Solar Photovoltaics: A Review

Authors Names	ABSTRACT
[a]*Mustaf. Malik. Saadoon,* [b]*Ibtisam A. Hasa,* [c]*Sahar R. Faraj* ***Publication data***: 18 /12 /2023 ***Keywords*:** PV, solar radiation, passive cooling, active cooling, surface temperature	The rise in surface temperature has a negative effect on P.V. module's output. This increase is due to the heat generated during the conversion of sunlight into electricity, which has an impact on the panel's durability, efficiency, and power output. The use of cooling solutions can potentially provide a way to avoid excessive PV panel heating and lower cell temperature. In addition to outlining several practical cooling techniques, this study also identifies next research directions and proposes unique and cutting-edge PV panel cooling solutions. To offer greater understanding and helpful advice for researchers who plan to explore, enhance, or optimize any form of cooling strategies for PV modules, many qualities and capabilities of each cooling strategy are presented. Due to the recent rise in fossil fuel prices and the associated global warming, alternative energy sources that are environmentally friendly have come to the forefront of discussion. Of these, solar photovoltaics is a dependable option to meet the sharp rise in worldwide energy demand. The development of low-cost, powerful solar cells has thus been a primary focus for the scientific community. The most major types of photovoltaic (PV) devices developed in the last six decades will be explored, together with certain novel ideas for high efficiency solar cells, for showing the state-of-the-art in solar PVs.

1. Introduction

PV systems are a dependable alternative among renewable energy sources to meet the world's energy needs. They convert solar radiation into electricity. Actually, more solar energy from the sun enters the Earth's atmosphere every hour compared to all of the planet's people use in a single year [1].

Despite the benefits of this limitless and clean resource, the installed PV devices must have a greater efficiency to cost ratio in order to be competitive with the traditional energy sources. Despite the fact that the target of 1 E per Watt peak is still not being reached, major strides were made in installed PV power over the previous three decades, as well as a reduction in costs (from the end of 2006 through 2011, the operating capacity regarding solar PV expanded by an average of 58% annually) [2]. The long-term trends in retail module prices over the years have largely been caused by adjustments made at the manufacturing gate. The worldwide supply/demand balance, the decline in manufacturing costs, and the adjustments in government incentives have all directly impacted factory gate prices. By appropriately boosting or reducing the growth in demand as well as the total funding cost of those subsidies, a balance between increasing and decreasing the incentives in accordance with the current market trend helped to lower the PV cost. Notwithstanding a long-term decline in retail module pricing and a reduction in expenses. [3]

There is a growing consensus that distributed PV systems, which deliver electricity at the point of consumption (such as PV power systems for individual buildings), will be the first to enter mainstream commercialization. Building integrated PV (BIPV) systems actually have lower overall costs compared to traditional PV since they can function as both a power supply and a building envelope (more particularly, as façades or roofs). The building could become self-sufficient by using BIPV systems in standalone, disconnected systems [4].

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As a result, it is projected that the PV industry will continue to expand over the coming years as a result of the creation of efficient, low-cost solar cells that meet BIPV standards (particularly, deposition on a variety of substrate types and extended life).[5]. For the bulk of second half of the 20th century, crystalline Si-based devices dominated the PV market because of the unique properties and advantages of Si over other PV absorbers (no toxicity, availability, sustainability, and long lifetime). Lately, concentrated PV systems depending on III-V compounds and organic solar cells and inorganic thin-film devices which compete with Si with regard to lower production costs were developed. When it comes to higher efficiency, these technologies compete with Si [6].

2. Types of solar photovoltaic cells

Solar cells, which are made up of many layers of semiconductive material, are used to generate electricity. The power is produced by the electromotive force that is created between these layers when the rays of the sun strike solar cells. With an increase in solar radiation intensity, electrical flow increases. The most utilized component for solar cells is Si. Since Si is made from sand and is one of the most common elements in earth's crust, there is a virtually limitless supply of raw materials, as shown in fig. 1, [7].

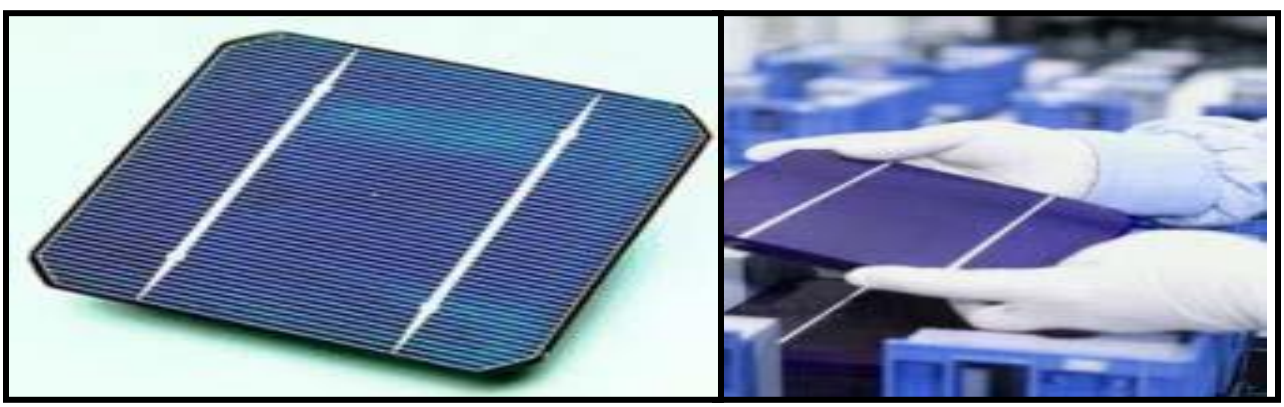

Figure (1): photovoltaic cell

Technologies for producing solar cells are:

- Polycrystalline.
- Monocrystalline.
- Bar-crystalline silicon.
- Thin-film technology.

Cells made of crystal Si are composed of a wafer, a single silicon crystal monocrystalline, or a whole block of silicon crystals (multicrystalline), and their efficiencies range from 12% to 19%, as shown in figure 2.

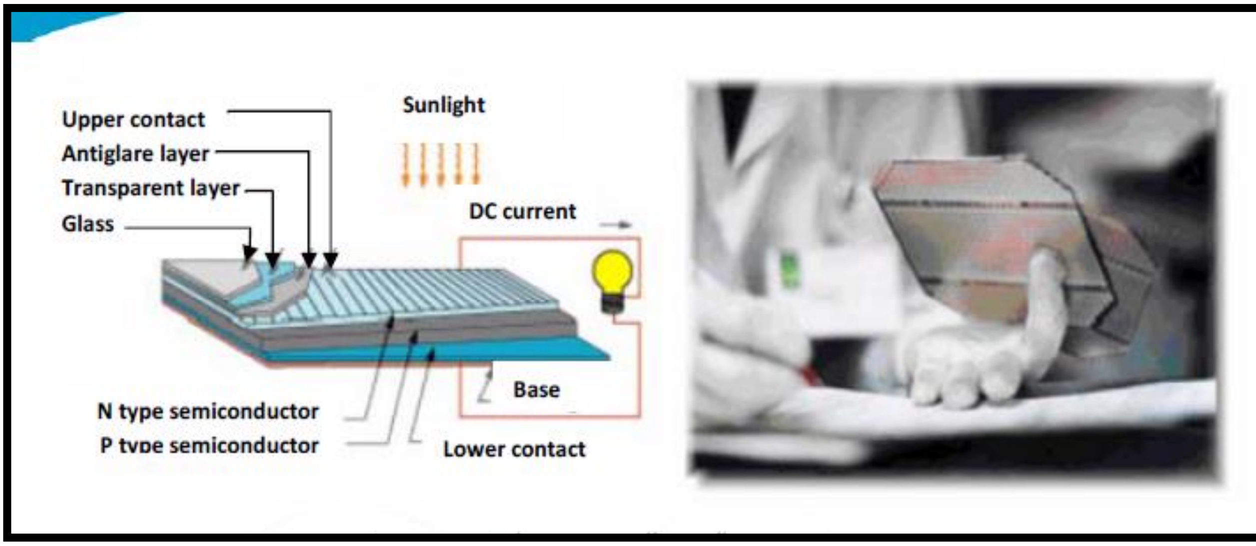

Figure (2): Typical monocrystalline cells

- • Monocrystalline Si cells: these cells' conversion efficiencies range from 13% to 17%, and they are usually considered to be in widespread commercial use. It is the most effective photovoltaic cell in good lighting. This type of cell could convert solar radiation of 1.000 W/m2 into 140 W of electricity using a 1 m2 cell surface. A semiconducting compound must be 100% pure in order to produce monocrystalline Si cells. From molten Si, thin chips (wafer) consisting of monocrystalline rods are taken out. A rather high degree of usability is made possible by this method of manufacture. These cells are expected to last for 25 to 30 years on average, and like with all photovoltaic cells, their output naturally deteriorates with time.[8].
- • Multicrystalline Si cells: these cells have a 1 m2 cell surface and can generate 130 W of power from 1.000 W/m2 of solar radiation. Compared to monocrystalline, these cells can be produced more inexpensively. After being poured into blocks, the liquid silicon is then sliced into slabs. Crystal structures of different sizes are formed during the solidification of materials, and at their edges, flaws may appear, resulting in a somewhat decreased efficiency for the solar cell, which ranges from 10% to 14%. It is anticipated that the lifespan would be between 20 and 25 years.[9].

• The benefit of using ribbon silicon is that wafer cutting, which could cause material losses of up to 50% throughout cutting, is not necessary. Yet, despite its high level of quality and potential for production, this technology won't overtake the competition very soon. These cells have an efficiency of about 11%.***[10]***

3- Photovoltaic Panels

The most well-known way to turn solar energy into electricity is through PV panels. Each module in a PV panel has several solar cells that are linked in series, parallel, or combination. A PV panel is made up of numerous modules. Solar cells typically receive their scientific names based on the semiconducting material they were constructed from. To absorb sunlight, such semiconducting materials need to possess particular properties. There are two different types of solar cells. The first type is created to capture sunlight that falls on Earth's surface, whilst the second is used in space [11]

4- Photovoltaic Panel Manufacturing Components

First, second, and third generations of solar cells are separated by their classification. The first generation of solar cells were conventional cells, wafer cells, or traditional cells. Those cells are constructed from Si that is both polycrystalline and monocrystalline. Second generation thin film solar cells include those made of cadmium telluride (CdTe), amorphous silicon, and copper indium gallium selenide (CIGS). Small standalone power systems, integrated PVs, and PV power plants frequently use this type of cell. [12] The third generation of solar cells, emerging PVs, comprises a number of thin-film technologies. Almost all of such solar cells have not yet been deployed commercially in markets and are currently in different stages of development or research. [13]

The silicon wafer used to make the PV cell is typically thin; each cell typically has dimensions of 10 cm 10 cm 0.3 mm. On top of the boron-doped silicon (P-type), which is a thicker layer, each cell has a very thin layer of silicon that has been doped with phosphorus (N-type). The mono- and poly-crystalline silicon-based PV panels are the ones that are used the most frequently. [14] Structure of monocrystalline solar panels. In fig 4

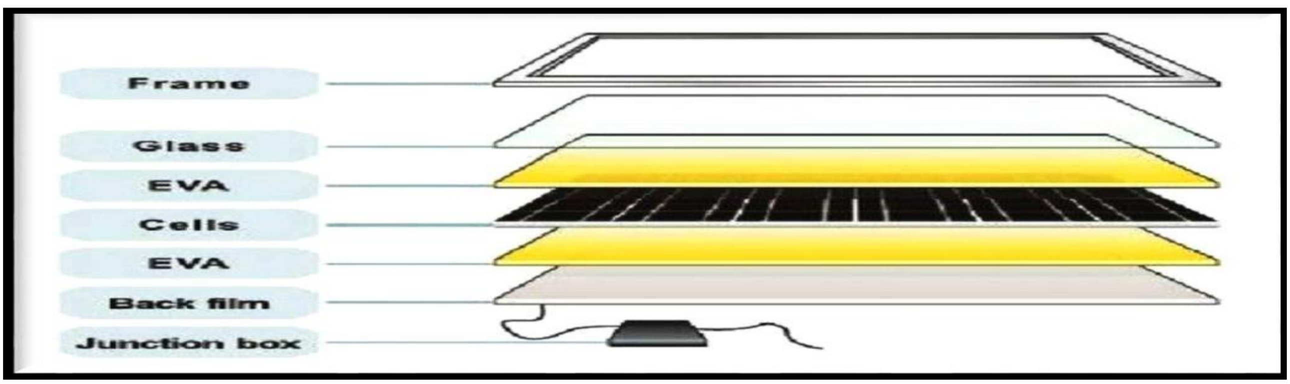

Fig (4): Structure of monocrystalline solar panels.

5- Photovoltaic Panel Performance

A built-in electric field and connections between the various materials used to make each PV panel are present. These junctions behave in a specific way when the panel absorbs sunshine photons since the energy of those photons exceeds the band gap energy regarding the semiconductors utilized to make the panel. [15]

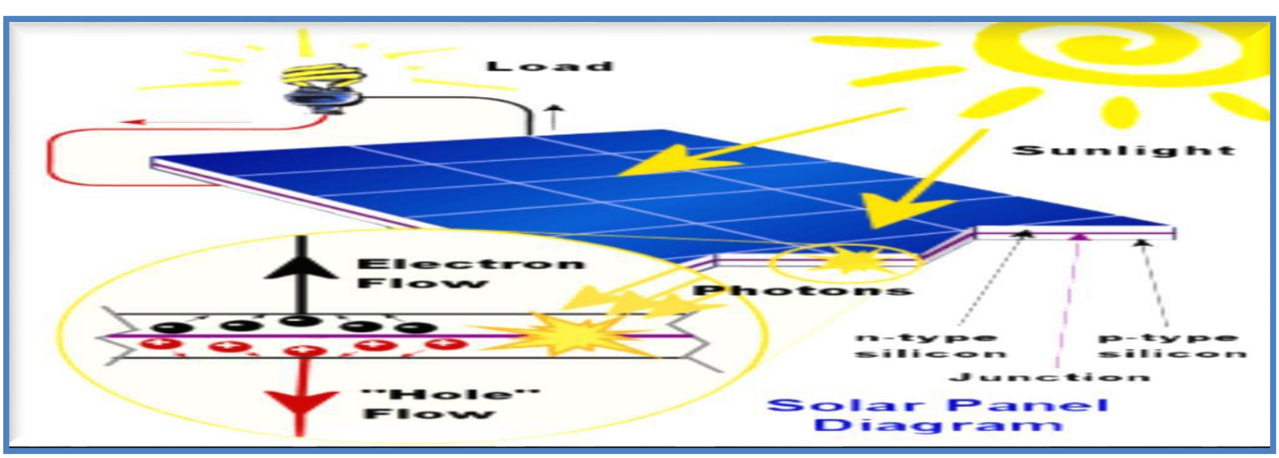

Figure (5): Solar Panel Diagram. [16]

Electrons are freed and transferred to the conduction band through the valence band after receiving photons from the sun. Thus, electron-hole pairs are generated. These electron hole pairs proceed across the circuit in opposite directions, resulting in the production of direct current (DC) [17].

The PV panel is affected by how much sunlight reaches its surface and converts this solar energy directly into electricity without the use of rotating elements. PV panels generate more power when they are exposed to more sunshine and absorb more solar radiation. Through placing the PV panel so that sunlight reaches its surface perpendicularly, this could be achieved. In order to create more power, a tracking system is utilized to position the PV panel as closely as possible to the sun. [18]

6- Photovoltaic Panel Cooling Techniques

In the case when the solar cells' temperature rises, a PV panel's efficiency will be significantly reduced if no less than 80% of the solar radiation it absorbs is converted into heat. A cooling technique should be added to the PV panel for maximizing output power and improve the performance of PV system.[19] For achieving this, PV panels convert approximately 20% of solar irradiation—defined as the amount of solar radiation gained by a PV panel per unit surface area (W/m2)—into electricity, with the remaining energy being converted into heat energy, which is then added to the high ambient temperatures in Iraq during the summer. The solar cells also generate heat while they work to provide power. Both the temperature of solar cells and the effectiveness of PV panels are affected by all of these factors. Passive and active cooling systems are the two different types of PV panel cooling techniques. Cooling techniques that utilize an external cooling source, like forced water, forced air, refrigerant cooling methods, or nano-fluid cooling methods, could be used to reduce the PV system's temperature. While passive cooling systems utilize natural resources like natural air, natural water, or phase change materials (PCMs) for cooling PV systems through conduction or convection. [18] [19] In the case when choosing the appropriate cooling approach for PV system, many factors should be considered, such as the type of PV technology being applied, the local climate in which PV system is located, and the various PV geometries. [20]

7- Active Cooling System

Devices like fans or water pumps are used in the cooling mechanism onto the PV panel surface in active cooling systems to absorb the heat from the PV panels and create fluid circulation for the system. [21]

Passive cooling is less expensive and more effective compared to active cooling overall. It is often used when waste heat recovery from household water heating is advantageous and when the increased efficiency of the panels is more than the energy required to operate the system. [22]

An earlier study demonstrates that by blowing air at a mass flow rate of about 0.035 kg/s through an aluminium air flow duct at the back of a PV Panel temperature dropped to 12 °C and maximum relative efficiency rose to 8.9% on a 0.924 m2 polycrystalline PV cell panel. According to another study, using air with a mass flow of 0.74 m3/s boosted efficiency by around 2% [23].

For a mono-crystalline PV panel with an area of 1.24 m2 and a closed case from the back side cooled by water flowing through it with a maximum mass flow of 0.06 kg/s, the temperature of the panel was lowered by 10 °C and efficiency increased to a maximum of about 2.8% when compared to a non-cooled module. [24]

8- Passive Cooling System

To transfer heat from PV panels and into the environment, passive cooling systems just require natural convection. The phase change material method is the most effective passive technique. There are two cooling forms for this method: complex form and simple form. The basic form increases heat transfer to the surrounding environment by using solid metals with high thermal conductivity (such aluminium and copper), a collection of fins, or other ejecting plates. On the other hand, the complex form uses phase change materials (PCMs) in conjunction with ways of natural circulation. [25].

Using two polycrystalline PV panels, one with aluminium fins acting as a heat sink and thermal grease applied, and the other without, a prior study found that electric efficiency may be boosted by roughly 9%. [26].

Another study found that employing 65W PV panels with 50 mm of the proper type of PCM material on the back and vertical aluminium fins to improve conduction led to a temperature decrease of 15 °C in comparison to the other PV panels without cooling, and a 9.7% increase in power output. [27-28]

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