International Journal of Engineering Applied Sciences and Technology, 2021
Vol. 6, Issue 6, ISSN No. 2455-2143, Pages 86-93

SOLAR POWER AS A GREEN ENERGY SOURCE

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Abstract - Today, the world still heavily relies on fossil fuels and even continues subsidizing them. Meanwhile the damage they cause - from greenhouse gas emission, climate change to health issues has reached record levels. Because of these reasons people are searching for a substitute to fossil fuel. Green energy sources like solar power, wind power and hydropower etc. are the fastest growing energy source in the world. More importantly they cause little environmental or climate damage. This review is mainly based on solar power. Especially solar thermal collectors and photovoltaic cells are discussed in detail.

Key words – Green energy source, Solar power, Solar thermal collectors, Photovoltaic cells

I. INTRODUCTION

The meaning of "sustainability" is avoidance of depletion of natural resources to maintain an ecological balance.[a]

United Nations adopted "The 2030 Agenda for sustainable development" in 2015. It provides peace and prosperity for people and the planet, present and into the future. Sustainable Development Agenda contains 17 sustainable Development Goals. Ensure access to affordable, reliable, sustainable, and modern energy for all is 7th goal of that agenda. According to UN report in 2018, 789 million people lack electricity. Affordable and reliable energy is critical for health facility. 1 in 4 hospitals not electrified in some developing countries. One solution for these energy crises is "green energy source".[b]

Green energy is any type of energy that is generated from natural resources such as wind, sunlight or water. The main advantage of these green energy resources is that they don't harm the environment by releasing greenhouse gases into the atmosphere.[c]

Green energy often generates from renewable energy technologies such as solar energy, hydroelectric power, biomass, geothermal energy, and wind power. Each of these technologies works in different manner. In order to define as green energy, a resources cannot produce pollutant such as carbon dioxide, methane etc. this means that all renewable energy source cannot define under green energy source. As an example power generation through burning organic material from sustainable forest may be a renewable energy source. But it's not necessarily green due to greenhouse gases emission.[c]

Green energy sources are usually natural renewed and often avoid mining or drilling operation that can damage the environment. The main green energy sources are solar energy, wind energy and hydroelectric power.[c]

Consumption of green energy sources gives valuable benefits over conventional methods. First one is that it can replace the negative effect of the fossil fuel combustion such as emission of greenhouse gases. Another benefit is that these green energies are derived from natural sources, and it is often renewable, clean and often readily available. These benefits are not solely good for the planet, but it is also better for the health of animals and human.[3]

Economical type of benefits of the consumption of green energy is that it can maintain the stable price as these energy sources are produced locally and not affected by geopolitical crisis etc. Another economic benefit is job market expansion in building facilities.[c]

Because of the easy access of sources like solar and wind power, the energy infrastructure is flexible and less dependent on the centralized sources like petroleum that may lead to disruption as well and also less resilient to climate change.[c] Green energy is also the best solution for

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[a] https://www.google.com/search?q=meaning+of+sustainability&rlz=1C1RLNS_enLK864LK864&oq=meaning+of+sustainablbiliyt&aqs=chrome.1.69i57j0i13l9.17356j1j7&sourceid=chrome&ie=UTF-8 (accessed on 21.07.2021)

[b] https://sdgs.un.org/goals/goal7 (accessed on 21.07.2021)

[c] https://www.twi-global.com/technical-knowledge/faqs/what-is-green-energy (accessed on 21.07.2021)

the energy crisis nowadays people are facing, specially within the developing world. These green energy sources only improve as the cost dramatically fall and further increasing the accessibility for energy sources whether that is taking power from the sun or using wind turbines or the flow of water to generate energy.[c]

1. Solar power

Solar energy is produced using photovoltaic cells capture sunlight and turn it into electricity. Also, it is used to heat buildings and for hot water as well as for cooking and lighting.[c]

2. Wind Power

This energy type is particularly suited to offshore and higher altitude sites. Wind energy uses the power of the flow of the wind to push turbines to generate electricity.[c]

3. Hydropower

This energy type is also known as “Hydroelectric power”. In here flow of water in rivers, streams, dams or elsewhere is used to produce electricity.[c]

Exactly how ‘green’ the above mentioned three types of green energy are dependent on how they are created. In this review is mainly focused on solar energy as the green energy source

1. Solar energy

The energy from the sun is known as solar energy that uses the sun’s light and heat to generate renewable or ‘green’ power. The Sun releases an enormous amount of radiation energy to its surroundings: 174 PW (1 PW = 1015 W) at the upper atmosphere of the Earth.[1] However, due to the atmospheric scattering, diffraction and absorption, the entire solar radiation emitted by the sun is not reached on earth. Thus, only 51% (89 PW) of the total incoming solar radiation reaches the land and the oceans.[1] Solar energy is a universally available source and most prominent alternative energy source. Solar thermal and solar photovoltaic (PV) are the main categories of solar energy harnessing systems. Solar heating, solar architecture, molten salt power plants and artificial photosynthesis are some other technologies that harness sunlight. Usually, the thermal system captures the solar energy and utilizes it for thermal applications such as space heating and cooling, water heating and desalination. Solar collectors and thermal energy storage components are the two core subsystems in solar thermal applications. Solar collectors require good optical performance to absorb heat as much as possible. Solar collectors need to have high thermal storage density, good long-term durability and a good heat transfer rate. In photovoltaics, semiconductor materials are used to convert sunlight directly into electricity, which is considered one of the most promising markets in the field of green energy. Recently, solar photovoltaic energy generation has increased at a 60% annual growth rate.[2] Traditional silicon-based solar cells for domestic and other commercial usage have been excluded due to their high cost, complex production procedures and low availability of high-quality solar-grade crystalline silicon. In recent decades, several organic solar cells and dye-sensitized solar cells have been invented with low-cost materials to overcome the above-stated issues.

1.1 Solar thermal collectors

The solar thermal collector is the main component of any solar system, which captures the incoming solar radiation, converts it into heat and, transfers this generated heat to a circulating media. The main component of any solar system is the solar collector, which is designed to absorb and convert incoming sun irradiation into thermal energy. This heat is transferred into a circulating fluid, usually air, water or oil. The fluid carries heat energy to a thermal storage tank, or it can be directly used. Non-concentrating or stationary collectors and concentrating collectors are the two methods that have been used to collect solar thermal energy. The first one uses non-concentrating collector configurations. It has the same absorbing as its intercepting area. The second method usually uses concave reflecting surfaces to focus, concentrate and gather the solar irradiation onto a collector which ultimately increases heat flux. Therefore, when concentrating collectors work under high temperatures thermodynamic cycle can achieve high Carnot efficiency. These collectors have a large intercepting area than the absorber.

1.1.1 Non-concentrating collectors

Usually, non-concentrating collectors have fixed positions and do not track the sun. Therefore, these need to be in a proper orientation to collect sunlight effectively.

A. Flat-plate collector(FPC)

This type is the most common non-concentrating collector that is extensively used for domestic space heating and water heating applications. A flat-plate collector is illustrated in Figure 1.1. Glazing covers, insulation layers, absorber plates, recuperating tubes (filled with heat transfer fluids), and enclosure are the main component in a typical flat-plate collector.

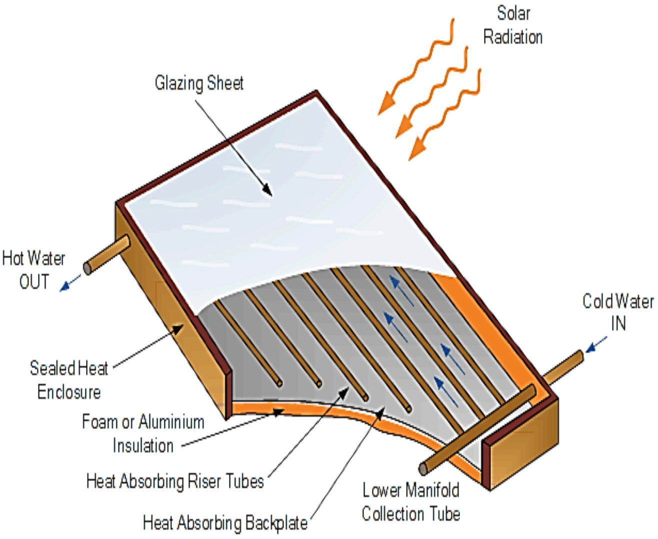
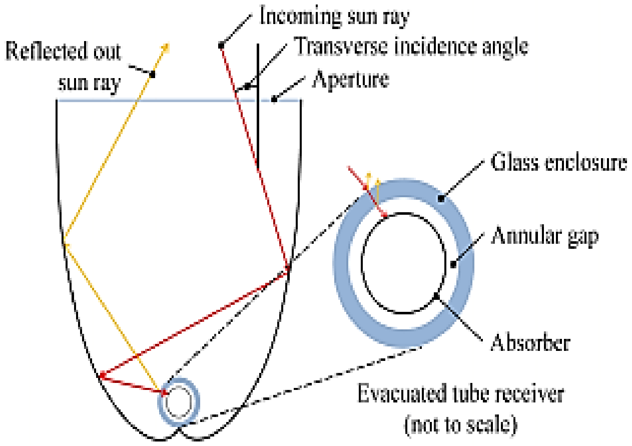


Figure 1.1 Flat plate collector[d]

Glazing is made up of single or multiple sheets of glass or plastics. It reduces convective losses from the absorber plate and further reduces the irradiation losses from the collector due to the greenhouse effect. These need higher transmittance for shortwave solar irradiation (90%) while having relatively low transmittance for long wave irradiation. Long wave radiation should be avoided; otherwise, it can cause an increase in the glass temperature and a loss of heat to the surrounding atmosphere by radiation and convection. Transmittance performance of glazing can be improved by doping glazing materials with transparent conductive oxides (TCO) such as aluminium-doped zinc oxide and tin-doped indium oxide.[3] Insulations are some materials such as fiberglass, which placed at the back and the insides of the collector to reduce heat losses. The absorber plate is covered with a flat black solar selective material to enhance the absorption of sunlight. However, according to the literature, various colours can be used for absorber plates.[4] Absorber plates are usually made of metal like copper or aluminium as the metals are excellent heat conductors. There are several different design principles and physical mechanisms to fabricate selective solar absorbing surfaces. Solar absorbers with two layers with various optical properties are known as tandem absorbers. Various types of tendem absorbers can be created to get desirable optical performance. A tendem absorber consists of a thin upper layer with high solar absorptance and high infrared transmittance and a thin-lower layer with high reflectance. According to current literature, some scientists have designed a novel 5-layered nanostructure of TiAlC/TiAlCN/TiAlSiCN/TiAlSiCO/TiAlSiO tandem absorber.[3] Commercial solar absorbers are made by electroplating, anodization, evaporation, sputtering and by applying solar selective paint.[4] The heat absorbed by the absorber plate must transfer to circulating working fluids with minimum energy loss. The temperature of the working fluid (usually water) rarely exceeds 80 ℃ in these collectors. Thus, flat plate collectors can be employed for low-temperature applications such as domestic hot water, air heating and space heating for industrial or agricultural applications.

B. Stationary compound parabolic collectors (CPC)

These collectors have multiple internal reflecting parabolic surfaces that direct the incoming solar radiation to an absorber tube, which is located at the bottom of the collector assembly as shown in figure 1.2. Therefore, compound parabolic collectors can capture a large amount of solar radiation over a wide range of angles with minimum energy loss. The main aim of these collectors is to focus a larger area of solar radiation onto a smaller area. These collectors have a fixed in a specific angle based on their orientation. “The acceptance angle of the collector is defined as the angle through which a source of light can be moved and still converge at the absorber”.[4.] All the radiation within the acceptance angle finds its way to the absorber tube. Stationary compound parabolic collectors need a minimum acceptance angle equal to 47 degrees to cover the declination of the sun from summer to winter solstices.[4]



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[d] https://www.alternative-energy-tutorials.com/solar-hot-water/flat-plate-collector.html (accessed on 13.10.2021)

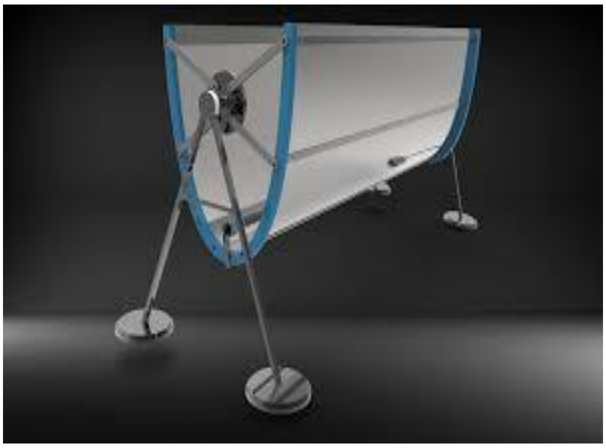

Figure 1.2 Stationary compound parabolic collectors

C. Evacuated tube collectors

Evacuated tube collector consists of a central heat pipe contained within a vacuum tube as shown in figure 1.3. There is a vacuum between the outer glass tube and the absorber, which helps to reduce the convection and conduction losses. Thus, evacuated tube heat pipe collectors can easily attain much higher temperatures and collect and retain heat even in cold or moist environments. These collectors have high efficiency even at low incidence angles. The heat pipe is attached to the absorber plate, and it allows for a rapid heat transfer. The heat pipe itself is a copper tube that contains a small amount of working fluid, which can undergo an evaporating-condensing cycle. Therefore, volatile liquid like methanol is used most of the time. The liquid gets evaporated when it absorbs heat and vapour travels to the heat sink region. Then it condenses and releases its latent heat, and condensed fluid again can return to the collector. This process is repeated. The manifold contains water or glycerol that takes up the heat from the heat pipe and eventually gives off its heat to a process or solar storage tank after circulating through another heat exchanger.

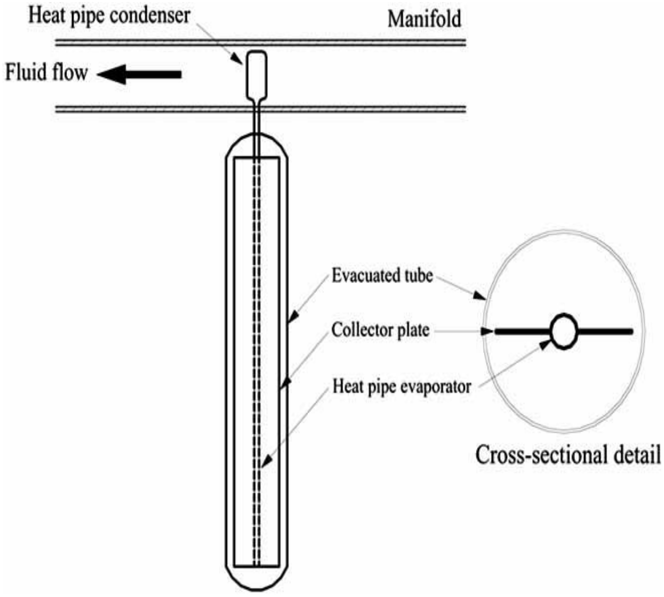

Figure 1.3 Evacuated tube collectors[5]

1.1.2. Sun tracking concentrating collectors

Concentrating collectors usually use concave reflecting surfaces to focus, concentrate and gather the solar irradiation onto a collector, which ultimately increases heat flux.

A. Parabolic trough collector

A parabolic trough collector consists of a parabolic mirror and a metal black tube (receiver) covered with a glass tube to minimize heat losses. The receiver is extending along the focal line of the receiver as shown in figure 1.3. The parabola needs to point towards the sun to incident parallel rays on the reflector. Then rays are reflected onto the metal receiver tube. The concentration of energy into a small receiver multiplies the intensity of the solar radiation. Then an oil heat transfer fluid inside the receiver tube gets heated and delivers heat to the process. Synthetic oil or molten salt mixture is frequently used to circulate through the receiver and heat exchanger tubes. In some cases, this heated oil is pumped through a series of heat exchanges to produce superheated steam.[5] This steam can be used to produce electricity through a steam turbine generator. The glass cover tube positioned around the receiver tube reduces the convective heat losses. These collectors need a reliable tracking mechanism to follow the sun and return to its original position during the night. Therefore collectors required tracking accuracy within a fraction of a degree. A parabolic trough collector can effectively produce heat at temperatures up to 400 ºC. Such heat is currently used for several applications such as desalination of seawater, production of hydrogen gas, production of hot water for industrial usage and steam generation application.

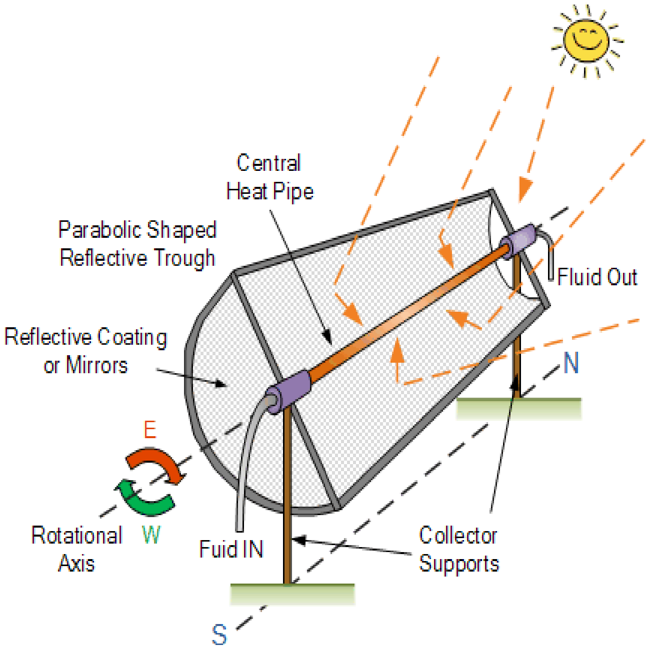

Figure 1.4 Parabolic trough collector

B. Linear Fresnel reflector (LFR)

Linear Fresnel reflector consists of long, narrow small parabola (or flat) mirrors mounted on linear solar trackers and linear receiver (one or more) oriented above the mirrors. A schematic diagram of a linear Fresnel reflector is illustrated in figure 1.4. Shallow curved mirrors focus incoming solar radiation onto the receivers. Then receivers further concentrate and focus the solar energy onto an absorber tube. The working fluid inside the absorber tube can be heated up to 250 ºC and produce superheated steam. This superheated steam is applied to run a turbine to generate electricity. The flat or curved reflectors of this collector are cheaper compared to parabolic glass reflectors. Therefore, LFR is the most appropriate solar system for remote areas in developing countries.

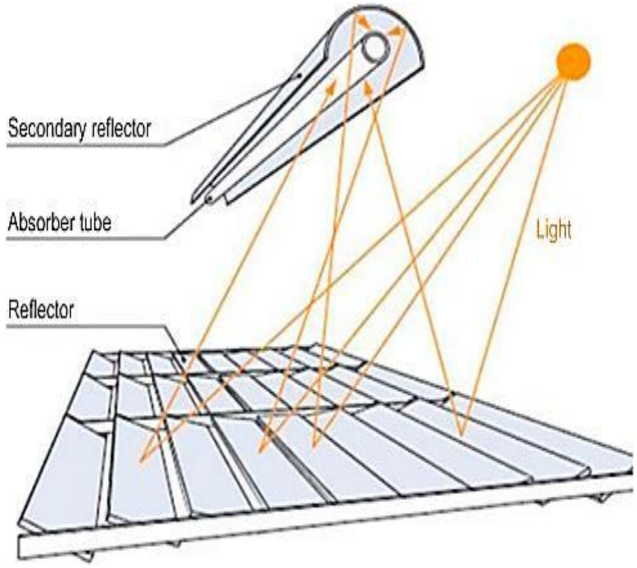

Figure 1.5 Linear Fresnel reflector[e]

C. Parabolic dish reflector (PDR)

A parabolic dish collector is similar in appearance to a large satellite dish as shown in figure 1.5. It has mirror reflectors and an absorber at the focal point of the dish. Parabolic dish collector uses a dual-axis sun tracker. The receiver absorbs the reflected solar radiation by the parabolic dish and converts it into heat energy in a circulating fluid. Usage of an engine generator that is coupled to the receiver can convert heat energy to electricity. On the other hand, heat energy can be transport through a pipe system to a central power-conversion system. Parabolic dish collectors are the most efficient of all collector systems as they can generate heat up to 1500 ºC.[6]

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[e] https://www.sciencedirect.com/topics/engineering/linear-fresnel-reflector (accessed on 13.10.2021)

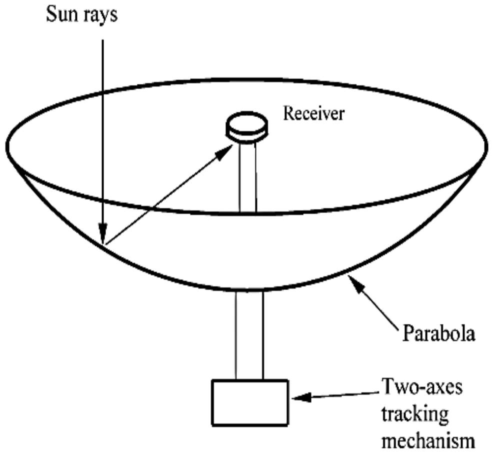

Figure 1.5 Schematic diagram of Parabolic dish reflector[1]

D. Heliostat field collector

Heliostat field collectors are also known as power tower or central receiver plant. Heliostats are located around a tower to reflect incident direct solar radiation onto the receiver head of the tower. Slightly concave mirror segments on the heliostats can direct a large amount of solar radiation onto the receiver. The receiver then transfers absorbed heat to a circulating fluid, which can store for later delivery to the power conversion system. Absorbed heat can be used to generate steam at high temperatures and pressure to run turbines in the power conversion system. These collectors minimize the thermal energy transport requirement as they collect and transfer solar radiation to a single receiver. The average solar flux entered in the receiver has values between 200 and 1000 kW/m^2. This high flux makes it work at about high temperatures of more than 1500 ºC.[6]

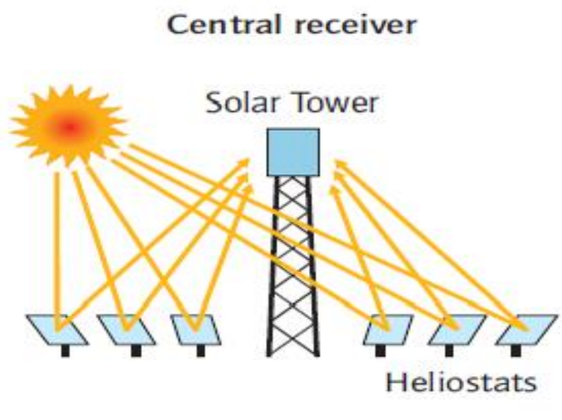

Figure 1.6 Schematic representation of Central receiver[6]

1.2 Photovoltaic solar energy

Photovoltaic solar cells are the devices that involved in direct conversion of solar photons into solar electricity. This is one of the most promising research areas in the field of green energy. This conversion occurs due to the photovoltaic effect in semiconductor materials. Semiconductors have two energy bands, in one of them electrons are present in the outermost layers and it is known as the valance band. Conduction band does not have any electrons. The energy range between the valance and the conduction band where electron states are forbidden is known as the band gap. [8,9,10] Semiconductors can gain energy from the solar radiation and supply that energy to the outermost electron in the valance band to cross the band in order to reach the conduction band. Then a hole- electron pair is generated in the system. This hole-electron pair is mainly responsible for the generating electricity. The charge carriers are separated by formation of a PN junction between two semiconductor materials which used to form the photovoltaic cell. This makes development of voltage across the junction. The PN junction is the main component of the cell where the light receiving portion is the N-type material and in the part below, the material is P-type as illustrated in Figure 1.7.[7] Eventually, the charges are swept away to the external circuit, thus creating a current through the system. This is the carrier transport mechanism in the photovoltaic cells.

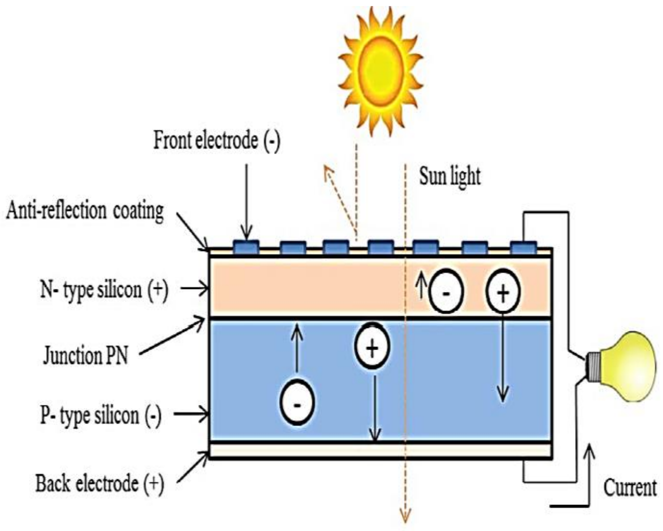

Figure 1.7 Schematic diagram of photovoltaic cell

The main categories of photovoltaic are to solid state solar cells, dye-sensitized solar cells, and organic solar cells. However, over years, many research studies have developed novel photovoltaic cells in addition to above mentioned cell types.

1.2.1 Solid state solar cells

Crystalline silicon based photovoltaics is the most popular even though they are high cost compared to traditional power sources. Thus, large scale implantation of silicon base solar cell is hindered. These types of solar cells produce relatively high efficiency of around 20% in converting solar energy into electricity.[7] Typically crystalline silicon solar cell has a value of 1.1 eV band gap. There are several strategies involved in production of novel silica based solar cells. One strategy is the use of hydrogenated amorphous silicon or amorphous silicon because these materials have higher energy absorption capacity compared to crystalline silicon. This is because randomness in the atomic structure has an important effect on the electronic properties of the material, causing a larger gap (1.7 eV).[6] Additionally, their synthesis procedure is inexpensive. According to the previous studies, alloying hydrogenated amorphous silicon with other elements like Germanium have given a broad range of band gaps from 1.25eV to 1.72 eV. [6,7]

Recently, researchers have found that silicon nanowire solar cells. These cells have a new way of converting solar energy to electricity with a better absorption of solar radiation, thus giving a higher efficiency. Silicon nanowire solar cells production procedures are low cost compared to traditional technologies as they require less silicon for the absorption of solar radiation. On the other hand, silicon nanowires exhibit excellent electrical characteristics than crystalline silicon.[11]

In constructing thin film solid state solar cells, copper indium gallium selenide (CIGS), cadmium telluride (CdTe), and gallium arsenide (GaAs) are used as alternative materials for silicon. Such thin films solar cells need fewer materials from the semiconductor to be produced to absorb the same amount of energy of sun radiation; up to less material than crystalline solar cells.[6,12] Therefore, their cost of production is very low. However, thin films convert solar energy into electricity in the range of 5% to 13%, whereas the conversion of crystalline silicon solar cells has conversion in the range of 11% to 20%.[6] Copper-indium-gallium selenide (CIGS) photovoltaic cells (Copper and indium diselenide (CuInSe2) and indium copper selenide (CIS)) contain semiconductor elements of groups I, III and VI of the periodic table. These solar cells are beneficial due to their high optical absorption coefficients and their electrical characteristics that allow the adjustment of the device.[7] Degradation under wet conditions, as it promotes changes in the properties of the material and the shortage of indium in nature are some challenges of these types of solar cells.

1.2.2. Organic photovoltaic cells

An organic photovoltaic cell consists of five layers with the transparent substrate, which is usually glass or polyester, through which the device is to be illuminated. Usually transparent conductive oxide, such as indium tin oxide (ITO) is used as anode, while gold (Au) can be used as the cathode in the organic solar cells. In organic photovoltaic, mainly pi conjugated organic materials with opposite electronic demand are used as the donor-acceptor pair. This is because delocalized pi-electrons are mainly responsible for the photovoltaic behavior of the semiconducting organic materials in the UV-visible range. Such pi conjugated organic polymers are the most promising materials for organic photovoltaic, as they are less expensive and flexible.

II. CONCLUSION

Solar energy is most prominent alternative energy source, and it is harnessed using wide range of modern technologies. Solar thermal and solar photovoltaic (PV) are the main categories of solar energy harnessing systems, which were mainly discussed in this review. In any solar system, solar thermal collector is the basic component. Non-concentrating or stationary collectors and sun tracking concentrating collectors are the two methods that have been used to collect solar thermal energy. The various types of non-concentrating collectors including flat-plate collector (FPC), stationary compound parabolic collectors (CPC), evacuated tube collectors and 4 types of sun tracking concentrating collectors namely parabolic trough collector, linear Fresnel reflector (LFR), parabolic dish reflector (PDR) and heliostat field collector are briefly discussed along with their working principle. Photovoltaic solar cells involved in direct conversion of solar photon into electricity. Over years, many research studies have developed novel photovoltaic cell types. As the most prominent photovoltaics, solid state solar cells and organic photovoltaic cells have also been reviewed.

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