. It's no longer limited to such specialty uses as satellites, remote cabins and highway call boxes. "Now, it's cost effective against grid power for homes and businesses in states that have the incentives," Yet manufacturing costs remain relatively high, making solar power as much as five times more expensive than energy from fossil fuels -- before tax credits and other incentives that states such as California offer. To lower costs, companies and researchers are trying different types of semi conducting materials, including amorphous silicon and gallium arsenide. These materials are also more flexible than crystalline silicon. Rather than being grown as crystals in high-vacuum chambers, they can be deposited inflexible thin layers, making bulk production cheaper. But there's a catch: Such photovoltaic harness about 8 percent of the total energy in sunlight, compared with about 15 percent for crystalline silicon. "Basically get half as much electricity from the same amount of sunlight," Ways to boost efficiency include layering photovoltaic cells so they capture a wider portion of the sun's range of energy. Another involves using lenses and reflectors to concentrate more sunlight on each cell. These techniques do raise the overall cost, but the Boeing Co. subsidiary Spectrolab, which makes solar power systems for satellites, has used them to reach a record efficiency of more than 34 percent -- in the lab. Researchers found sunlight can be concentrated as much as 500 times.

7.2 Discovery may spur cheap solar power

A major European chip maker said this week it had discovered new ways to produce solar cells which will generate electricity twenty times cheaper than today's solar panels. STMicroelectronics, Europe's largest semiconductor maker, said that, by the end of next year, it expected to have made the first stable prototypes of the new cells, which could then be put into production. Most of today's solar cells, which convert sunlight into electricity, are produced with expensive silicon, the same material used in most semiconductors. The French-Italian company expects cheaper organic materials such as plastics to bring down the price of producing energy. Over a typical 20-year life span of a solar cell, a single produced watt should cost as little as $0.20, compared with the current $4. The new solar cells would even be able to compete with electricity generated by burning fossil fuels such as oil and gas, which costs about $0.40 per watt, said Salvo Coffa, who heads ST' research group that is developing the technology. "This would revolutionize the field of solar energy generation," he said. ST's trick is to use materials that are less efficient in producing energy from sunlight but which are extremely cheap. Coffa said the materials should be able to turn at least 10 percent of the sun's energy into power, compared with some 20 percent for today's expensive silicon-based cells. "We believe we can demonstrate 10 percent efficiency by the Following that, ST and others would need to develop production technologies to make solar cells and panels in large quantities to achieve the $0.20 per watt target, he said. "Our target is fixed at $0.20," said Coffa, who expects no major technological difficulties in going from prototypes to mass-produced commercial products. Renewable energy is an essential part of research for ST, which says its chip and material expertise can be used to develop future solar cells and fuel cells. ST said three weeks ago it had found a new way to produce tiny yet extremely efficient fuel cells that could power a mobile phone for 20 days.

7.3 Solar cells less pricey, more efficient

SAN JOSE, California (AP) -- Every minute, the sun bombards Earth with enough energy to supply its power needs for a year. Yet only two one-hundredths of a percent of all the electricity fed into the U.S. grid originates from sunlight. The world still largely relies on diminishing supplies of environmentally unfriendly and politically destabilizing fossil fuels. Despite decades of research, it's still cheaper to burn coal than get power from the sun. But photovoltaic technology is improving efficiency and lowering costs for solar power, and experts believe the development will in the next few years drive solar adoption far faster than any government incentives or environmental concerns. "Today, if solar energy were available in a quantity and at a cost comparable to fossil fuel, it would be a revolutionary change," said Stephen Empedocles, business development director at Nanosys Inc. The Palo Alto, California-based startup is working on photovoltaic cells so small and cheap that they can be sprayed or even painted onto surfaces. Solar power research is proceeding on two fronts: Making cheaper versions of crystalline silicon cells that comprise 80 percent of the solar market, and creating less expensive photovoltaic technologies with the reliability and efficiency of crystalline silicon. All the research is built on semiconductors, which absorb the sun's photons. Electrons are bumped along a predictable path by those photons until the current flows into something useful, such as an appliance. This photovoltaic effect, first noticed in 1839, is the same way the flow of current is manipulated in computer logic and memory chips. In fact, moneysaving advances in the chip industry, such as increasing the size of silicon wafers and perfecting how they are sawed from ingots, are now being exploited in photovoltaic, said Dan Shugar, president of Power Light Solar Electric Systems.

7.3.1 Nanotech meets solar tech

The most futuristic approach involves arranging nano size semiconductors in a matrix of plastic-like materials that are expected to be much less expensive to produce. Nanosys is working on nanorods that are just 7 nanometers by 60 nanometers in a polymer. Because of their size -- a nanometer is about 10,000 times narrower than a human hair -- nanorods are arranged by chemical reactions. "The manufacturing of Nan composite solar cells is more like the production of photographic film, which is done in extremely high volumes with miles of precisely engineered materials per day at extremely low costs," Empedocles said. The efficiency should be on par with crystalline silicon within three years, he said. But there are doubts over how quickly such technology might be on the market. "That is an interesting technology to watch but today it is not a viable technology," said Nasser Karam, director of advanced programs and optoelectronics for Spectrolab. "I would suspect with a lot of government funding, the feasibility will probably show in three to five years." Though some are skeptical about the future technologies, companies that sell today's solar-power systems note that traditional photovoltaic are dropping in price and eventually pay for themselves even at today's costs. Power Light even touts some of its systems as added protection for roofs. "Those other technologies are really interesting and I hope they succeed, but we don't need those to succeed for us to succeed," Shugar said. "We're not betting our future on one technology horse."

7.4 An unexpected discovery could yield a full spectrum solar cell

BERKELEY, CA — Researchers in the Materials Sciences Division (MSD) of Lawrence Berkeley National Laboratory, working with crystal-growing teams at Cornell University and Japan's Ritsumeikan University, have learned that the band gap of the semiconductor indium nitride is not 2 electron volts (2 eV) as previously thought, but instead is a much lower 0.7 eV. Semiconductor indium nitride is not 2 electron volts (2 eV) as previously thought, but instead is a much lower 0.7 eV. A newly established low band gap for indium nitride means that the indium gallium nitride system of alloys ($In_{1-x}Ga_xN$) covers the full solar spectrum. The serendipitous discovery means that a single system of alloys incorporating indium, gallium, and nitrogen can convert virtually the full spectrum of sunlight -- from the near infrared to the far ultraviolet -- to electrical current. "It's as if nature designed this material on purpose to match the solar spectrum," says MSD's Wladek Walukiewicz, who led the collaborators in making the discovery. What began as a basic research question points to a potential practical application of great value. For if solar cells can be made with this alloy, they promise to be rugged, relatively inexpensive -- and the most efficient ever created.

7.4.1 In search of better efficiency

Many factors limit the efficiency of photovoltaic cells. Silicon is cheap, for example, but in converting light to electricity it wastes most of the energy as heat. The most efficient semiconductors in solar cells are alloys made from elements from group III of the periodic table, like aluminum, gallium, and indium, with elements from group V, like nitrogen and arsenic.

7.5 Nanorod Technology Improves New Types of Solar Cells

The next time painting home, it is wanted to consider a shade made with photovoltaic cells. Berkeley scientists have developed solar cells that can be painted onto any surface to provide a low-energy source. "We have made a hybrid cell in which electrons are transported by inorganic nanorods, and holes are transported by a semiconductor polymer," said Paul Alivisatos, a professor of chemistry at UC Berkeley and a member of the Materials Science Division of Lawrence Berkeley National Laboratory. The photovoltaic cells developed by Alivisatos and his group, which currently produce only .7 volts, are hybrid cells composed of both organic and inorganic material. Nanorods—microscopically small conducting rods—made of a chemical compound known as cadmium solenoid are dispersed in a type of plastic called poly-3-hexythiophene, which is better known as P3HT. The cadmium solenoid and P3HT mixture is then coated onto a transparent electrode, forming a layer 200 nanometers, or 200 billionths of a meter, thick. Organic solar cell researchers have been challenged by the problem of efficient electron transport. For the solar cell to work, electrons generated by the absorption of light are transported from one region of the cell to another to create electricity. Fully organic solar cells are engineered to have networked pathways which are used for electron transport. Unfortunately, problems arise because incomplete pathways are common and cause lower efficiency for the solar cell. Alivisatos solved this problem by using inorganic nanorods, like those used in typical solar cells, as the electron carriers. "The inorganic rods are small enough that they can still be cast from solution, so in a way we aim to get the best both of both worlds: the superior electrical characteristics of in organics, and the ease and low cost of processing of organics," Alivisatos said. Alivisatos' new solar cells are also much more cost-effective than traditional solar cells, as they require less heat energy during production. "Inorganic solar cells require high-temperature processing at around 2500 degrees Celsius," said Janke Dittmer, a postdoctoral fellow in the group. "They also need a high-powered vacuum for the electrodes, and this makes things awkward for larger areas. Our solar cells are processed at low temperatures, from solution." The lower temperatures also allow for greater flexibility in the application of the solar cells. "The high temperatures required for typical inorganic solar cells would melt plastic substrates," Dittmer said. "The hybrid cells can literally be painted or screen-printed onto the substrate." The research has gained praise from other scientists who see the study as a step toward making solar energy a viable alternative to traditional energy sources. "There has been much interest recently in the possibility of making cheap, plastic solar cells," said Keith Barnham, a professor of physics at Imperial College in London. "However, the efficiencies of these polymer-based cells are currently far too low for commercial exploitation. I think this hybrid approach is a most promising way to achieve the efficiencies necessary to make plastic solar cells commercially viable. It would help to make solar electricity competitive with fossil fuels." However, the research team must still overcome another hurdle before the technology can be used in consumer goods. The scientists must still improve the efficiency of the solar cell so that it meets commercial standards and becomes viable for consumer production. "10 percent efficiency is when it makes sense to use on a roof," Dittmer said. "We're at 1.7 percent now, and in the next couple of years, we should reach five percent. We're more than one conceptual breakthrough away from 10 percent,, which should be in about a decade." The research has also sparked interest in nanotechnology companies. Nanosys Incorporated, a firm co-founded by Alivisatos, is interested in developing the technology further. "Regardless of the success or failure of this particular device, advances in nanotechnology may well lead to improvements in solar cells in the future." Alivisatos said.

7.6 Summary

The aim of this chapter is to describe how scientist is trying to improve solar cell efficiency by trying different materials. As use renewable energy sources is rapidly increasing so it is desired to find out less expensive and more safe way of energy production in order to replace old power station fashion by using combined method (hybrid power station). In order to replace old fashion scientist are searching for new materials and high quality materials in regard to protect from any kind of uncertainty. At the end of chapter it is described that scientist have approached some improved way to increase the life and efficiency of solar cell.

CHAPTER EIGHT

Advantages and disadvantages of solar power

8.1 Advantages:

- Solar energy is a renewable resource.
- Sunlight is free.
- Australia's climate is well suited to solar energy.
- Solar power does not produce dangerous emissions.
- Solar hot water systems reduce the need for electricity and hence the need for fossil fuels.
- Photovoltaic cells or solar cells convert sunlight directly to electricity.
- Solar power can provide electricity to remote areas of Australia that are not connected to the electricity grid.

8.2 Disadvantages:

- Energy collected from solar cells or solar collectors has to be stored in batteries.
- Thermal solar systems used for electricity production are expensive.
- An array of solar collectors takes up a lot of area.
- Solar collectors need tracking devices, which adds to the cost.
- Dust and smoke and weather conditions in general affect the performance of solar collectors.
- The silicon used for making photovoltaic cells is the same as that used for computer chips, which is not in large supply.

8.3 Solar power and the environment

Solar power generators produce no greenhouse gas emissions or other pollutants. Solar cells and solar thermal generators can impact on the environment. Mining the sand required for the manufacture of photovoltaic cells can severely damage the extraction area and have serious consequences for the environment. Mining operations are now required to have a regeneration program, which can add to the cost of raw materials. Solar power generators do not cause any pollution. One advantage of solar power generation is that it is modular and can be established anywhere. This has particular relevance in Australia, as it is especially suitable for this type of power generation. These power stations can be decentralized reducing energy losses resulting from the transmission of electricity, and reducing greenhouse gas emissions. Solar thermal power has the greatest potential for a cost effective method of introducing a renewable, non-polluting energy source. The possibilities for the development of solar thermal technologies are:

- Large scale introduction of solar thermal generating plants;
- Solar hybrid systems used in conjunction with efficient cogeneration equipment;
- Solar boosted fuels where coal and natural gas are modified by solar energy to produce less CO_2 emissions

Australia is a world leader in solar energy research and the sale of the resulting technologies into overseas markets can earn valuable export revenue.

CONCULUSION

In this project the aim was to observe and analyze the benefits and uses of renewable energy sources in modern world. In this project it is observed that how the solar that a kind of renewable energy sources is useful for modern world. Solar energy is a free natural energy so scientists observed and adopted it as less costly and more beneficial for electric generation. As power engineers try to find out the better way to convert solar energy into electric energy they started to improve the solar cell that was used in small scale in old days. So researchers observed that they can improve the efficiency of solar cell, more over life time of solar cell by using different materials. Also the way to convert the DC obtain from the solar into AC is a important factor therefore there is lot of work done on this task that how an effective converter can be used in large scale conversion such as in solar power stations or in small scale applications. Another important factor is where to build solar power station, when decision of building the power station is taken it is analyzed according to area that which type power station is useful and economically beneficial for this area. Usually where there is no water around or transmission is not easily possible solar power station decision are taken. So before decision making about a power station construction lots of calculation work is done by using economical factors and others factors that can affect the project. This project explains the most famous applications of solar energy in usual life. Some how solar energy usage is a developing field and whole world is now thinking to get benefit from solar energy. Also scientists and researchers are trying to find out a method that can combine the renewable energy sources in single power station to generate electricity, some how it is practically implemented that wind and solar power can be combined to make a hybrid power station that can work under sunny condition and under windy condition. And some time renewable energy sources used as back up systems for hydraulic or other type power generation system. So in this project it is concluded that solar energy is a major application of renewable energy sources and its economic benefits, reliability of the system and the reason of clean energy enhance the importance solar energy in modern world more over it is more advantageous than energy generation systems.

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