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Effect of Temperature and Solar Panel Position on Solar PV System Performance: A Review

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Abstract: Most people think that the sun's energy is the most valuable and plentiful of all the energy sources in the world. Getting electricity from the sun's energy can be done in many ways that have been tried and tested. Solar PV systems that use sunlight to generate electricity are well-known and widely used technology. The performance of PV technology depends on the solar panel's temperature, how much dust it is exposed to, and how the panel is tilted. Changing the panel's materials may alter its performance but the effects of other parameters are still questionable. Few research works have examined individually how the temperature of the panel, as well as the panel angle, affect the performance of the solar PV system but still, the impact of the integration of both systems needs to be better studied. Therefore, this review aims to investigate how the temperature of the solar panels and the angle of the automated control panels affect solar PV performance.

1. Introduction

One of the essential factors in the growth of a country's economy is energy. Traditional energy sources, including oil, coal, and natural gas, are crucial for the modern world economy. Historically, conventional energy sources have played a significant role in promoting economic expansion. As a result, more people are looking for "renewable energy sources" as substitutes for conventional energy sources. According to the definition of "renewable energy," it is energy produced from unending sources (Ostergaard et al., 2020; Zobaa & Bansal, 2011; Gross et al., 2003). Since the dawn of human history, people have used renewable energy. It is regarded as the primary energy source for maintaining human life. The sun usually gives the earth the heat it needs to have good places to live. It comes from solar radiation, and plants require it to grow. These plants provide the habitats with the energy they need to live healthy lives and do valuable work. The energy required by humans is between 60 and 90 W for maintenance and between 40 and 70 W for work and other activities. A human can start working at a maximum rate of 330 W for four hours and 2000 W for around one minute (Serensen, 1991). Renewable energy was first used by humans when they first used fire. Wind power was used to make sailships about 5,500 years ago. Today, wind power is used to make electricity. Renewable energy sources are already widely used, and many countries are trying to do the same in different parts of the world. When it comes to providing high-quality energy, it has no rivals. Even though there are several renewable energy sources around the globe, this technology still needs to be more common because there is no suitable technique to convert it (Serensen, 1991; Timmons et al., 2014; Breyer et al., 2022).

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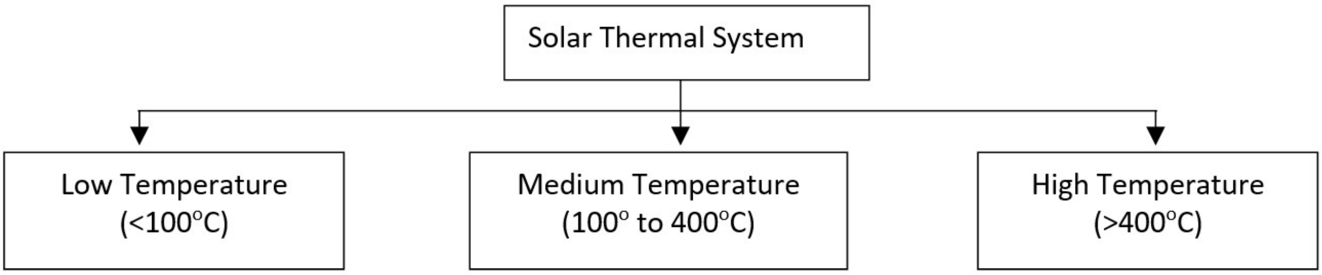

Fig.1: Different types of helio-thermal Processes.

Two methods are used for turning the energy from the sun into electricity. The first is called the helio-thermal process or solar thermal generation. In this process, the heat is generated simply from the sun's light. This group is again divided into three categories regarding the working fluid temperature (low, medium, and high), as shown in Fig. 1.

In the helio-thermal process, solar energy is used to heat water or air to produce steam or air flow that powers heat engines or wind turbines to produce electricity. The second way is to use a photovoltaic, or solar cell, to collect energy from the sun and turn it into electricity. A solid-state device that resembles a transistor or microchip is a solar cell. It mimics the characteristics of semiconductors like silicon to convert sunlight straight into electricity. Semiconductors that resemble silicon are used to make solar cells. Solar cells are arranged in parallel and in series to form PV solar panels. In a photovoltaic cell, silicon electrons get some of the energy from the photons that hit them. The silicon atoms can be separated from their parent silicon atom using this energy. Unbounded electron mobility is possible with n-type silicon. Using electrodes and external rotation, electrons are transferred from n-type to p-type (Nanu et al. 2004; Veith-Wolf et al. 2018).

1.1. Types of solar PV panel material

The first generation of solar panels is the cleanest and best choice for most situations. They don't take up much room and only have 15-20% output efficiency. However, heat and extreme temperatures impact them, shortening their lives. Second-generation solar panels include both amorphous silicon solar cells and thin-film solar cells. They are typically used in solar power though the solar plants built inside buildings and are a part of smaller power systems since they are less expensive and more versatile. The module's efficiency is between 9 and 17%, and it doesn't last as long as monocrystalline or polycrystalline cells. The three categories of third-generation solar panels are biohybrid, cadmium telluride (CdTe), and concentrated solar cells. With a module efficiency of more than 22%, they are 100 times more effective than first-generation cells. The optimal locations for high-concentration photovoltaic (HCPV) panels have a lot of direct, ambient light. They cost less and pay for themselves faster, but if you eat or breathe them in, they could be harmful (Bagher et al., 2015; Ranabhat et al., 2016).

1.2. Performance of Solar Cell

Capturing energy from the sun and converting it into power for everyday life is considered a great idea, but the technologies are concerned with many limitations and problems that need to be fixed before the use of this power. It is generally known that temperature and solar irradiation levels affect solar cells' efficiency and output power. The irradiance level has an impact on power output when it is exposed to a multi-crystalline silicon solar module. The high-power output is reflected when the irradiance level is found high. This is also responsible for increasing the module surface temperature and reducing the power output significantly. For the solar irradiation level close to 1000 W/m2, a mono-crystalline silicon solar module's output power is found maximum. The higher mono-crystalline silicon solar module temperature significantly decreases the power output of the module. In an amorphous silicon solar module, the power output is high even though the solar irradiance level is low. These types of cells are better than bulk silicon solar cells at absorbing light. Even though the amorphous silicon solar module doesn't show any drop in power at a lower temperature. Studies showed that silicon solar cells can't handle heat as well as amorphous silicon solar cells. CIS solar modules can produce more power even in low sunlight. Like amorphous silicon solar cells, the CIS solar cell absorbs light very well. The rising module temperature has little impact on the CIS solar module's output power

(Amin et al., 2009; Singh and Ravindra, 2012; Gaur and Tiwari, 2013).

1.3. Barriers and Improvement

The efficiency of a solar cell is described by the energy conversion factor, making it a photoelectrical energy conversion device. The effectiveness of a solar cell is described by the ratio of the cells' power output to the product of total irradiation and the module surface area. The solar system performance depends on the types of solar cells, batteries, inverters, controllers, etc., that are the main components of this system (Qureshi et al., 2017; Malik et al., 2013).

The most extensively used module technologies on the market are crystalline and thin-film solar cell technologies. Single or multi-crystalline silicon wafer-based solar cells known as first-generation solar cells are available on the commercial market. The development of second-generation solar cells is based on thin film technology, which offers higher efficiency during the initial stages due to the small number of materials required. Amorphous silicon, cadmium telluride, copper indium selenide, and copper indium gallium are the different categories of this type of solar cell. The performance of the second-generation solar cell is low, but the production cost is high due to introduce flaws. The second-generation cell efficiency at the laboratory level is between 1–23%, which is much lower than the first generation. Dye-sensitized solar cells and organic solar cells are named the third generation of PV cell technology. They developed based on technological, material, and processing cost criteria. This technology, which is still in the early stage and offers a laboratory-level performance of 4–12%, is less effective than the other two generations (Emery and Osterwald, 1986; Fesharaki et al., 2011; Siddiqui & Bajpai, 2012; Dubey et al., 2013; Siecker et al., 2017).

The efficiency of a solar cell is inversely proportional to temperature since the temperature has a significant impact on the silicon band gap, resulting in decreasing the cell's open-circuit voltage, and efficiency dropping significantly. Normally, about 6–20% of solar radiation is converted into electricity depending on the materials used in the solar cell and the surrounding conditions. Some part of the solar radiation is converted into heat result an increase in the temperature of solar panels and a decrease the performance or efficiency (Dubey et al., 201; Singh and Ravindra, 2012; Chegaar, and Mialhe, 2008; Siddiqui and Bajpai, 2012) It was discovered that electrical performance improved with a temperature drop of 3 to 9oC, enabling a decrease in PV area from 25 to 23 m2. According to reports, a conventional solar home system has a PV temperature reduction of around 20 °C at high irradiation, which, depending on the stratification, increases electrical production by 9–12%. The efficiency of a PV module decreases by 0.5% for every increase in surface temperature of 1 °C (Siddiqui & Bajpai, 2012; Dubey et al., 2013; Siecker et al., 2017; Fesharaki et al., 2011).

2. Solar tracking system

2.1. Passive solar tracking system

Passive solar trackers point their sensors toward the sun's rays without using any moving parts. Instead, it uses shape-memory alloys or low-boiling-point compressed gas fluids as actuators. When the panel is exposed to light that isn't evenly distributed, it moves to cause thermal expansion in expandable gases or shape-memory alloys and bring back irradiance balance. When one side of the liquid gas absorbs more heat energy than the other, the gas expands and moves towards that side of the tracker. The panel tilts until it is in a position of equal light because of the uneven gravitational attraction it produces. Although it is simpler to use and functions well, low temperatures make it less effective (Hafez et al., 2018; Brito et al., 2019).

2.2. Active Solar Tracker

In active tracking, the panels are lined up with the sun's rays with the help of electrical motors and gear trains. Since it combines sensors, motors, and microprocessors for tracking, it is more accurate and practical than passive solar trackers. However, they use energy because they require power to operate. When the trackers do not face the sun, the sensors get different amounts of light, making them send out a different signal. A comparator or a microcontroller uses this different signal to figure out how to move in the right direction. The motors are subsequently given the proper signal. The process is complete when each sensor gets the same light, and the PV module is in the right place to catch the sun's rays. In an experiment to improve thermal efficiency, the tracker-based system could store 40% more thermal energy than the fixed system. Many studies have been conducted on the performance of active solar tracking systems. Table 1 contains a summary of the research work (Kasburg, and Stefenon, 2019).

Table 1 Performance analysis of different solar PV systems.

Author	Findings
Jamroen et al., 2021	The outcome of this article is that dual-axis tracking increases solar cell performance when compared to LDR-based tracking. The data demonstrates that a UV sensor-assisted solar panel produced a higher electrical gain compared to others.
Zhu and Yang, 2020	This research makes a new single-axis tracking structure for a PV system so that it can get more energy from the sun.
Abdelghani-Idrissi et al., 2018	In this article, the performance of solar cells with and without solar trackers is compared. It is found that the total amount of thermal energy stored goes up by 40% when solar trackers are used.
Thorat et al., 2017	This research mentioned that a properly tracked system can produce up to 20.98% more electricity than a fixed system.
Eldin et al., 2016	A solar system with a sun tracker has increased electrical energy generation by about 39% in Germany. Whereas in Egypt, this increment is increased by 8%. It can be concluded that solar tracking systems aren't effective in some ambient conditions.
Lazaroiu et al., 2015	In this paper, the effectiveness of a PV system was assessed and experimented with using a sun tracker. The energy gain increased by up to 20% when compared to fixed panels.
Eldin et al., 2012	According to the findings of this paper, dual-axis tracker-assisted PV systems can generate 30% more energy than fixed PV systems.
Mousazadeh et al., 2009	The finding of this paper is that a single-axis assisted PV system generates 24% more power than a normal system.
Abdallah, 2014	This paper highlighted that the electrical power gain was 15.69% for north-south tracking, 34.43% for vertical tracking, 37.53% for east-west tracking, and 43.87% for two-axis tracking in Amman, Jordan, as compared to a fixed surface inclined to the south.
Al-Mohamad, 2004	Compared to a system that doesn't track, a PV module's daily power output went up by more than 20% with a tracking system.

2.2.1. Active solar tracker with single-axis system

The rotation axis is the sole degree of freedom in a single-axis tracking system. Rizk and Chaiko worked on the research for more effective solar panel usage. The panel was maintained at the proper angle to the sun's rays using a single-axis tracking solar system with a stepper motor and light-dependent sensor. Power gain was increased by 30% when compared to a fixed horizontal array (Rizk and Chaiko, 2008; Alvarado-M et Al., 2020).

2.2.2. Active solar tracker with dual-axis system

It makes use of two rotary axes that are parallel to one another. It works better than systems with only one tracking axis but needs a complicated control system (SAT). The enhanced double-axis tracking method offered an efficiency boost of about 15%–17% compared to a single-axis tracking approach (Amelia et al. 2020).

2.2.3. Chronological solar tracker

A chronological solar tracker is a time-based tracker that moves at the same speed and angle every day and month. As a result, the motor or actuator is programmed to rotate slowly, on average, once per day (15° per hour). This tracking system figures out where the sun is at any given time using pre-programmed algorithms based on mathematical projections of the sun's path. The PV panels are then set up in the right way. On a cloudy day, constant rotation uses more energy and takes more work, even though it loses less energy and has fewer tracking errors (Amelia et al. 2020; Pulungan and Son 2018).

3. Effect of Cooling System on PV Panel

PV modules need solar radiation to produce electricity. The performance of the modules has long been recognized to suffer from temperature. The heat from the sun increases the solar panel's surface temperature and reduces its efficiency significantly. Heat gain by the solar panel or PV module depends on the materials used for manufacturing the module. Therefore, it should be considered when designing a PV module. To receive the best performance from the solar panel, it is important to maintain a constant temperature and it can be achieved by using an appropriate cooling system. The most common cooling methods for PV systems are air cooling, water cooling, and heat pipe cooling. The example of the most common cooling systems are floating tracking concentrating cooling, hybrid solar photovoltaic/thermal (PV/T) and hybrid solar photovoltaic/thermoelectric (PV/TE) system cooling, water immersion cooling, transparent thermoelectric cooling systems, using phase-change materials (PCM), etc. (Teo et al. 2012; Peng et al. 2017).

3.1. Hybrid solar Photovoltaic/Thermal (PV/T)

The goal of a hybrid photovoltaic/thermal (PV/T) system is to increase the performance of PV systems. The system consists of thermal collecting pipes attached to the PV module's back. Rectangular pipes give the PV module and the thermal collecting pipes more surface area to contact. Water is used as a circulating fluid, and a DC pump powered by the PV module or other sources pumps the fluid through the paired thermal collecting pipes. The performance of the hybrid system drops when working fluid is exposed to solar radiation and its temperature increases significantly (Widyolar et al. 2017; Slimani et al. 2017).

3.2. Hybrid solar Photovoltaic/Thermoelectric (PV/TE)

In the PV/TE system, the thermoelectric (TE) module absorbs the heat from the PV module's surface. On top of the TE, the module has one thermal resistor and other thermal resistors are placed around it. The temperature increases as the PV/TE system is exposed to solar light. When there is a difference in temperature between the top and bottom surfaces, the thermal resistors on top and below have a minimal temperature difference. The charge carriers move through the thermoelectric materials. The PV module makes electricity, which is lost in the resistor and then stored in a battery. The PV module's surface cools due to the heat sink allowing the module's heat to escape (Van Sark, 2011; Li et al. 2018).

3.3 Phase-Change Materials (PCM)

In the PV system, phase-change materials (PCM) can be used for cooling the module indirectly. Normally, the PCM is placed on the back side of the PV panel; it absorbs extra heat from the panel in the form of latent heat and keeps the panel's surface at the right temperature for a long time. Different fin patterns can be used to improve and control conduction, which is how heat moves from the panel to the PCM (Ma et al. 2015).

3.4 Water Immersion Cooling

In this method, the panel is submerged in the water, and it is used as the immersion fluid. Water absorbs heat to keep the PV module's surface temperature at a standard level. The panel is submerged in large bodies of water like rivers, seas, lakes, canals, etc. The water then takes in the heat from the PV module, which has a cooling effect and makes better production of electricity (Zhu et al. 2011; Siecker et al. 2017). Table 2 explains some research studies on PV panel cooling systems and their performance.

4. Discussion

An optoelectronic device known as a solar cell is capable of directly converting solar energy into electrical energy. A solar cell is often exposed to temperatures between 15 and 50°C, with concentration systems in space and at much higher temperatures. It is common that as temperatures rise, photovoltaic solar cells become less efficient.

From the comparison of the development of crystalline silicon, thin film, and concentrator photovoltaic (CPV) solar cells, it is found that the performance of the CPV solar cell is in a higher order compared to the other two types, as shown in Figure 2.

A concentrating photovoltaic (CPV) system employs a sophisticated optical system to concentrate a lot of solar energy onto each cell for enhanced efficiency while still converting light energy into electrical energy in the same way as regular photovoltaic technology. According to Bagher et al. 2015, solar trackers and cooling systems are frequently used with CPV systems to further boost efficiency. According to Anwar (2018), power generation from solar cells with a cooling system assisted by an electric motor has shown significantly better performance

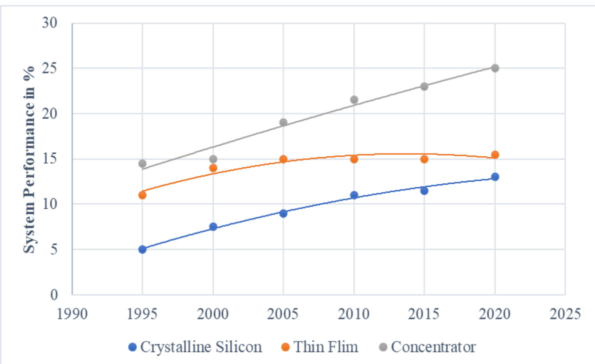

Fig. 2: Different solar System Performance (Bagher et al., 2015).

Table: 2 Selected Research Studies on PV Cooling Systems and their Performance.

Author	**Technology**	**Findings**
Shoeibi et al., 2022	PV/TE	This paper highlights different methods of thermoelectric cooling and heating for electricity generation. Thermoelectric cooling is used to enhance the efficiency of solar energy systems.
Hashim and Bomphrey, 2016	PV/TE	The article covers a model that was created to optimize thermoelectric modules. The simulation results show significantly improved electrical generation from the thermoelectric modules.
Popovici et al., 2016	PV/TE	This research discusses the angle between the heat sink's ribs and base plate to assess system effectiveness. A cooling technique reduces the temperature of the PV panels by 10 degrees Celsius.
Ali et al., 2016	PV/TE	This paper talks about the electricity generation capacity of a PV module when a pin-shaped thermoelectric generator is embedded with the system and air is used as cooling media.
Tang et al., 2010	Hybrid PV/T	The article introduced a cooling system with PV panels, an evaporator, and a condenser used in conjunction with a micro-heat pipe array. Findings show that water cooling is better than air cooling because it increases electrical efficiency by 3%, while air cooling only increases it by 2.6%.
Kroib et al., 2014	Hybrid PV/T	In this research, seawater is used to cool the PV/T hybrid panels so that they can generate more electricity than usual. A reverse osmosis (RO) desalination plant is also introduced into this system.
Tonui and Tripanagnostopoulos, 2007	Hybrid PV/T	This article suggests suspending metallic sheets or fins attached to the rear of the PV panel so that panel can be cooled faster to keep the temperature standard. Both natural and forced convection processes are suitable for this process. In this process, the module's performance was significantly enhanced.
Hosseini et al., 2011	Hybrid PV/T	This study suggested that a thin layer of water be used to cool the PV system, which made the modules work better at making electricity.
Ebrahimi et al., 2015	Vaporization Cooling	The research advised a natural vaporized cooling system for PV modules. This method reduces temperature by 7 to 16 degrees Celsius while increasing electrical generation efficiency by 7.3%.
Alami, 2014	Evaporative cooling	This investigation advised using a copper cooling sheet with the PV module. The sheet is covered in synthetic clay. The results show a 19.1% electrical gain.
Sun et al., 2014	Immersion cooling	This research used dimethylsiloxane oil as an immersion fluid for cooling a solar module. The findings suggest that temperatures between 20 and 31 °C can be effectively managed by using these methods.
Zhu et al., 2011	Immersion cooling	In this investigation, deionized water is used as an immersion fluid to cool photovoltaic cells. The system is also integrated with a two-axis dish concentrator tracking system. The results showed that the CPV module temperature can be maintained at 45 °C when solar radiation of 920 W/m^2 is present, the ambient temperature is 17 °C, and the water temperature is 30 °C when entering the system.
Abrahamyan et al., 2002	Immersion cooling	The focus of this study is to analyze the efficiency of solar cells when they are submerged in an isotropic liquid. The electricity generation efficiency increases by 40–69% when it is submerged in the isotropic liquid.
Chandel and Agarwal, 2017	PCM technology	Inorganic PCM is used for cooling and enhancing the solar cell's performance. Results show that the improvement in efficiency is only about 5%.
Huang et al., 2006	PCM technology	This article focuses on comparing the thermal conductivity of a single flat aluminum plate with internal fins for a bulk amount of PCM. The PV/PCM system's internal fins reduced the temperature by 30 °C.

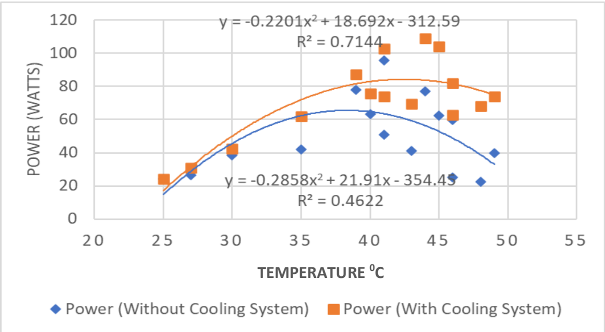

Fig. 3: Comparison of solar cell power output with and without cooling system (Anwar, 2018).

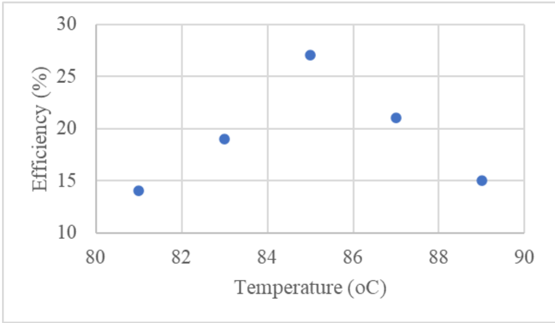

Fig. 4: Relation between temperature and Efficiency of crystalline silicon (c-Si) solar cell (Qusay et al. 2015).

than without a cooling system. Although the cooling system improves performance, the results do not show a significant relationship because the R square value is less than 0.8, as shown in Figure 3.

According to Rakin et al. (2019), every 1°C increase in solar panel surface temperature reduces solar cell efficiency by about 0.5%. For this study, a basic solar panel with 50 watts of power and 12 volts was used as a cooling object, and it was discovered that the average output power increased by about 40% while the temperature decreased by about 12.66%. According to Crăciunescu et al. (2016), when an air-cooled system is combined with a PV panel, the power output increases by 4.37%. When an air cooling system is replaced with a water cooling system, performance improves. Revati and Natarajan (2016) investigated the effect of temperature on solar cell performance and found that the performance of the solar cell increased with a decrease in temperature. Qusay et al. (2015) have researched to determine the temperature effect on crystalline silicon (c-Si). The relationship between temperature and efficiency is shown in Figure 4.

At 85°C, the maximum efficiency of 27% is shown in Figure 4. The study also showed that using a cooling system to maintain temperatures around 85 °C, the crystalline silicon (c-Si) PV solar cell has shown better performance compared to other temperatures. The study also showed that Thin-film solar panels were discovered to be less temperature sensitive, with temperature coefficients for mono-crystalline and poly-crystalline panels of -0.0984%, -0.109%, and -0.124%, respectively.

Additionally, the angle that the sun's light makes with a horizontal surface affects how well a PV solar cell performs. The maximum power output is provided by the smallest incidence angle. The effective solar tracker might aid in maximizing the output of the PV solar cell. Numerous kinds of solar tracking systems have been effectively integrated with solar PV systems.

The solar tracking system has increased the efficiency of PV solar cells by around 40% compared to fixed-panel systems and enhanced the energy received over time as well. The dual-axis tracking system has shown 50% more efficiency than single-axis or fixed-panel PV solar systems.

This study gives an overview of current solar tracking and cooling systems made with different designs and methods, focusing on performance analysis. Many physical factors, including the choice to use tracking, affect how well the solar system functions. The most important of those elements is temperature.

After examining all approaches taken to address the temperature issue and boost efficiency, it is crucial to present the findings clearly and understandably to anyone interested in these technologies. To receive better performance from a cooling system, it must be integrated with a solar tracking system in the PV panel. Any cooling system keeps the solar cells' temperature low and stable. Using heat energy for other good things should also be possible.

5. Conclusion

The focus of this review is to determine the possibility of integrating solar tracking and cooling systems. A review showed that the integrated system has a significant effect on the performance of the solar PV system. Many articles from different scientific fields were examined and grouped based on their goals, contributions, and the cooling technology they used. The goal of the future study should be to better understand how to steadily and precisely gather heat from a PV module's surface and cool it.

Disclosures

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