A Study of Solar Energy and its Electricity Production

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ABSTRACT

**Background:** This study aims to study about solar energy and to have a review on it. The general introduction contained a summary of the principle. Solar energy offers only a supplement to other energy sources and can never provide a 100% replacement. Solar energy can be used in various fields such as water heating, space heating or generation of electricity. A solar collector is one way to collect heat from the sun. Two ways to generate electricity from solar energy are photo voltaic and solar thermal systems. PV is still enjoying large research and development efforts in order to produce more efficient and cheaper solar cells. But solar electricity is already economically feasible compared to other energy sources for a number of applications.


**INTRODUCTION**

Solar energy is radiant energy that is produced by the sun. Every day the sun radiates, or sends out, an enormous amount of energy. The sun radiates more energy in one second than people have used since the beginning of time! It comes from within the sun itself. Like other stars, the sun is a big ball of gases-mostly hydrogen and helium atoms. The hydrogen atoms in the sun’s core combine to form helium and generate energy in a process called nuclear fusion. During nuclear fusion, the sun’s extremely high pressure and temperature cause nuclei to separate from their electrons. At this extremely highly energized state, the nuclei are able to fuse, or combine. Hydrogen nuclei fuse to become one helium atom of a higher atomic number and greater mass and one neutron remains free. This new helium atom, however, contains less mass than the combined masses of the hydrogen isotopes that fused. This transmutation (changing one element to another) of matter results in some mass being lost. The lost matter is emitted into space as radiant energy. The process of fusion occurs most commonly with lighter elements like hydrogen, but can also occur with heavier nuclei, until Iron (Fe) is formed, because iron is the lowest energy nucleus, it will neither fuse with other elements, nor can it be fissioned (split) into smaller nuclei.

It can take 150,000 years for the energy in the sun’s core to make its way to the solar surface and then just a little over eight minutes to travel the 93 million miles to Earth. The solar energy travels to the Earth at a speed of 186,000 miles per second, the speed of light. Only a small portion of the energy radiated by the sun into space strikes the Earth, one part in two billion. Yet this amount of energy is enormous. About 30% of the sun’s energy that hits the Earth is reflected back into space. Another 25% is used to evaporate water, which, lifted into the atmosphere, produces rainfall. Solar energy is also absorbed by plants, the land and the oceans. The rest could be used to supply our energy needs (Fig. 1) [9].

Jahanbaksh and Edalatdoust [3] in an article explained that Climate of regions play a decisive role in the type of building and housing, quantity, the need of people for energy consumption and to provide energy. Kaviani (2002) stated that High dependence and the growing need for energy resources as a key factor for growth and economic activity as well as restrictions on oil reserves and other fossil fuels had caused the world in recent years to face with very complicated issue of how needed energy should be provided for the future. Khoshakhlagh et al. [5] presented an article and explained that solar energy is one of the main types of renewable energies in Iran. In this study we want to explain solar energy, its uses and how it produces electricity.

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Materials:

Solar collectors:

Heating with solar energy is not easy as you think. Getting it to work is difficult because the solar energy that reaches the earth is spread in a wide area. The sun does not deliver that much energy to any one place at any one time. How much solar energy a place receives depends on several conditions. These include the time of day, the season of the year, the latitude of the area and the clearness or cloudiness of the sky. A solar collector is one way to collect heat from the sun. A closed car on a sunny day is like a solar collector. As sunlight passes through the car’s glass windows, it is absorbed by the seat covers, walls and floor of the car. The light that is absorbed changes into heat. The car’s glass windows let light in, but don’t let all the heat out [2].

Solar space heating:

The space heating means heating the space inside a building. Today many homes use solar energy for space heating. There are two general types of solar space heating systems: passive and active. Hybrid systems are a combination of passive and active systems.

Passive solar homes:

In a passive solar home, the whole house operates as a solar collector. A passive house does not use any special mechanical equipment such as pipes, ducts, fans, or pumps to transfer the heat that the house collects on sunny days. Instead, a passive solar home relies on properly oriented windows. Since the sun shines from the south in North America, passive solar homes are built so that most of the windows face south. They have very few or no windows on the north side. A passive solar home converts solar energy into heat just as a closed car does. Sunlight passes through a home’s windows and is absorbed in the walls and floors. To control the amount of heat in a passive solar home, the doors and windows are closed or opened to keep heated air in or to let it out. At night, special heavy curtains or shades are pulled over the windows to keep the daytime heat inside the house.

In the summer, awnings or roof overhangs help to cool the house by shading the windows from the high summer sun. Heating a house by warming the walls or floors is more comfortable than heating the air inside a house. It is not so drafty. Passive buildings are quiet, peaceful places to live. A passive solar home can get 30 to 80% of the heat it needs from the sun. Many homeowners install equipment (such as fans to help circulate air) to get more out of their passive solar homes. When special equipment is added to a passive solar home, the result is called a hybrid system.

Active Solar homes: Unlike a passive solar home:

An active solar home uses mechanical equipment, such as pumps and blowers and an outside source of energy to help heat the house when solar energy is not enough (Fig. 1). Active solar systems use special solar collectors that look like boxes covered with glass. Dark-coloured metal plates inside the boxes absorb the sunlight and change it into heat. (Black absorbs more sunlight than any other colour.) Air or a liquid flows through the collectors and is warmed by this heat. The warmed air or liquid is then distributed to the rest of the house just as it would be with an ordinary furnace system. Solar collectors are usually placed high on a
roof where they can collect the most sunlight. They are also put on the south side of the roof in a location where no tall trees or tall buildings will shade them.

**Storing solar heat:**

The challenge confronting any solar heating system—whether passive, active, or hybrid—is heat storage. Solar heating systems must have some way to store the heat that is collected on sunny days to keep people warm at night or on cloudy days. In passive solar homes, heat is stored by using dense interior materials that retain heat well—masonry, adobe, concrete, stone, or water. These materials absorb surplus heat and radiate it back into the room after dark. Some passive homes have walls up to one foot thick. In active solar homes, heat can be stored in one of two ways—a large tank filled with liquid can be used to store the heat, or rock bins beneath a house can store the heat by heating the air in the bins. Houses with active or passive solar heating systems may also have furnaces, wood-burning stoves, or other heat-producing devices to provide heat during extremely cold temperatures or long periods of cold or cloudy weather. These are called backup systems.

**Solar water heating:**

Solar energy is also used to heat water. Water heating is usually the second leading home energy expense, costing the average family over $350 per year. Depending on where you live and how much hot water your family uses, a solar water heater can reduce your water heating bill 50 to 80%. A well-maintained system can last 15–20 years, longer than a conventional water heater. A solar water heater works in the same way as solar space heating. A solar collector is mounted on the roof, or in an area of direct sunlight. It collects sunlight and converts it to heat. When the collector becomes hot enough, a thermostat starts a pump. The pump circulates a fluid, called a heat transfer fluid, through the collector for heating. The heated fluid then goes to a storage tank where it heats water. The hot water may then be piped to a faucet or showerhead. Most solar water heaters that operate in winter use a heat transfer fluid, similar to antifreeze that will not freeze when the weather turns cold.

**Discussion:**

**Solar electricity:**

In addition to heating homes and water, solar energy can be used to produce electricity. Two ways to generate electricity from solar energy are photovoltaics and solar thermal systems.

- **Photovoltaic cells and power generation:**

Photovoltaic comes from the words photo meaning “light” and volt, a measurement of electricity. Sometimes photovoltaic cells are called PV cells or solar cells for short. Solar-powered calculators, toys and telephone call boxes all use solar cells to convert light into electricity. We will explain four steps that show how a PV cell is made and how it produces electricity. Current PV cell technology is not very efficient. Today’s PV cells convert only about 11–27% of the radiant energy into electrical energy. Fossil fuel plants, on the other hand, convert about 35% of their fuel’s chemical energy into electrical energy. The cost per kw-h to produce electricity from PV cells is currently about twice as expensive as from conventional sources. However, PV cells make sense for many uses today, such as providing power in remote areas or other areas where electricity is difficult to provide. Scientists are researching ways to improve PV cell technology to make it more competitive with conventional sources [6].

The sun is a constant Fusion reactor in which hydrogen is combined to produce helium and release incredible amount of energy:

$$4 \text{ H} \rightarrow 2\text{He} + 26/7\text{MeV}$$  \hspace{1cm} (1)

Batteries in the system work when sun does not shine. Thus, an additional electric generating system can store solar energy. Small cell or panel array are located on the roof as well as west side and balcony in a building or structure. Thus, the building will have a moderate temperature, even in the hot summer. [8] (Fig. 2).

Photovoltaic cells are made of silicon which in fact, is ingredient of sand. Silicon is second most abundant compound in nature. When sunlight hits the solar cell, it causes the movement of electrons and movement of electrons result in electric flow and so the electricity is generated. The size of the current depends upon the intensity of the incoming radiation. Not all the energy of the light is converted into electrical energy.

There are a number of semiconductor materials from which solar cells can be made. Until recently the most commonly used was mono-crystalline silicon. At the moment poly-crystalline and amorphous silicon are becoming more important. Table 1 gives the theoretical and achieved conversion efficiencies for a few types of solar cell materials [8].

Instead of falling directly onto the flat plate modules, the sunlight can be concentrated first by the use of lenses or mirrors. The concentrated sunlight can be focussed on a solar cell, which increases the efficiency of the cell. In this way a record efficiency of 31% was recently achieved for a silicon-gallium arsenide tandem cell. This
method enables a reduction of the costs of the array but on the other hand extra costs are incurred by the lenses; the system as a whole also becomes more complex. The technology for concentrating sunlight is still under research and is not commercially available [7].

The solar cell is the basic building block of solar photovoltaics. The cell can be considered as a two terminal device which conducts like a diode in the dark and generates a photo voltage when charged by the sun. Usually it is a thin slice of semiconductor material of around 100 cm² in area. The surface is treated to reflect as little visible light as possible and appears dark blue or black. A pattern of metal contacts is imprinted on the surface to make electrical contact (Fig. 3a). When charged by the sun, this basic unit generates a dc photo voltage of 0.5 to 1 volt and, in short circuit, a photocurrent of some tens of milliamperes per cm². Although the current is reasonable, the voltage is too small for most applications. To produce useful dc voltages, the cells are connected

![PV generator consisting of solar panels, support structure and DC-cabling](Image)

**Fig. 2:** Solar system complete graphic.

<table>
<thead>
<tr>
<th>Types</th>
<th>Theoretical</th>
<th>Achieved in laboratory</th>
<th>Achieved in Industrial production</th>
</tr>
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<tbody>
<tr>
<td>Monocrystalline silicon</td>
<td>25</td>
<td>21</td>
<td>13</td>
</tr>
<tr>
<td>Polycrystalline silicon</td>
<td>23</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>Amorphous silicon</td>
<td>24</td>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>GaAs</td>
<td>28</td>
<td>24</td>
<td>-</td>
</tr>
<tr>
<td>CuInSe</td>
<td>22</td>
<td>14</td>
<td>-</td>
</tr>
<tr>
<td>CdTe</td>
<td>28</td>
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Together in series and encapsulated into modules. A module typically contains 28 to 36 cells in series, to generate a dc output voltage of 12 V in standard illumination conditions (Fig. 3b). The 12 V modules can be used singly, or connected in parallel and series into an array with a larger current and voltage output, according to the power demanded by the application (Fig. 3c). Cells within a module are integrated with bypass and blocking diodes in order to avoid the complete loss of power which would result if one cell in the series failed [8].

Modules within arrays are similarly protected. The array, which is also called a photovoltaic generator, is designed to generate power at a certain current and a voltage which is some multiple of 12 V, under standard illumination. For almost all applications, the illumination is too variable for efficient operation all the time and the photovoltaic generator must be integrated with a charge storage system (a battery) and with components for power regulation (Fig. 3d). The battery is used to store charge generated during sunny periods and the power conditioning ensures that the power supply is regular and less sensitive to the solar irradiation. For ac electrical power, to power ac designed appliances and for integration with an electricity grid, the dc current supplied by the photovoltaic modules is converted to ac power of appropriate frequency using an inverter (Fig. 4).

The solar cell can take the place of a battery in a simple electric circuit (Fig. 5). In the dark the cell in circuit A does nothing. When it is switched on by light it develops a voltage, or e.m.f. (electromotive force), analogous to the e.m.f. of the battery in circuit B. The voltage developed when the terminals are isolated (infinite load resistance) is called the open circuit voltage (Voc). The current drawn when the terminals are connected together is the short circuit current (Ic) [8].

The photovoltaic cell differs from a simple dc battery in these respects: the e.m.f. of the battery is due to the permanent electrochemical potential difference between two phases in the cell, while the solar cell derives its e.m.f. from a temporary change in electrochemical potential caused by light. The power delivered by the battery to a constant load resistance is relatively constant, while the power delivered by the solar cell depends on the
incident light intensity and not primarily on the load (Fig. 6). The battery is completely discharged when it reaches the end of its life, while the solar cell, although its output varies with intensity, is in principle never exhausted, since it can be continually recharged with light (Ibid.).

The battery is modelled electrically as a voltage generator and is characterised by its e.m.f. (which, in practice, depends upon the degree of discharge), its charge capacity and by a polarisation curve which describes how the e.m.f. varies with current [10]. The solar cell, in contrast, is better modelled as a current generator, since for all but the largest loads the current drawn is independent of load. But its characteristics depend entirely on the nature of the illuminating source and so I and Voc must be quoted for a known spectrum, usually for standard test conditions (Ibid.).

![Diagram](image1)

**Fig. 3:** (a) Photovoltaic cell showing surface contact patterns (b) In a module, cells are usually connected in series to give a standard dc voltage of 12 V (c) For any application, modules are connected in series into strings and then in parallel into an array, which produces sufficient current and voltage to meet the demand. (d) In most cases the photovoltaic array should be integrated with components for charge regulation and storage.

![Diagram](image2)

**Fig. 4:** Clustered inverter configuration (Master – Slave) 9.

![Diagram](image3)

**Fig. 5:** The solar cell may replace a battery in a simple circuit.
Fig. 6: Voltage-current curves of a conventional battery (grey) and a solar cell under different levels of illumination. A battery normally delivers a constant e.m.f. at different levels of current drain except for very low resistance loads, when the e.m.f. begins to fall. The battery e.m.f. will also deteriorate when the battery is heavily discharged. The solar cell delivers a constant current for any given illumination level while the voltage is determined largely by the resistance of the load. For photovoltaic cells it is usual to plot the data in the opposite sense, with current on the vertical axis and voltage on the horizontal axis. This is because the photovoltaic cell is essentially a current source, while the battery is a voltage source [8].

Fig. 7: From silicon to electricity.

How a photovoltaic cell works: a summary:

Step 1: A slab (or wafer) of pure silicon is used to make a PV cell. The top of the slab is very thinly diffused with an “n” dopant such as phosphorous. On the base of the slab a small amount of a “p” dopant, typically boron, is diffused. The boron side of the slab is 1,000 times thicker than the phosphorous side. The phosphorous has one more electron in its outer shell than silicon, and the boron has one less. These dopants help create the electric field that motivates the energetic electrons out of the cell created when light strikes the PV cell. The phosphorous gives the wafer of silicon an excess of free electrons; it has a negative character. This is called then-type silicon (n = negative). The n-type silicon is not charged—it has an equal number of protons and electrons—but some of the electrons are not held tightly to the atoms. They are free to move to different
locations within the layer. The boron gives the base of the silicon a positive character, because it has a tendency to attract electrons. The base of the silicon is called p-type silicon (p = positive). The p-type silicon has an equal number of protons and electrons; it has a positive character but not a positive charge. (Fig. 7).

Step 2: Where the n-type silicon and p-type silicon meet, free electrons from the n-layer flow into the p-layer for a split second, then form a barrier to prevent more electrons from moving between the two sides. This point of contact and barrier is called the p-n junction. When both sides of the silicon slab are doped, there is a negative charge in the p-type section of the junction and a positive charge in the n-type section of the junction due to movement of the electrons and “holes” at the junction of the two types of materials. This imbalance in electrical charge at the p-n junction produces an electric field between the p-type and n-type silicon (Fig. 7).

Step 3: If the PV cell is placed in the sun, photons of light strike the electrons in the p-n junction and energize them, knocking them free of their atoms. These electrons are attracted to the positive charge in the n-type silicon and repelled by the negative charge in the p-type silicon. Most photon-electron collisions actually occur in the silicon base (Fig. 7).

Step 4: A conducting wire connects the p-type silicon to an electrical load, such as a light or battery, and then back to the n-type silicon, forming a complete circuit. As the free electrons are pushed into the n-type silicon they repel each other because they are of like charge. The wire provides a path for the electrons to move away from each other. This flow of electrons is an electric current that travels through the circuit from the n-type to the p-type silicon. In addition to the semi-conducting materials, solar cells consist of a top metallic grid or other electrical contact to collect electrons from the semi-conductor and transfer them to the external load, and a back contact layer to complete the electrical circuit (Fig. 7).

**Concentrated solar power:**

Like solar cells, solar thermal systems use solar energy to make electricity. It is important to understand that solar thermal technology is not the same as solar panel, or photovoltaic, technology. Solar thermal electric energy generation concentrates the light from the sun to create heat and that heat is used to run a heat engine, which turns a generator to make electricity. The working fluid that is heated by the concentrated sunlight can be a liquid or a gas. Different working fluids include water, oil, salts, air, nitrogen, helium, etc. Different engine types include steam engines, gas turbines, Stirling engines, etc. All of these engines can be quite efficient, often between 30 and 40% and are capable of producing 10’s to 100’s of megawatts of power. Concentrated solar power technologies focus heat in one area to produce the high temperatures required to make electricity. Since the solar radiation that reaches the Earth is so spread out and diluted, it must be concentrated to produce the high temperatures required to generate electricity. There are several types of technologies that use mirrors or other reflecting surfaces to concentrate the sun’s energy up to 2,000 times its normal intensity.

**Parabolic troughs:**

Use long reflecting troughs that focus the sunlight onto a pipe located at the focal line. A fluid circulating inside the pipe collects the energy and transfers it to a heat exchanger, which produces steam to drive a turbine. The world’s largest parabolic trough is located in the Mojave Desert in California. This plant has a total generating capacity of 354 megawatts, one-third the size of a large nuclear power plant.

**Power towers:**

Use a large field of rotating mirrors to track the sun and focus the sunlight onto a thermal receiver on top of a tall tower. The fluid in the receiver collects the heat and either uses it to generate electricity or stores it for later use.

**Dish/engine systems:**

Are like satellite dishes that concentrate sunlight rather than signals, with a heat engine located at the focal point to generate electricity. These generators are small mobile units that can be operated individually or in clusters, in urban and remote locations.

**Concentrated Solar Power (CSP):**

Technologies require a continuous supply of strong sunlight, like that found in hot, dry regions such as deserts. Developing countries with increasing electricity demand will probably be the first to use CSP technologies on a large scale.

**Conclusion:**

Today, we know the sun as our closest star in the universe. This ball of gas has a large build up of heat and pressure in its core that causes it to emit heat and radiant energy. Solar energy supports all life on earth and is the basis for almost every form of energy we use. The sun makes plants grow, which provide energy to humans in the form of food. Plant matter can also be burned as biomass fuel or, if compressed underground for millions
of years, form fossil fuels like coal or oil. Heat from the sun also causes different temperatures, which produce wind that can power turbines. More energy from the sun falls on the earth in one hour than humans consume in one year. Unlike various forms of conventional types of energy like coal, oil or natural gas, solar energy is a renewable form of energy. A variety of technologies have been developed to take advantage of solar energy in recent years.

REFERENCES