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Performance assessment of photovoltaic and photovoltaic/thermal systems under the impact of shadowing

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ABSTRACT

The rapid depletion of energy resources makes it necessary to turn to renewable energy sources. At this point, it is one of the most popular energy sources, especially with its solar potential. Photovoltaic thermal (PV/T) systems, which allow benefiting from thermal energy as well as modules that can produce electricity with direct photovoltaic (PV) systems, have made rapid progress in recent years. In this study, basic dynamics are tried to be determined by highlighting the basic parameters that affect the performance of PV and PV/T systems. In addition, the shading effect, which is quite common in applications, is discussed. Then, the studies, which increase the performance of the systems, are included together and the opportunity to compare the studies is presented. With innovative approaches, it is seen that good results can be obtained even at smaller scales with different applications of PV systems. With combined systems, the applicability in buildings is analysed by providing both electricity generation and thermal benefits in small-area applications.

Gölgeleme etkisi altında fotovoltaik ve fotovoltaik/termal sistemlerin performans değerlendirmesi

ÖZ

Enerji kaynaklarının hızla tükenmesi yenilenebilir enerji kaynaklarına yönelmeyi zorunlu kılmaktadır. Bu noktada özellikle güneş enerjisi, potansiyeliyle en popüler enerji kaynaklarının başında gelmektedir. Doğrudan fotovoltaik (PV) sistemlerle elektrik üretebilen modüllerin yanı sıra termal enerjiden yararlanmaya olanak sağlayan fotovoltaik termal (PV/T) sistemler de son yıllarda hızlı bir ilerleme kaydetmiştir. Bu çalışmada PV ve PV/T sistemlerin performansını etkileyen temel parametreler öne çıkarılarak temel dinamikler belirlenmeye çalışılmaktadır. Ayrıca uygulamalarda oldukça yaygın olan gölgeleme etkisi de ele alınmaktadır. Daha sonra sistemlerin performansını arttıran çalışmalara bir arada yer verilerek çalışmaların karşılaştırılmasına fırsat sunulmaktadır. Yenilikçi yaklaşımlarla PV sistemlerin farklı uygulamalarıyla daha küçük ölçeklerde bile iyi sonuçlar alınabileceği görülmektedir. Kombine sistemler ile küçük alan uygulamalarında hem elektrik üretimi hem de ısıl fayda sağlanarak binalarda uygulanabilirliği analiz edilmektedir.

Anahtar Kelimeler: PV and PV/T sistemler, havalı ve sulu toplayıcılar, sistem performansı, gölgeleme, verim, I-V and P-V eğrisi

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1. Introduction

Due to the increasing human population, electricity consumption in living spaces is increasing day by day. When technological developments are added to this situation, more primary sources are needed to meet the energy demand. Currently, the biggest reason why this situation poses a danger is the continued use of fossil fuels in energy production. In the last century, meeting the energy need mainly with fossil fuels is the only unresolved problem. This increase in the use of fossil fuels will cause economic, global, and social problems in the future and will reach a level of threat due to CO_2 emissions [1]. Considering all these effects, the use of renewable energy sources gains vital importance as an alternative to fossil fuels. Renewable energy sources are incredibly attractive since they are environmentally friendly and their CO_2 emissions are low or even 0 in some cases [2]. Renewable energy sources are expected to meet half of the total energy production by 2060 [3]. Solar energy is different from other renewable energy sources. The sun can be used for both thermal and electrical energy [4]. In order to generate electricity, renewable energies use a medium or some mechanism. PV modules can convert solar radiation directly into electrical energy [5]. PV systems not only produce electricity directly but also let thermal energy production with some integrated applications [6]. These systems are called photovoltaic thermal (PV/T) systems. PV/T systems enable the use of thermally transferable energy by not converting it into electrical energy when the sun falls on the PV modules. At the same time, by removing this thermal energy from the modules, they contribute to lowering the temperature and thus increasing the efficiency [7]. The performance of PV systems depends on temperature and solar radiation and cannot be expressed with analytical equations [8]. For this reason, in this study, the performance of PV and PV/T systems is managed in every aspect, and the production and climatic parameters that affect the performance of the system are examined first. Then, the shading effect, which should be considered during the installation phase of the system, is presented and the work done is reviewed. Studies to improve the performance of PV and PV/T systems are presented to the readers comparatively by scanning the literature. Finally, hybrid studies on PV systems are included.

2. Module Efficiency and Parameters Affecting PV and PV/T Performance

The increasing human population and the significant increase in energy demand have led to the questioning of energy resources in recent years. Especially considering that energy sources are fossil-fuelled, environmental pollution poses a potential danger to human health in the coming years. For these reasons, the dissemination of renewable energy sources is extremely important. However, another prominent issue is the efficient use of these resources. In recent years, researchers have been doing plenty of research on the efficiency of energy systems and presenting new studies for the improvement of existing systems. In addition to the diversity of renewable energy sources, it draws attention, especially in terms of solar energy potential. Solar energy is used for space and water heating as well as for generating electricity. PV systems, which are popularly used to generate electricity, directly convert solar radiation into electricity [9]. The determining effect on the performance of these systems, which are constantly dependent on the sun, is temperature and solar radiation. It is of extremely vital importance to provide a suitable working environment for the PV system. Therefore, it is necessary to extract the performance parameters. Researchers suggest various methods for this [10]. Radziemska [11] works to experimentally evaluate the effect of temperature on power output in a single-crystal solar cell. It comparatively presents the output powers (PL) versus varying voltage values (UL) under constant lighting load at 28, 40, 60, and 80 temperatures (Figure 1A). It also shows the maximum power output depending on the temperature in Figure 1B. Claims that temperature rise causes a drastic reduction in power output.

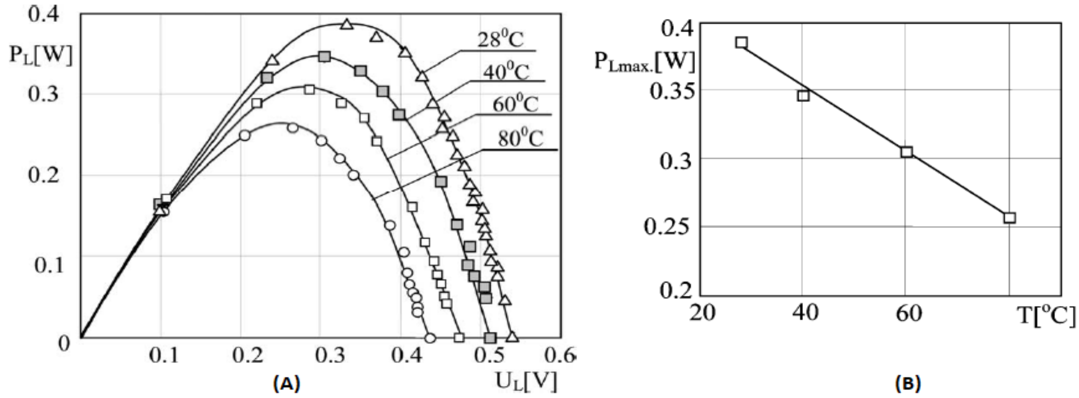


Figure 1. Power curve for different voltage values of a single-crystal silicon solar cell for 4 different temperature values (a), power output depending on temperature (b) [11].

Cuce and Cuce [12] evaluate the effect of air cooling on thermodynamic performance in silicon photovoltaic cells. In their numerical study, they show the voltage values versus current and power data for different cell temperatures at constant illumination intensity of G=1000W/m² in Figures 2a and 2b. Similarly, they show in Figure 2c that the maximum power output of the photovoltaic module decreases linearly with increasing cell temperature. They use different temperatures of air to lower the cell temperature as the cell temperature directly reduces the performance. The table of average cell temperatures and performance parameters for different air speeds and temperatures is given in Figure 3. Mahmoud et al. [13] interpret the performance of PV systems with different mathematical models. They perform current-voltage analysis on PV modules for different temperatures and solar radiation values. They show that while performance decreases with temperature, it increases with radiation intensity.

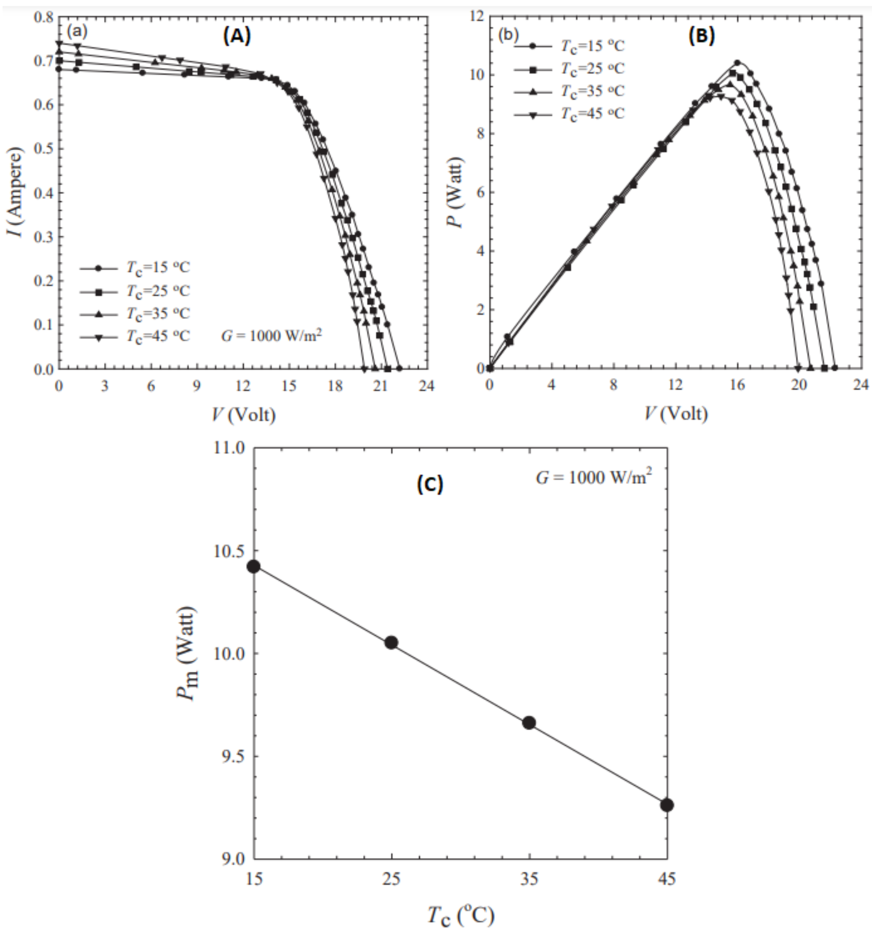
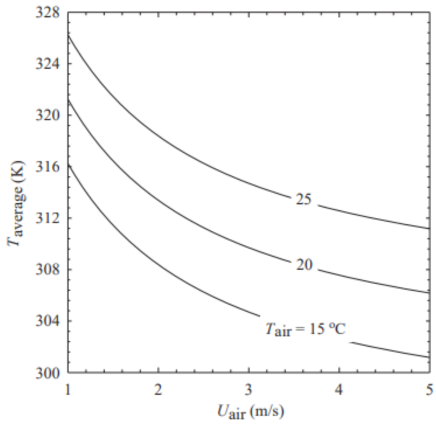


Figure 2. (a) I-V, (b) P-V characteristics for different PV cell temperatures, and (c) Variation of the maximum power output of the photovoltaic module with photovoltaic cell temperature [12].



	U_{air} (m/s)	η_e	η_{pc}	η_{ex}	P_m
T_{air} = 15 (°C)	1	18.34	14.94	11.62	9.34
	2	18.46	15.21	12.01	9.65
	3	18.52	15.34	12.18	9.79
	4	18.55	15.41	12.29	9.87
	5	18.57	15.46	12.36	9.93
T_{air} = 20 (°C)	1	18.26	14.77	11.38	9.15
	2	18.38	15.04	11.77	9.46
	3	18.44	15.16	11.94	9.59
	4	18.47	15.24	12.05	9.68
	5	18.49	15.29	12.12	9.73
T_{air} = 25 (°C)	1	18.18	14.60	11.14	8.95
	2	18.30	14.87	11.52	9.26
	3	18.36	14.99	11.70	9.40
	4	18.39	15.07	11.80	9.48
	5	18.41	15.12	11.87	9.54
Without cooling		17.99	14.02	10.32	8.30

Figure 3. Average cell temperature ($T_{average}$) graph for different air velocities (U_{air}) and temperatures (T_{air}) and its effect on performance parameters [12].

The performance of PV systems in the literature is discussed extensively by researchers experimentally. In general, it is observed that the parameters affecting module efficiency are solar radiation, initial temperature, dust-shading, humidity, wind speed, and material. PV systems convert solar radiation directly into electricity. When the PV cells are exposed to sunlight continuously during the day, the temperature of the modules rises. In this case, the electrical efficiency of the cells with increasing temperature mitigates. Maximum electricity efficiency is achieved in the early morning and evening hours. Figure 4 shows the change in electrical efficiency during the day depending on the cell temperature [14]. The performance of PV cells differs depending on the cell temperature at different irradiation intensities. Najafi and Woodbury [15] develop a MATLAB-based mathematical model to examine the performance of PV systems. They show that keeping the PV cell temperature low will improve system performance. In Figure 5, they give a graph of power output depending on different cell temperatures and irradiation intensities.

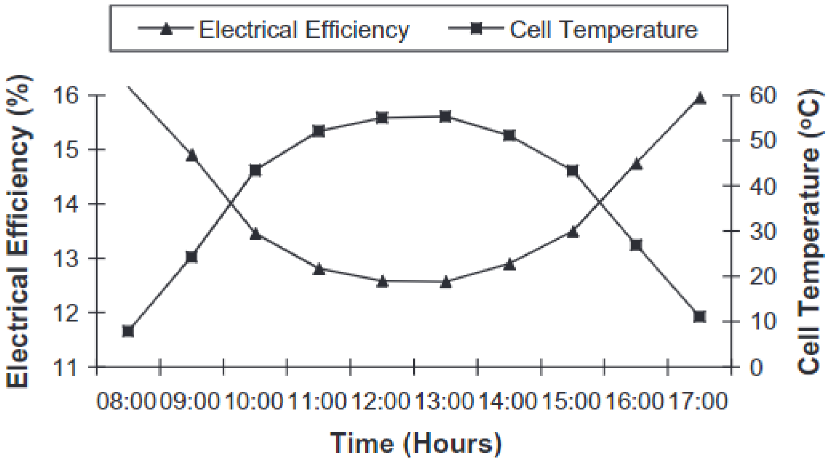


Figure 4. Hourly electricity efficiency graph based on cell temperature on a typical day in the low season [14].

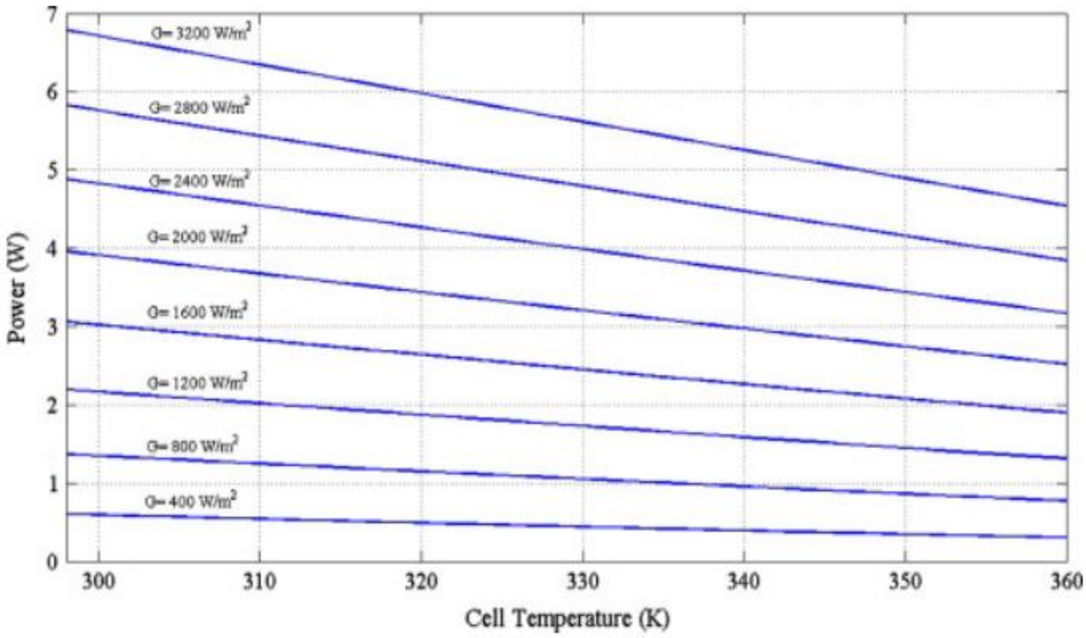


Figure 5. Graph of power performances of PV cells depending on the temperature at different irradiation intensities [15].

Salim et al. [16] assess the effect of dust on the performance of PV systems in a solar village near Riyadh. They claim that there is a 32% mitigation in the performance of the system with the dust effect when compared to the clean PV systems. Hammad et al. [17] develop two different models to determine the effect of dust and temperature on performance and the ideal cleaning frequency in PV systems. In the study conducted for the Jordan region, they show that the yield decreased by 0.607% and 0.768% per day for the two models, respectively, due to dust in measurements made over 192 days. Researchers claim that the performance of PV systems can be protected by regular maintenance and cleaning against the dust effect [18]. According to Katkar et al. [19] argue that the performance of PV systems will first increase and then decrease rapidly with temperature. They give the variation in the efficiency of the system for different temperatures in Table 1. In the literature, parameters affecting the performance of PV modules have been studied extensively by researchers. In general, it is seen that the studies are intense such as cell temperature, wind, solar radiation, ambient temperature, dust, and sand. In Table 2, some of the studies in the literature are given. The relative humidity is also important in PV performance, like other parameters. Relative humidity affects other climatic parameters as well as other climatic parameters. Therefore, it must be considered when evaluating PV performance. Kazem and Chaichan [20] interpret the PV performance between July and September 2015, considering the climatic parameters and relative humidity. When the results are examined, they find that the relative humidity is quite effective on the PV performance. They claim that PV efficiency remains low at high relative humidity levels. In areas with high dust concentration, the humidity formed on the PV surface and the dust in the air will adhere to the surface more, contributing to the mitigation of performance and an increase in maintenance costs [21]. Meyer and Van DYK [22] develop an energy model based on the performance of 3 Si-based PV modules, namely edge-defined-film-fed growth (EFG), mono, and multi, based on total daily solar radiation and maximum initial temperature. The model is applicable only when the maximum temperature and total daily irradiation are known.

Table 1. PV efficiency for different cell temperatures [19].

Temperature (°C)	PV efficiency (%)	Temperature (°C)	PV efficiency (%)
32.5	10.0	45	6.5
35	11	47.5	5.5
36.1	12	50	5.4
37.5	11.5	52.5	4.5
40	8	55	3.9
42.5	7	57.5	2.3

Table 2. Parameters affecting PV module performance.

Reference	Parameters	Working method	Findings
[23]	Cell temperature	Mathematical	An increase in cell temperature lowers voltage and power output.
[24]	Cell temperature	Experimental	An increase in cell temp. reduces the max. power.
[25]	Sand accumulation systems	Experimental	17% decrease in PV performance due to sand accumulation.
[26]	Cell temperature	Theoretical	Increased solar radiation improves efficiency, but temperature rise lowers power output.
[27]	Solar radiation Wind speed	Mathematical	Although wind speed does not have much of an effect, they claim that increasing speed will increase thermal efficiency while increasing solar radiation will increase thermal efficiency.
[28]	Dust and ambient Temperature	Experimental	Temperature and dust accumulations are extremely effective for PV performance.
[29]	Temperature and wind speed	Computer simulation	An increase in the inlet temperature of the module lowers the performance parameters, while an increase in the inlet air velocity, on the contrary, increases it. It measures electrical efficiency at approximately 10%.
[30]	Dew and rain	Experimental	Since water droplets formed due to condensed air and rain on the PV panels scatter radiation, it is tried to reduce efficiency.
[31]	Humidity	Experimental	The effect of humidity on PV performance is interpreted for monocrystalline (m-Si) and polycrystalline silicon solar cell (p-Si) cell technologies. The effect of humidity on performance is negligible.

3. Shading Effect in Photovoltaic Systems

Gao et al. [32] offer a configuration to evaluate the performance of PV systems under rapidly changing shading effects. With experimental work, they claim that a PV system with direct converter input single-cell voltage is ideal. Hong et al. [33] calculate the usable roof area in cities using hillshade analysis. They calculate hourly the areas where electricity can be generated via PV modules on the roofs of Gangnam City in Seoul. They claim that whilst 35.9% of the total roof area can be used at 7 am, the maximum roof utilization rate is 73.2% at 10 am. In this case, they emphasize that the shading effects of the buildings are the cause. Mishra et al. [34] model in MATLAB/Simulink environment regarding the optimum arrangement of PV modules to achieve maximum power under partial shading conditions. They argue that the performance of their newly designed NS configuration will provide a 13.2% maximum increased power for cross-shading movements compared to the total cross-linked (TCT) configuration. Ko and Chung [35] propose a monitoring system that considers the shadow effect to increase the efficiency of PV systems. They calculate the distance between the PV modules and the height which will not create a shading effect. An example image is given in Figure 6. They claim that the system will deliver 6.86 kW more power per day and 123 kW more per month than the traditional model. Jang et al. [36] claim that by developing an algorithm, by optimally adjusting the distance between the PV module strings, an extra 10 kW of electricity can be produced per day and up to 120 kW per month. They support their algorithms with experimental work.

Figure 6. Example of PV array [35].

Lodhi et al. [37] analyse the maximum power point (MPP) of PV modules under partial shading conditions via MATLAB/Simulink. They compare particle swarm optimization (PSO) and incremental conductivity (INC) algorithms in terms of power output. They claim that the global peak power point (GMPP) of the PSO algorithm hovers around 298 W, while the INC algorithm hovers around 260 W. They emphasize that the PSO algorithm gives healthier results in abruptly changing environmental conditions than INC. Ahmed and Salam [38] compare the approaches used to reduce the shading effect in PV systems. They claim that the Maximum power point tracer (MPPT) algorithm is the most applicable and economical model for the shadowing effect. Karakose and Baygin [39] use an image-processing algorithm on detecting shadow motions for reconstruction in PV arrays. With the new approach they use, the efficiency of the system increases, and they claim a 15% increase in power output. The power output and current graphics of the system against voltage are as in Figure 7 before and after configuration.

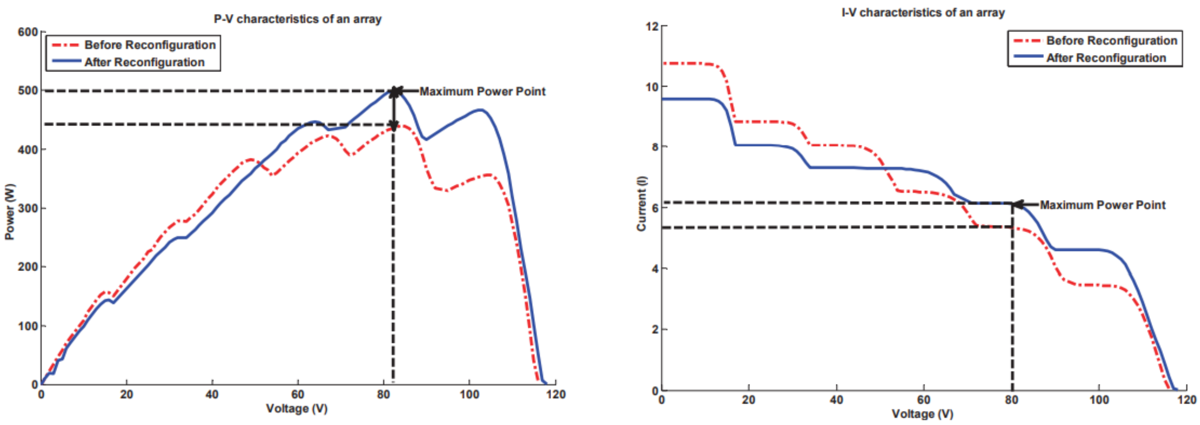


Figure 7. Voltage-power and voltage-current graphs before and after reconfiguration [39].

Taheri et al. [40] argue that the Conventional Maximum Power Point Tracking (MPPT) technique may fail to monitor the global power of PV systems, and this is partly due to shading effects. Alternatively, they propose an algorithm based on Differential Evolution (DE) that can track MPP under partial shading. In their results solved with MATLAB/Simulink, they emphasize that DE can track MPP very quickly and accurately. They also observe that Perturbation and Observation (PO) is very slow to reach MPP. Ishaque and Salam [41] present a review of the most advanced MPPT techniques for PV system applications. They claim that Evolutionary Algorithm (EA) methods are the most promising method for partial shading. With the MPPT method, they give the graph of current and power against different voltages in Figure 8.

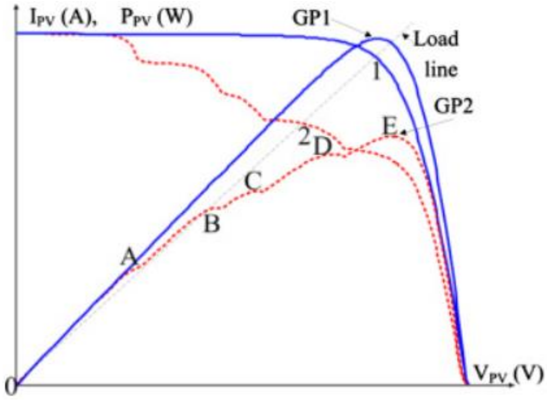


Figure 8. Current (I) and power (P) versus voltage (V) curves are used to evaluate the performance of different MPPT methods [41].

In most Photovoltaic Thermal (PV/T) systems, the PV cells are closed with a cover to reduce heat loss and increase efficiency. Unlike ordinary PV systems, these covers may cause partial shading, resulting in a decrease in the performance of the system. Wang et al. [42] analyse this situation with mathematical modelling. They claim that under partial shading, parallel-connected circuits will suffer more performance loss than series-connected ones and that the efficiency will decrease by 39% in the worst case with the shading effect. They also argue that the shadowing effect can be reduced by reducing the number of cells close to the frame edges. In PV systems, the MPP is difficult to monitor in case of shading effects and damage to some cells. In this case, disabling the part that is exposed to the shadow effect may be effective for the performance of the system. Karatepe et al. [43] monitor the operating voltage of the system by equipping each PV array with DC-DC converters. In this way, they discover the shaded PV modules and determine the MPP of the unshaded PV modules. A 20-30% increase in PV array power output can be expected using the MPPT converter, but with the recommended configuration, the power output of a partially shaded PV array can support a 300% increase.

For PV systems, the shading effect is a fundamental problem, especially for small-area applications. For this reason, applications that will eliminate or minimize the shading effect gain importance. Considering the effects of traditional PV applications such as erosion, microclimate changes, and deforestation, innovative approaches are inevitable [44]. One of the innovative approaches that will minimize the shading effect is PV trees. The features can minimize the shading effect of PV trees that can be used in landscape applications [45]. An example of the system is given in Figure 9.

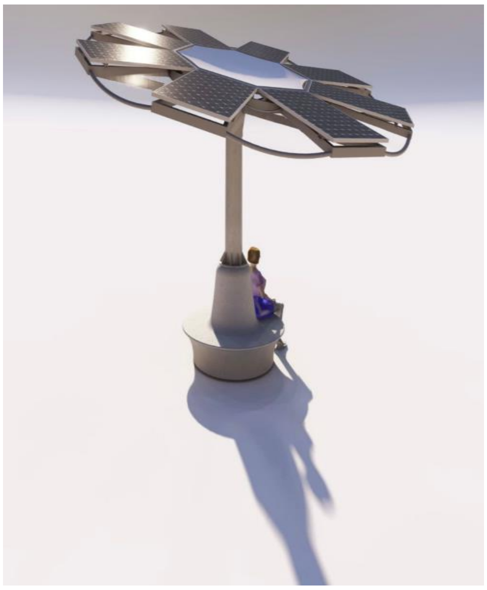


Figure 9. Modelling of PV tree installed at a certain height from the ground.

Table 3. Suggestions for improvement of shadow effect on PV systems

	Advantages	Disadvantages	Outcomes
Bypass diode	The utilisation of a bypass is intended to safeguard solar cells from overheating, ensuring the smooth transfer of incoming current to shaded cells. This ensures the passage of the entire current, allowing the system to persist without interruption [46].	A considerable quantity of bypass diodes is necessary for these systems to pre-empt issues, incurring an associated cost burden [47].	In a comprehensive study investigating scenarios involving complete shading of one, two, and three modules, various assessments are documented on the application of bypass. The purpose is to demonstrate the efficacy of bypass in enhancing efficiency. The results, when categorised individually for one module, two and three modules, with and without bypass, reveal improvements ranging from 17.96% to 12.79%, 14.5% to 9.63%, and 6.87% to 3.59%, severally [48].
DC-DC converter	In extensive systems, every solar submodule has the potential to be linked to a DC-DC converter, which oversees its MPP and can operate in proximity to this optimal point. Consequently, this contributes to an overall enhancement in the efficiency of the entire system [49].	The requirement for DC-DC converters may match the number of solar modules, posing a potential challenge for larger systems [50].	Deline [51] conducts a study to investigate the impact of shadows on the performance of PV systems. The findings indicate that the incorporation of a DC-DC converter results in a 5-10% increment in annual power production. Moreover, the performance loss attributed to shadows is mitigated by 24-48% due to the utilisation of the DC-DC converter.

Table 3 provides a concise overview of the advantages, disadvantages, and findings related to partial shading conditions. This information is valuable in mitigating issues such as multiple peaks, hot spot formation, and electrical mismatch, ultimately enhancing system performance. In addition to the techniques outlined in Table 3, current methods for improving performance include PV array reconstruction. An example is the competence squared cloud method, as investigated by Dhanalakshmi and Rajasekar [52]. They apply this method with various configurations to address shadows in PV systems. Various shading configurations, namely short-wide, short-narrow, long-narrow, and long-wide, were examined using the competence squared method. The results indicated a significant maximum efficiency increase of 24.4% for the short-wide shadow pattern. In contrast, the short-narrow pattern showed a minimum improvement of 6.6%. Additionally, the efficiency squared method was calculated to prevent a reduction in power loss, ranging from 30% to 49%. In order to observe MPP, there are also restructuring methods such as Skyscraper [53], Magic square [54], and Dominance square [55].

In conclusion, while advanced shadow management techniques offer substantial benefits in terms of efficiency and performance improvement in PV systems, it is essential to carefully consider associated costs, complexities, and space requirements. Research findings consistently highlight the positive impact on energy harvesting and power loss reduction, demonstrating the potential for significant improvements in system reliability and overall effectiveness.

4. Studies for Performance İmprovement of PV and PV/T Systems

PV systems are among the favourites of clean energy for the future. However, it is a great advantage that solar energy is safe, clean, relatively low cost, and efficient [56]. Nevertheless, even the most efficient examples of PV systems currently on the market are below 20% [57]. So much so that PV modules convert 82-85% of solar radiation to heat and 15-18% to electricity [58]. The reason for the low efficiency of PV systems is the decrease in the electricity produced by the system with elevated temperatures. Therefore, in order to increase the performance of the system, the cell temperature must be lowered. Environmental factors affecting PV cell temperature can be listed as ambient air velocity, solar radiation, relative humidity, and ambient dust [59]. This environmental, also known as climatic factors, should be taken under control as they affect the cell temperature. However, for an established system, these effects cannot be changed because they depend on geography. Therefore, additional applications are needed to lower the cell temperature. There are different applications in the literature to improve the performance of the system. In general, there are applications in the form of removing the heat from the module to eliminate the high-temperature situation. In this way, the power output and performance of the system can be improved by artificial cooling [60]. An increase of 0.4-0.5% in the temperature of Crystal Silicon (c-Si) modules causes a 0.65% decrease in PV efficiency [11]. In light of these data, an effective cooling to be applied to the modules will allow significant increases in the performance of the system. In order to increase the efficiency of PV systems, solar radiation must be converted into electricity by means of modules and the thermal energy must be absorbed and removed from the modules with additional systems. Thermal systems integrated with modules in this way are called photovoltaic thermal (PV/T) systems [61]. In PV/T systems, air or fluid can be used to remove the heat from the modules of the system. In systems using fluids, the cold water passed through the pipes placed in the part where the modules are placed is used to remove the heat. The schematic view of the system is given in Figure 10.

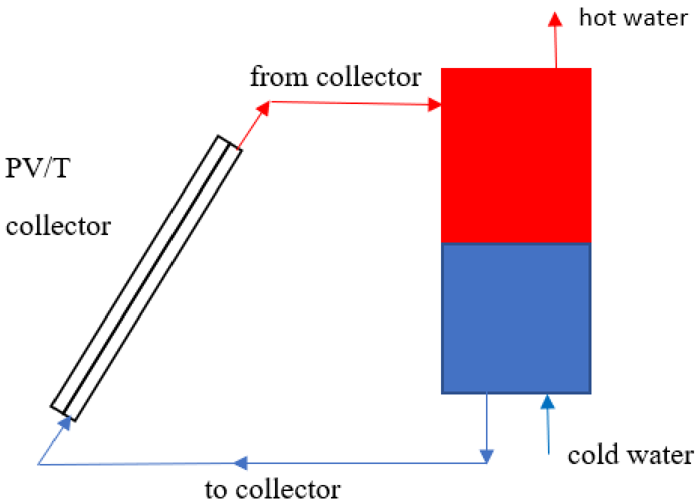


Figure 10. Liquid-based PV/T system schematic [27].

Zondag et al. [62] mathematically evaluate the performance of the combined PV/T system. They compare performance in 4 different designs: sheet-and-tube PVT, channel PVT, free-flow PVT, and two-absorber PVT (insulated type). They claimed that the channel-type design had the best thermal efficiency. They emphasized that the single cover plate and tube type PV/T design can be used as an alternative, where only 2% lower efficiency is achieved compared to the channel type. Kalogirou and Tripanagnostopoulos [63] design a combined system that will reduce the module temperature in the PV/T system and meet the thermal energy and hot water needs of the house. In their analysis with TRNSYS simulation, they claim that although the non-hybrid PV system is 38% more efficient, it is a useful application since most of the hot water needs of the spaces will be met with the system. Some researchers compare using the natural convection effect of air instead of water to remove heat in PV/T systems. Nizetic et al. [64] evaluated the effect of water spray cooling on the performance of the PV module with an experimental study. The effects of water spray on the system performance are compared by applying 3 different ways: only from the front, only from the back, and from both the front and the back of the panel. The schematic view of the system is given in Figure 11. With the panel with an area of 0.31 m^2, it is measured that a power output of 35 W is obtained without cooling at 1000 W/m^2 solar radiation and 25 degrees ambient temperature. Then, 39.9 and 40.1 W output is measured under the same conditions with spray cooling only from the front and only the rear region, respectively. Finally, 40.7 W output is measured with bidirectional spray cooling. Moharram et al. [65] work to determine the minimum amount of water required to cool the PV modules in high temperature and arid regions and for minimum energy consumption. They use a mathematical model to calculate at what temperature the cooling process of the panels with water spraying will start and how long the cooling process will take. They claim that maximum power output is obtained when the cooling process starts when the panel temperature reaches 45°C. They find the cooling rate as 2°C/min under the relevant working conditions. Salih et al. [66] evaluated the effect of water spraying on the front surface of PV systems on the performance of the system with a large-scale experimental study. They emphasize that the average efficiency is 17.8% while taking a cooling rate of 4'/min during the day. They also claim that with the increase in efficiency, more power can be drawn from smaller PV fields.

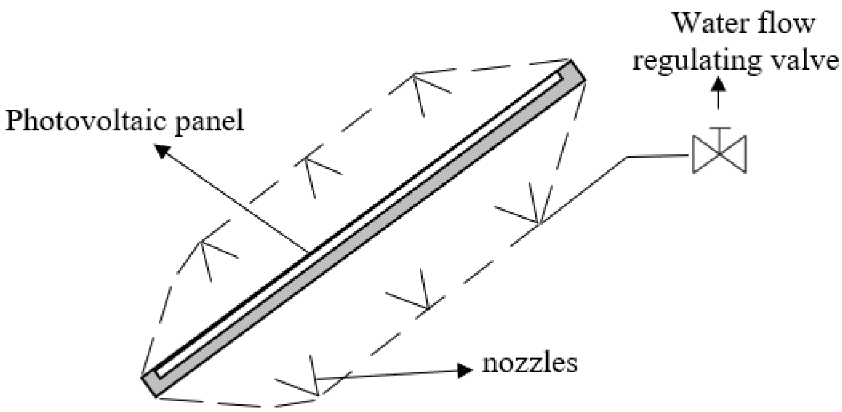


Figure 11. Schematic view of the water spraying cooling system applied to the PV system [64].

Tripanagnostopoulos [67] interprets the performance of PV/T systems by creating 4 different designs with an experimental study. First, it uses an air duct instead of a copper tube water exchanger to remove heat. In addition, it uses an additional air duct in the first stage in both water exchanger and air duct designs. Then, it compares the effect of closing the module with a glass cover on the system performance for both cases. The schematic view of 4 different models is given in Figure 12. They claim that the best result for the module efficiency of the PV/T system will be obtained from a dual system with a water heat exchanger and air duct, but for building concepts, a copper tube-based water heat exchanger design will be more useful in terms of hot water supply. They show that the thermal efficiency of the system will be 30-70%, and the electrical data will be 10-16%. Water, which is used as the most common liquid to provide heat dissipation in PV/T systems, is widely used because it provides more stable thermal performance [68].

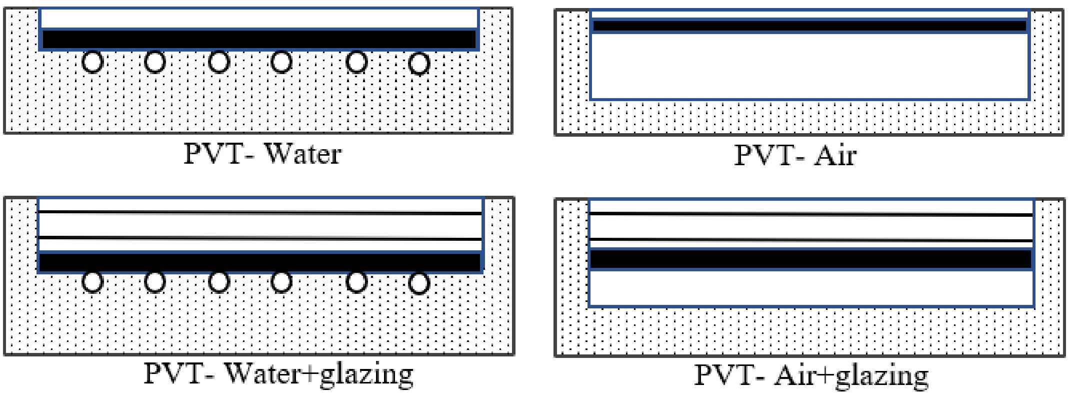


Figure 12. Glass-less PV designs with water or air support. [67].

Air can be used instead of water to remove heat to prevent temperature rise in PV/T systems. Due to the high heat capacity of water, it is expected to remove more heat from the system than air. Tripanagnostopoulos et al. [69] compare the performance of poly-crystalline (pc-Si) and amorphous silicon (a-Si) PV cells by setting up a PV/T system. They claim that with the cooling system, PV efficiency increases by about 10% and that water provides better cooling than air circulation. Alshibil et al. [70] compare the performance of PV and PV/T systems with an experimental study. They evaluate electrical and thermal performance in 3 different situations for the classic PV module, the classic PV/T system with copper absorber plate (a-PV/T), and the new fin design PV/T system (BiF-PV/T). They claim that the cell temperature of the other 2 designs is 19.2°C lower than the standard PV system and that 7.56% electrical efficiency and 66.17% thermal efficiency are achieved with the new design. Bahrehmand et al. [71] evaluate the performances of single- and double-glazing PV systems under forced transport conditions. In addition, the performance of PV systems is compared depending on the rectangular and triangular fin effect, the channel depth, and the Re number. In the results obtained with the mathematical model, they claim that the fin-containing and thin metal sheet (TMS) systems are more efficient than the others. For values of Reynold (Re) number greater than 22000, the exergy efficiency is negative, for a two-glass cover with TMS. Saygin et al. [72] evaluate the effect of the change in the distance between the PV module and the glass on the performance by using air cooling in the PV/T system. They claim that with the analysis of variance (ANOVA) method, the best thermal efficiency is obtained at 3 cm, and the best electrical efficiency is obtained at 5 cm, with air inlet from the middle of the glass cover. There are numerous studies in the literature on the cooling of PV and PV/T systems. Looking at its main lines, it is seen that the studies concentrate on certain topics. Some researchers classify fluid type as natural and forced convection in terms of flow characteristics. In Table 4, there is a section of the studies of researchers using air and water to cool PV and PV/T systems.

Table 4. Studies for performance improvement of PV systems.

Reference	Coolant material	Findings
[73]	Water	Decreased module temp with liquid circulation increases efficiency
[74]	Water	It is seen that the PV system consisting of laminate performs better than the traditional PV system with its water-cooling effect. With the new concept, it is determined that the electrical efficiency is 7.2% and the thermal efficiency is 33%
[75]	Water	When the hot water production per unit collection area exceeds 80 kg/m2, the PV efficiency is approximately 10.15%
[76]	Water	Partially closed PV/T system with PV will give better performance, thermal efficiency will be between 40-55% and electrical efficiency will be 11-12%
[77]	Water	Glazing is a performance-enhancing method for PV systems. However, this is not the case in all cases. Factors such as radiation, water flow, glazing area, and ambient temperature should be evaluated
[78]	Water	The efficiency of PV systems decreases by 8-15% due to the increased temperature because of reflection. Efficiency can be increased by lowering the cell temperature with a thin water film layer. In addition, the heated water can be used for different purposes
[79]	Water	The PV/T system with a 2m^2 collector area is closed first with a 0.605m^2 PV module and then complete with a PV module and the results obtained are compared numerically. When the entire area is covered with the PV module, the thermal energy gain is reduced by 9.8%. Closing the entire collector with a PV module increases electricity production
[80]	Water	They perform energy and exergy analysis of the glazed PV/T system. They claim that the overall efficiency of the system will be higher relative to the first law efficiency at low water inlet temperature, but the actual efficiency will be higher according to the second law analysis when essentially higher temperatures are reached
[27]	Water	Increasing the water flow rate from 0.01 kg/s to 0.1 kg/s in the PV/T system reduces the average cell temperature from 84C to 34C. As a result, thermal and electrical efficiency increases
[81]	Water	Application of Roll-bond flat plate aluminium absorber in a water-cooled, glazed PV/T system improves performance
[82]	Water	In the experimental study, they state that the thermal efficiency is 25-58% and the electrical efficiency is 12-16% with the energy and exergy analysis of the water-cooled combined PV/T system. They emphasize the usability of the concept for household use
[83]	Air	They show that an air cooling-based PV/T system using a compound parabolic concentrator will give better thermal and electrical performance than the standard system
[84]	Air	The performance of 2 types of PV modules with glass-to-tedlar and glass-to-glass features is compared. Electricity efficiency is in the range of 9.5-11% during the day. Glass-to-glass PV/T concept shows better thermal efficiency
[85]	Air	They evaluate the performance effect of connecting additional modules in series or parallel in the PV/T system. They claim that the parallel module connection, which will allow dual air inlets and outlets, will give the best thermal and electrical efficiency
[86]	Air	The efficiency of the air-cooled PV/T system is 20% higher than the traditional PV electricity efficiency
[87]	Air	The cooling effect of air in PV panels is compared under natural and forced convection conditions. For 970 W/m^2 radiation intensity, the efficiency is 2% higher with forced convection under the same conditions.
[88]	Water / Air	Water or air cooling of the PV system is considered for different flow rates and channel depths. It is seen that the thermal efficiency varies between 50-67% when heating water and 17-51% when heating air
[89]	Water / Air	4 different PV/T systems, unglazed with tedlar (UGT), glazed with tedlar (GT), unglazed without tedlar (UGWT), and glazed without tedlar (GWT), are compared. It is seen that the water-integrated system performs better than the air

Solar chimney power plants are large structures that work on the principle of rising heated air [90]. Due to the pressure difference at the inlet and outlet of the high chimney in its structure, the air inside it moves upwards continuously. This mobility can be used to lower or stabilize the temperature of the PV module. The schematic view of the solar chimney photovoltaic thermal (SC-PV/T) system is given in Figure 13. With the chimney to be integrated into the PV/T system, the electrical efficiency is 18% higher than standard PV modules, reducing the temperature of the PV module [91].

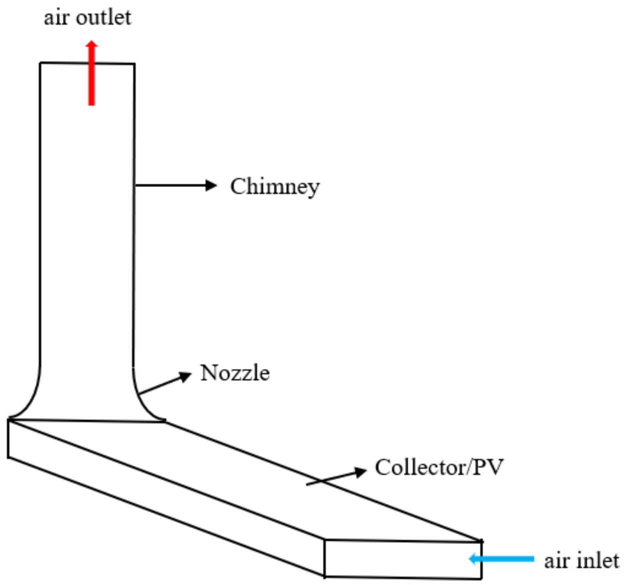


Figure 13. Solar chimney integrated air-cooled PV/T system schematic [91].

The solar chimney concept does not work in such a way as to reduce the module temperature by only supporting the airflow over the PV module. With the structures to be directly integrated into the system, power output can be obtained from both PV modules and solar chimney power plants. Haghighat et al. [92] design a combined system by placing PV modules in the collector of the solar chimney. They evaluate the performance of the system and the solar chimney together with PV modules of different widths. With the system, they achieve a 5°C drop in PV module temperature. They claim that when 50 cm wide PV is placed, the power obtained from the solar chimney decreases, but this situation is more than compensated by the increase in panel efficiency. Jamali et al. [93] design a solar tower photovoltaic (STPV) based on the dimensions of the Manzanares pilot plant. The collector of the turbine-free solar chimney system is laid with completely transparent PV modules. They claim that the temperature of the panels will be reduced by approximately 45°C thanks to the airflow created by the solar chimney with a radiation intensity of 900 W/m^2. They show that according to the radiation intensity, the system will increase PV efficiency by up to 29%.

PV/T systems are used in the literature in combination with different systems. Mohamed et al. [94] claim that the COP of the absorption cooling system with the integrated PV/T system will be about 5. They also state that electricity savings will be achieved with the system. Cao et al. [95] design an effective system that can be used in cold regions with a heat pump integrated into the PV/T system. They emphasize that the average COP coefficient of the unit designed using the air source heat pump PV/T collector output reaching 76.6°C by the TRNSYS simulation will reach 4.1 and it is an effective method for heating mode. Solar photovoltaic water pumping system (SPVWPS) installed for agricultural lands far from the settlement is one of the effective applications that can be an alternative to fossil fuel generators [96]. Chen et al. [97] perform numerical and experimental analysis by integrating a heat-pipe solar (HPS) heat pump and a PV/T system. They emphasize that ambient temperature and solar radiation are the main factors affecting the performance of the system. They claim that the efficiency of the system is in the range of 30-50% according to the heat pipe range, and the COP value is in the range of 3.4-5.6. They especially draw attention to the usability of the system in small houses and buildings.

Thin film PV cells and their integration into building elements are in the centre of interest especially in recent years due to the increasing application of modern architecture [98]. Shadowing is also an issue in building elements like thin film PV glazing systems. Even partial shadowing plays a significant role in the reduction of power output. In this regard, facade design is of vital importance for optimum energy efficiency. Energy efficiency and optimum energy generation in such systems is usually expressed with solar cell parameters and their dependency on main environmental factors such as solar radiation and ambient temperature [99]. Maximising solar radiation falling on the aperture glazing while minimising the cell temperature can be considered as the optimal solution in most cases for enhanced current and voltage parameters thus higher power output and efficiency [100].

5. Conclusion

Renewable energy has the potential to break the dominance of fossil fuels, which have dominated energy production for 200 years. It is obvious that renewable energy will continue to increase its power in the coming years, especially thanks to the use of solar energy all over the world and its endless potential. This study evaluates the performance parameters by shedding light on the performance of PV and PV/T systems. It also aims to give an idea to manufacturers by providing comparisons for development studies. The findings obtained from the study can be listed as follows.

- Solar energy has enormous potential and is very useful for both electrical and thermal energy.
- PV modules, which are widely used to generate electricity from the sun, can be used regardless of geography.
- Environmental temperature and solar radiation have a primary effect on the performance of PV modules.
- Low ambient temperature and high solar radiation mean maximum power output for PV modules.
- For standard climatic conditions, the efficiency of PV modules is 13-15%. This efficiency range is maintained as long as the PV module remains at a temperature lower than 60°C.
- The performance of PV modules is also affected by the material produced. Polycrystalline Si modules outperform Monocrystalline Si's.
- Especially in arid climatic regions, sand accumulation is very effective in the performance of PV modules. Sand build-up can cause performance degradation of up to 17%.
- Humidity is not an effective parameter in performance. However, humidity can have a performance-reducing effect as airborne dust clings to the PV modules. Similarly, the Dew effect is another point to be considered.
- It is good for high power output to install large-scale systems. However, the increased shading effect can be a disadvantage. Therefore, optimum module spacing, ideal positioning, and angle adjustment are required.
- Comparing by trying different methods for performance monitoring under the effect of shadowing gives healthier results.
- The PV tree method can be used effectively, especially in places with shading effects and installation space problems.
- PV/T systems, which are used to increase the performance of PV modules and to benefit from thermal energy, are extremely useful for buildings.
- Module efficiencies of PV/T systems are 20% higher than traditional PVs.
- It is highly effective for air and water cooling, most commonly used for PV/T systems. Since the heat capacity of water is higher than that of air, it gives better performance for cooling.
- PV modules can eliminate the dependence on energy-needing vehicles such as pumps and drills on fossil fuels in agricultural lands in remote areas.

Conflict of Interest Statement

The authors declare that there is no conflict of interest.

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