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A novel concept of solar photovoltaic partial shading and thermal hybrid system for performance improvement

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Abstract

Large values from external causes, such as partial shade, can greatly influence output power of PV. The applications of partial shading are frequently utilized in simulation software. However, in this research work, partial shading and the integration of the photovoltaic Thermal (PV/T) Hybrid Solar Panel is implemented, and analysis is done to see how it affects the output power of solar panels under genuine climatic circumstances. Many research investigations have been conducted and researchers continue to look at PV/T systems to enhance their performance. The application is designed to provide information on solar panel output power under normal and partial shading situations. The maximum amount of power that solar panels can generate is 298.50 W. Under typical circumstances, partial shading in a solar panel can result in a maximum power value of 141.13 W, and this partial shading leads the power to increase.

Keywords: Solar Irradiation, Solar Panel, High-frequency inverter, Partial Shading module, Bypass Diode, photovoltaic Thermal (PV/T) Hybrid Solar Panel, Wireless power transmission (WPT), I (V) and P (V) characteristics

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1. Introduction

Fossil fuels must eventually reach a specific limit to continue providing the world's energy needs. Every human activity that uses excessive amounts of fossil fuels will result in unfavorable events. This phenomenon is caused by pollution of the environment and the atmosphere, which leads to acid rain, the emission of greenhouse gases effect, severe climate change, as well as global warming, and other problems. Since 1970, research has shown a link between the usage of fossil fuels and several natural occurrences. Because of the greenhouse gas discharges such as methane (CH4) as well as carbon dioxide (CO2), fossil fuels have turned into the cause of these occurrences in nature. There are two ways to mitigate the effects of this phenomenon: either increase the standard or efficacy of fossil fuels, or else switch to more ecologically friendly, clean, and renewable energy sources. In comparison to other forms of renewable sources of energy, including wind, geothermal, as well as water pressure, solar energy is a renewable resource since it is distributed equally and in plenty across nature and it is considered the best option [1]. These improvements are meant to lower the demand for fossil-fuel nuclear power plants. Street lighting is presently the only application for solar power plants In Indonesia. The amount of sun radiation that solar cells receive is crucial for the production of solar energy. The amount of power generated by solar cells can be impacted by irradiance [2].

Thus, PV/T collectors are a crucial component of a superior solar energy exploitation strategy. Comparing these systems to solar thermal collectors as well as PV modules individually reveals that they can produce more energy per unit surface area. Approximately 15-20% of the solar power is converted into electrical output after being absorbed by a PV panel. The PV cells are heating up as a result of the residual solar energy, which causes several issues. For instance, the increased internal temperature of the cell causes the electrical efficiency to degrade, which results in a 0.45–0.6% reduction in efficiency per degree compared to a PV cell operating at ambient temperature. The precise rate of reduction is influenced by both the materials and the environment.

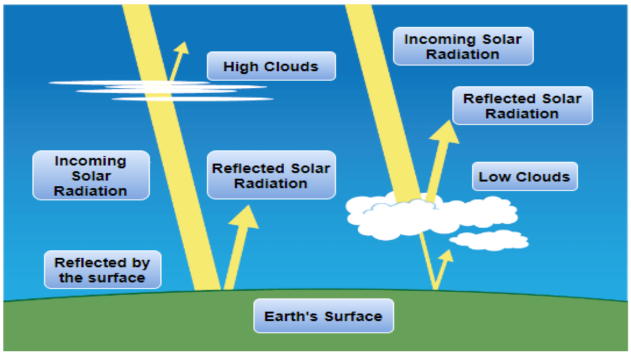

Figure 1. A representation of the sun's radiation type

Therefore, a significant increase in the deterioration of electrical efficiency was noted [3] in areas or sites where the climatic conditions are harsh, and the temperatures are high mostly in the summer. Another issue brought on by the cell's high internal temperature is total annihilation as a result of the overheating. It follows that cooling the PV panels is a task that must be completed. In addition to improving electrical efficiency, the cooling of PV can also benefit from using thermal energy for other purposes, such as heating water or any other liquid. As a result, hybrid PV/T modules have drawn a lot of attention from both academia and industry, as is detailed in the next section.

Electromagnetic radiation is the sort of energy that the sun emits. Depending on the type of beam, the radiation's value can alter. Direct and diffuse beams make up the two categories of beam types. Direct radiation is solar energy that strikes the planet directly and does not flatten out on the surface of the atmosphere. One form of solar radiation is diffuse radiation, which spreads to the atmosphere. The spread causes a reduction in the amount of radiation that reaches the planet. Figure 1 [3] provides a diagram showing the radiation that the sun generates.

Weather conditions that the planet encounters have an impact on changes in irradiation levels. In sunny weather conditions, the sun's direct radiation causes more than 900W/m^2 of irradiation to reach the Earth. The amount of radiation the planet receives decreases between 400 and 800 W/m^2 when it is overcast due to diffuse radiation. In foggy situations, direct irradiation from the sun diffuses into the atmosphere. The resulting irradiation value lowers as a result of the dispersion of radiation that the transmission experiences on the atmosphere's surface. This circumstance results in a decrease worth 50% of overcast conditions. [4]

The solar radiation that Earth receives varies throughout time. Based on the recent Earth revolution, the sun's location is what causes these variances. Based on the irradiation period, the sun may deliver the most radiation from this point. The daylight has the highest level of ideal irradiation. The aforementioned occurs because the sun is perpendicular to the earth's surface, which causes the irradiation value to be more than 1000W/m^2. Thus, the sun's real exposure to the radiation curve, which is depicted in Figure 2 [5], is where the ideal amount of radiation may be discovered. The sun's declination angle causes it to move in the morning and the evening. The amount of solar radiation that the earth's surface receives decreases with the declination angle.

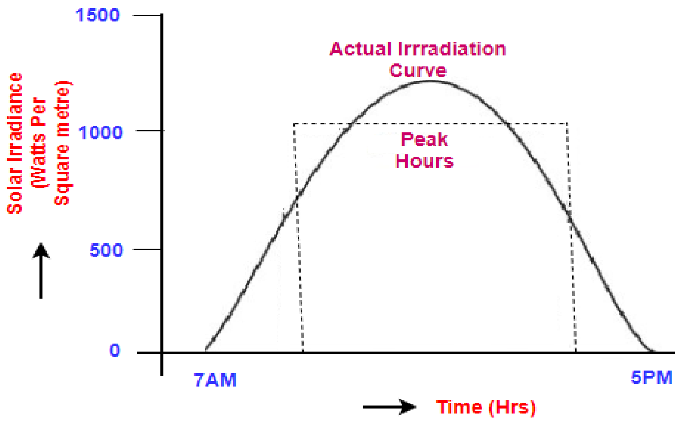

Figure 2. The sun's actual irradiation curve

The earth's surface might receive solar radiation at intervals of 800-1000W/m^2 between the hours of 9 AM and 2 PM. At 8 AM and 3 PM, irradiation readings are available in intervals of 600-800 W/m^2. At 7 AM and 4 PM, there are irradiation levels between 400 and 600 W/m^2 [6]. The quantity of sun radiation has a significant impact on solar cells. The quantity is inversely related to the greatest current output which solar cells are capable of producing. Expenditure of solar radiation depends on typical testing occurring and having the value of 1000W/m^2 and it is received once peaked. If the value drops, resulting in a decline in the output current value, this value may create a high current value. Figure 3 [6] depicts how irradiation has an impact.

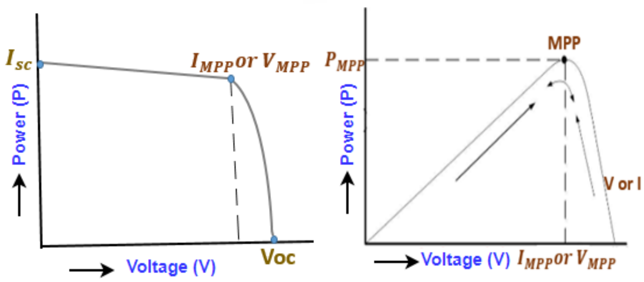

Figure 3. Modeling the characteristics of the I-V and P-V curves for solar modules at 25 °C and 1000 w/m^2)

The temperature which is present in the environment wherever these photovoltaic cells are installed can additionally affect their voltage output value. The amount of heat that solar cells produce is proportional to their voltage at the output. Thus, the output voltage generated lowers as the temperature rises. According to Figure 3 [6], the output voltage might decrease for every 1 deg C increase in temperature. Partial shading refers to the protection of a photovoltaic cell's closed surface from exposure to light. According to author Belhaouas et al., the obstruction to the solar photovoltaic cells which is induced by the object's presence was the cause of the issue. Obstructing solar photovoltaic cells will lead to a lower in the amount of output power they produce. As illustrated in Figure 4 [6], the sun's radiation to which solar cells are exposed reduces the measured value of the current output generated, which is the reason for the reduction.

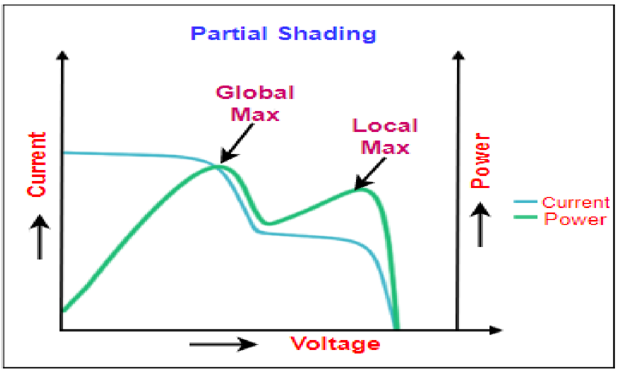

Figure 4. Partial shading's effects on solar photovoltaic cells

Giving the module or array a bypass diode will avoid partial shading. The purpose of the bypass diode can stop the opposite (reverse) flow that happens when solar photovoltaic cells are partially shaded. By turning off all of the cells associated with the bypass, as shown in Figure 5 [7], the bypass effect is achieved.

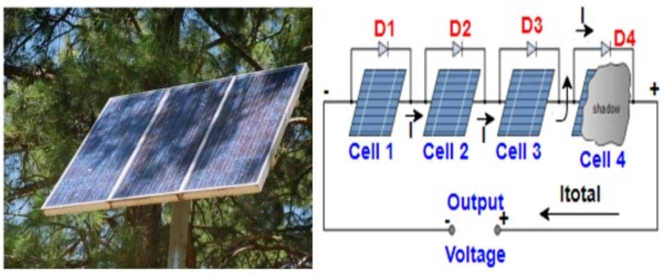

Figure 5. Bypass diodes and the PV partial shading are interconnected through the cell's module

Solar cell installation in a location is expensive. As a result, while selecting a generator location, the plant's efficiency is taken into extremely careful consideration. The area has to be at the proper temperature and has a lot of sun irradiation. The angle at which the sun shines on the planet affects the environment's temperature and irradiation. With the earth's rotation or at any time, the angle of sunlight can shift [8].

The structure of the paper is as follows, first and second section contains the introduction part and the description of the methodology, and its material used. The third section explains the proposed system analysis in detail. Result and its discussion are briefly explained in fourth section. Fifth section conclude the proposed system and its future work.

2. Materials and Methodology

2.1 PV shading

The primary issue with a Solar Photovoltaic Array module (SPVA), which includes both series and parallel connections, is non-linear internal impedance, which is linked to cells connected in series. Further complicating the problem is the shading effect that occurs when SPVA are exposed to non-uniform solar radiation. Data is gathered from noon to one o'clock. Each data collection's time interval is one minute [9]. Additionally, data were only collected on eight days, four of which were under normal conditions and the remaining four under conditions of partial shading. Since there are only two seasons in India—the one is the rainy season and the other one is the dry season —the time is carefully considered. A solar photovoltaic panel connected with a 250-Watt peak power capacity was used for this study. Also, three types of bypass diodes are utilized in solar photovoltaic panels. 24 solar cells are linked in parallel to each bypass diode [10]. When one or more cells are shaded, the function of the bypass diode is to stop backflow. The solar panels utilized are polycrystalline and the characteristics are shown in Table 1 on them.

Table 1. Solar photovoltaic panel specification

S.No	Parameter	Ratings
1	Maximum Power Rating (P_{max})	250W
2	Maximum Power Voltage Rating (V_{mp})	36V
3	Maximum output Power Current (I_{mp}	7.24A
4	Open Circuit Voltage Rating (V_{oc})	44V
5	Short Circuit Current Rating (V_{sc})	9A
6	The temperature of the Normal Operating Cell (NOCT)	46±2°C
7	Amount of System Voltage present	1000V
8	Maximum Fuse present in Series Fuse	17A

9	Dimension Rating	1957 mm; 993 mm ;42 mm (Length ;Width ;Height)
10	Standardized solar Photovoltaic panel Test Condition	-
11	Irradiance Power Rating	1000W/m^2
12	Solar Panel Temperature Rating	25^{o}C

A particular kind of semiconductor, solar cells, converts light from the sun's power into electrical energy. When stimulated by sunlight, electrons are released, which is how energy is converted. The semiconductor substance that transforms energy into silicon in solar panels. A charge that is negative (N) layer and a positive charge (P) layer make up the substance [11]. The ideal equivalent circuit for solar cells works to obtain the I-V (Current-Voltage) characteristic curve. As depicted in Figure 6, thus, the circuit only has one current source and one diode. According to the above circuit diagram, I_{ph} (A) represents the current produced by solar, I_d (A) represents the current that is flowing at the junction of the diode, I(A) represents the current that is flowing through the solar photovoltaic cell, V(V) represents the solar cell voltage, and KB represents a constant value, T(DegC) represents actual attainable temperature range, q(Coulomb) represents the charge in electron, and the Boltzmann constant (J.K-1) is the equation.

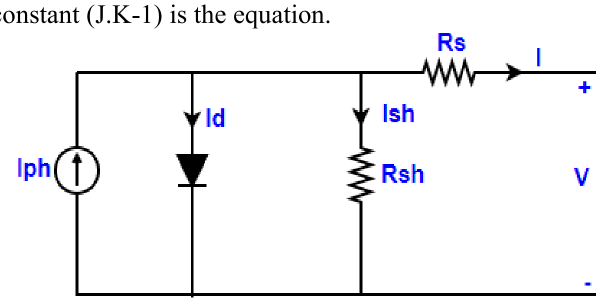

Figure 6. Ideal solar photovoltaic panel equivalent circuit

The Kirchhoff current law concept is used to generate the equation such that Equations 1 and 2 may be used to express it [12]. System design has a significant impact on component preparation and the intended outcome. Voltage and current sensors, storage of transient data, temperature sensors used in the environment, as well as irradiance sensors, were the elements used for this Solar Panel Research application.

$$I_{out} = I_{ph} - 1I_s\left(e^{\frac{qXV_d}{kXT}} - 1\right) \quad (1)$$

$$V_{out} = \frac{kXT}{q}\ln\left(\frac{I_{ph}}{I_s} + 1\right) \quad (2)$$

The solar panel being utilized has 72 cells, thus when there is any partial shadowing, there will be 48 instead of 72 cells that are actively present in the panel. Thus, the decrease in the total number of photovoltaic cells in Equations 3 and 4 is then obtained using the partial shading Equation.

$$V_{partial} = 48XV_{out} \quad (3)$$

$$P_{partial} = V_{partial}XI_{out}XFF \quad (4)$$

2.2 Photovoltaic thermal (pv/t) hybrid solar panel

Sheets of corrosion-resistant stainless steel are used to construct the heat exchanger's protective enclosure, and its air-exposed elements are insulated with glass wool. The tubes are composed of aluminum and the fins direct airflow [13]. Heat is transferred from the solar photovoltaic panel to the fins through conduction because the uppermost side of the fins is bent as well as firmly connected to the solar panel's rear-type surface. Thus, the rate of heat transfer by conduction through materials is given by equation (5).

$$\frac{Q}{t} = \frac{kAdT}{d} \quad (5)$$

Where A is the area of heat transmission, dT is the panel's temperature differentiation between the elements, d represents the thickness, and k is the material's thermal conductivity. As a result, the thermal conductivity of particles as well as to maximize in the area of heat transmission, and thus results in heat transformation occurs [14]. But when the transmitting material's thickness increases, the rate of heat transmission reduces. Aluminum's thermal conductivity is lower than copper's, but because it is more affordable, It may have been utilized as a medium for transmitting heat. The exchange of heat material was composed of a thin (1 mm thick) aluminum sheet since the rate of heat transfer is inversely linked to the thickness of the heat exchange material.

The PVT system's performance has been compared to that of the same solar panel in an outdoor external setting. Similar 50 W and 12 V multi-crystalline solar PV panels have been employed in both PVT and conventional systems [15]. For many days, measurements of both systems were taken simultaneously under outside conditions. The tests are conducted in Dhaka, Bangladesh. PV panel voltage and current have been measured using digital millimeters [16]. The thermocouple has been used to measure the air temperature at the PVT system's intake and outflow.

3. Proposed system analysis

By separating the panels into three pieces, the simulation of the solar panel's design is carried out. The number of solar panel cells determines how the panels are distributed. Figure 7 shows a block schematic representation of the solar PV system as it is currently being implemented. According to the illustration, solar panels can activate their series-arranged solar cells when they are exposed to sunshine with a specific amount of irradiation. The processing functioning of producing a voltage output value which is impacted by ambient temperature activates the cells.

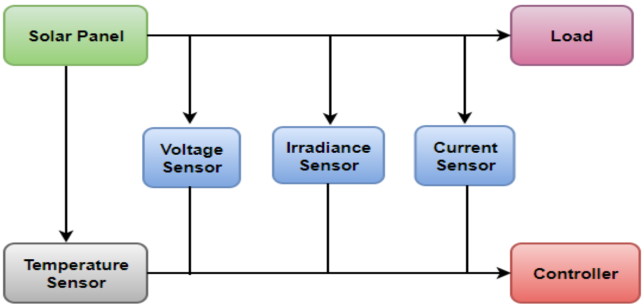

Figure 7. Block diagram representation

By supplying input parameter values, an experiment is conducted to test the solar photovoltaic panels which are present under nominal criteria circumstances as well as the partial shading situations. Based on data collected during hardware testing, input parameters are determined by the test's findings, including the output current, output voltage, sun irradiation, output power, and ambient temperature. The simulation test's parameters for input are solar irradiance and ambient temperature, which are derived from these data. Figure 7 shows that the output current, as well as voltage from the solar photovoltaic panel, are identical. The solar cell's current and voltage may be calculated using Equation 6, as shown in Figure 8.

$$I = I_{ph} - I_d\left(e^{\frac{qV}{K_B T}-1}\right) \tag{6}$$

Figure 8 provides examples of both normal circumstances and partial shading conditions. The simulation's findings revealed the I-V characteristic curve under typical conditions. The collected sample data are then combined with the curve. Analysis was done on the merger's results. By contrasting the simulation findings with the hardware, an analysis was carried out.

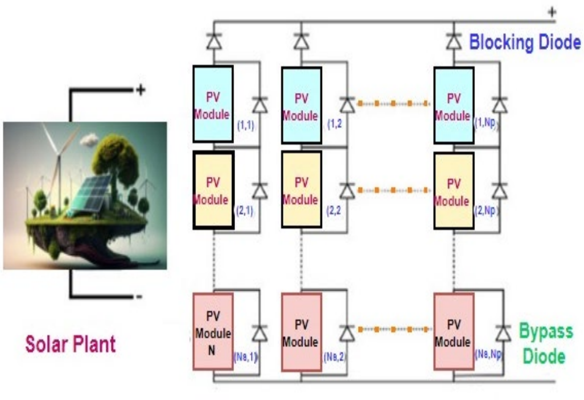

Figure 8. Solar panel circuit diagram

Additionally, the total number of various bypass diodes which is employed in solar photovoltaic panels allows us to see cell division. Thus, the design specification parameters of a solar photovoltaic panel simulation software called Matlab Simulink comprises 24 interconnected cells linked in series connection on each panel and further, one more bypass diode which is interconnected with parallel type on each panel. Thus, the specification construction serves as the foundation for the findings of the solar photovoltaic panel simulation circuit. There are two types of external factors: the first one is the radiation from the sun's rays and another one is the surrounding temperature. The simulation's output parameter values for these two variables are utilized. In a typical condition test, these parameters specification are had been taken from the solar panel specification [5].

The voltage divider sensor is the one used in this situation. The microcontroller's input range is 0 to 5 volts; thus, the voltage must be decreased to be accepted by it. The microcontroller will receive the voltage in analog form. A microcontroller will turn the analogue data into digital data. The ACS 712 sensor is the one that is currently in use. A microcontroller will transform input from the sensor signal, which is a voltage signal that converts into a current signal. DHT 11 serves as the temperature sensor. The DHT 11 sensor can measure temperatures from 0° to 50°C with a 2°C error tolerance. LDR (Light-dependent resistor) is used by solar irradiation sensors.

4. Results and discussion

4.1 Shading analysis for solar photovoltaic systems

The output of this results experiment demonstrates how to include shade into a solar photovoltaics (PV) module or plant. The Simscape language was used to develop the solar plant block. When solar radiation is not uniformly distributed among all solar PV modules or cells, shading in a solar plant or module takes place. This illustration may be used to examine how shading and PV cell junction temperature affect a single PV module or a sizable, linked solar array. The Solar Photovoltaic block has a diode of blocking and bypass to increase maximum output and prevent the solar panel from overheating. Set the Irradiance and Temperature parameters' values to specify the shading.

Both bypass and blocking diodes are included in the Solar Panel block. The protective diodes are modeled using a Diode block. Bypass diodes have a relationship between PV modules to ensure the bypass of a solar PV module in a cell's string that cannot provide sufficient irradiance to support the solar PV string current. Thus, the decreased string voltage of the solar photovoltaic string is isolated by the blocking diodes. The lifespan and power output of solar photovoltaic modules are increased with protection diodes. To define the protective diodes in the solar plant, set the solar module protection type parameter as follows No blocking or bypass diodes are present in the solar power plant and only a bypass diode between modules is present in the solar plant; there is no such type of blocking diode between solar PV cell strings. In the solar plant, there are two protective diodes: the first one is the bypass diode and another one is the series module strings blocking diode.

This partial shading amount needs to be more than zero. Set the Number of cells in Parallel Strings, and Number of cells in Series strings, parameters to 1 to investigate the effects of shadowing on a single solar PV panel. Indicate the parameters' values and determine the number of solar cells in the solar panel by counting the number of modules that are connected in series, Ns, and the number of modules that are connected in parallel, Np. The parameters which are used to elaborate the value of irradiance, as well as the temperature, range in every solar cell present in the solar panel are the Cell temperature matrix and the Irradiance matrix. Set the appropriate Solar Plant block Ns, and Np values to alter the shade field area. The parameters can also be used to specify a cluster of PV cells with a constant temperature and irradiance. The number of cell clusters with varying temperatures and irradiance may be determined using the Ns and Np parameters.

The amount of input parameters for solar irradiation that are being emitted and exposed to photovoltaic panels affects changes in the typical characteristics of the I-V curve presented in Figure 9. The total amount of solar Photovoltaic radiation then feeds the input value and is supplied to the photovoltaic panel, and the output current waveform which is shown in Figure 9 has drastically dropped. The value and range present in the output power electricity which is generated by solar Photovoltaic panels are impacted by this decline.

Simulink software simulation is carried out under typical conditions test ratings on solar PV panels may be used to analyze the impact of variations in the ambient temperature. The solar panel is unobstructed and in good shape. The simulation-based outcomes are displayed in Figure 10 as solar panel I-V characteristic curves. The input settings for ambient temperature factors that solar panels are subjected to the particular value have an impact on changes in the typical I-V curve in Figure 10.

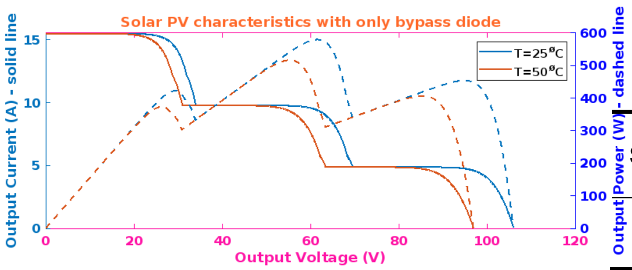

Figure 9. Solar PV characteristics with only bypass diode

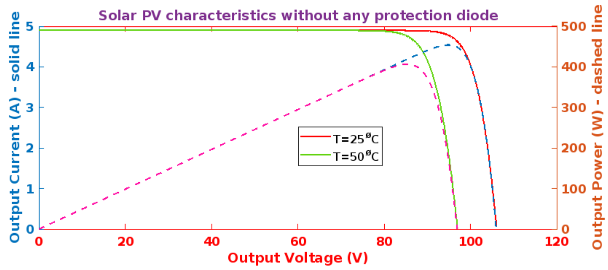

Figure 10. Solar PV characteristics without any protection diode

Depending on the input temperature value, which is supplied to the solar PV panel, thus, the waveform of the voltage output shown in Figure 11 has drastically dropped. Changes in the ambient temperature have a great impact on the panel of solar photovoltaic output voltage. Thus, the range and value of the output voltage decrease with increasing solar panel ambient temperature. The output power rating is generated by solar PV panels, and it is spoiled by this drop.

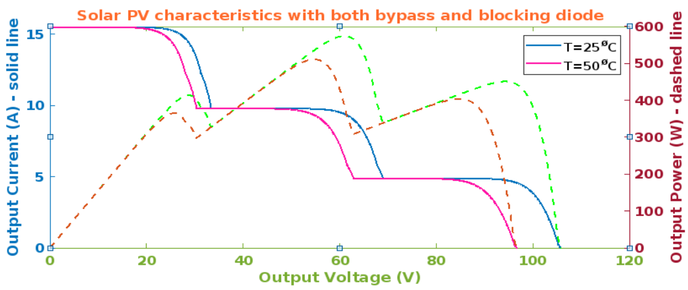

Figure 11. Solar PV Characteristics with both bypass and blocking diode

The solar photovoltaic Cell junction temperature in degC, maximum power point current in A, voltage in V, and Power in W and it is shown in Table 2.

Table 2. Specification of junction temperature, maximum current, voltage, power

S.No	Junction Temperature	Maximum Current	Maximum Voltage	Maximum Power
1.	25	12.156	90.226	1096.8
2.	50	11.981	81.117	971.88

4.2 Photovoltaic thermal (PV/T) hybrid solar panel

Using a hybrid PV/T solar panel, this result analysis demonstrates how to predict the cogeneration of electrical heat and power. To heat water for domestic use, heat is created. In the network's electrical component, there is a Solar Cell is present as a block that mimics a group of load system as well as the photovoltaic (PV) cells that simulates a resistive load type. The thermal temperature network models the transportation of heat from the environment to the surface of the PV panel (heat exchanger, glass cover, and back cover). The transport of heat occurs via radiation, conduction, and convection. Thus, the thermal-liquid network consists of a tank, a pipe, and pumps. The system's liquid flow is managed by the pumps.

Air temperature at the Intel and PVT system outlet

The result demonstrates that the heat exchanger effectively transfers heat from the PVT system to the circulating air, which should assist to increase the PVT system's electrical output.

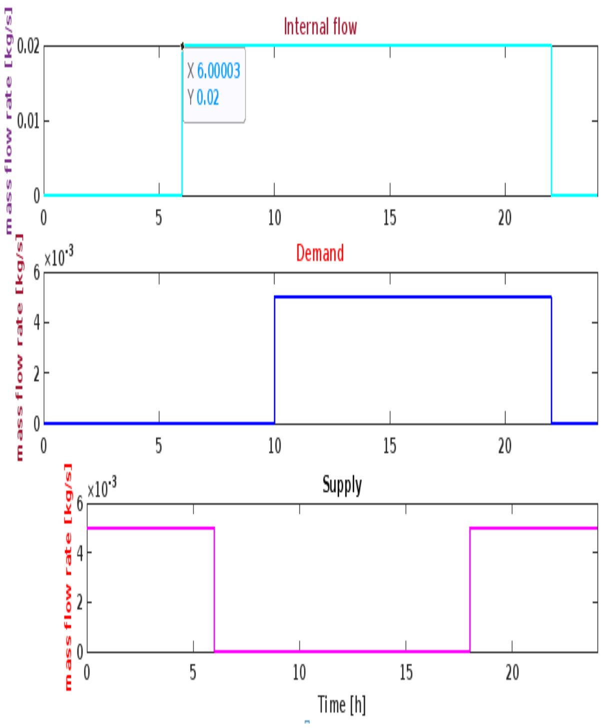

Figure 12. Air temperature at the intel and PVT system outlet

The airflow rate is a crucial factor in the performance assessment of the hybrid solar PV and heating system. The speed of the cooling fan may be adjusted to manage the rate of airflow through the heat exchanger. We did not quantify the air flow rate during our trials; instead, we used natural airflow. Figure 12 shows the air temperature internal flow, demand, and supply of the PVT System.

Short circuit current and open circuit voltage

This result shows that heat is successfully being misplaced from the system of PVT to the circulating air by the heat exchanger. The greatest improvement and enhancement in open circuit voltage Voc is 1.4 V, with an average improvement of 0.97 V. On the other hand, as demonstrated in Figure 13, the PVT system's reduced short circuit current (Isc) as compared to a typical PV system is not appreciably lower. The PVT system has an average Isc decrease of 0.05A when correlated to the standard system as well as the maximum short circuit current Isc reduction of 0.17 A. Readings of the voltage and current of the PVT and regular systems as well as the air's temperature at the input and PVT system outlet all support one another.

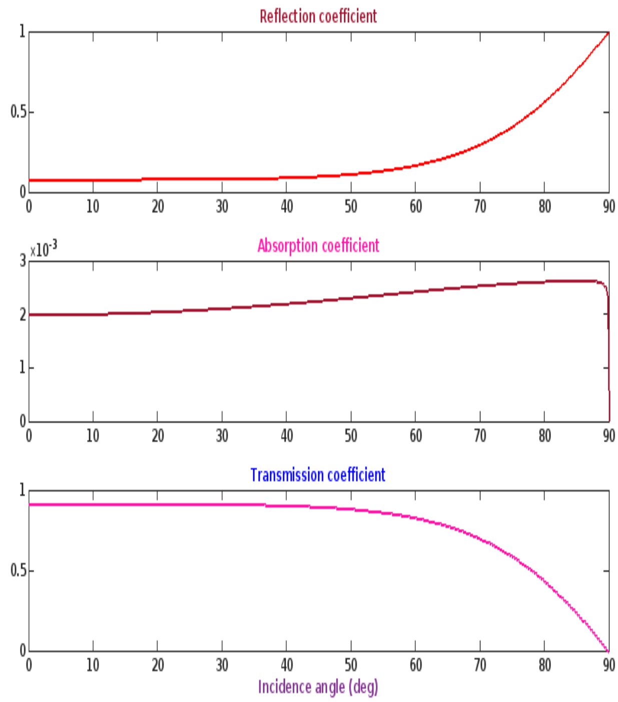

Figure 13. PVT System of reflection, absorption, transmission coefficient

Power output of PVT system

The temperature differential between the PVT system's input and output air is a blatant sign of the system's temperature decline. This temperature reduction has caused the system's output power to increase. Although the power output of the PVT and standard systems is entirely similar to the system, thus, the PVT system is significantly less efficient after 1:00 p.m. This type of system might be because there is a minimum difference between the PVT system's outlet temperature as well as the surrounding air present in the afternoon. When the ambient temperature is comparatively lower than the temperature of the air at the system output, thus, the PVT system performs better. Figure 14 shows the solar irradiance and inclination.

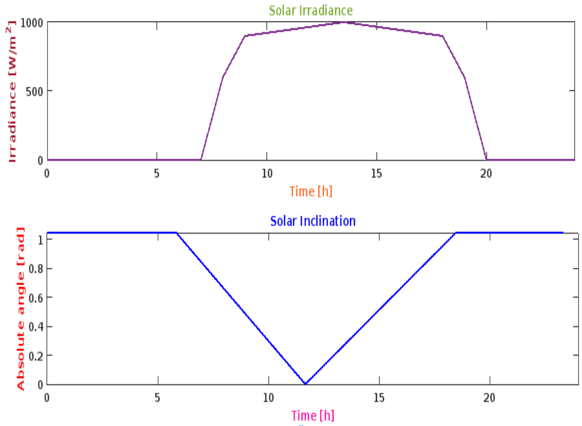

Figure 14. Solar irradiance and inclination

The electrical efficiency is comparable to that of normal PV cells, but when thermal efficiency is taken into account, the energy production improves dramatically, reaching levels comparable to cogeneration plants. Installation of controls for the pumps and electrical load would be another improvement that would push the system to different operating points and improve performance. Figure 15 shows the electrical power output, thermal power to the water supply, the temperature of the water, and the exchanger of the PVT system.

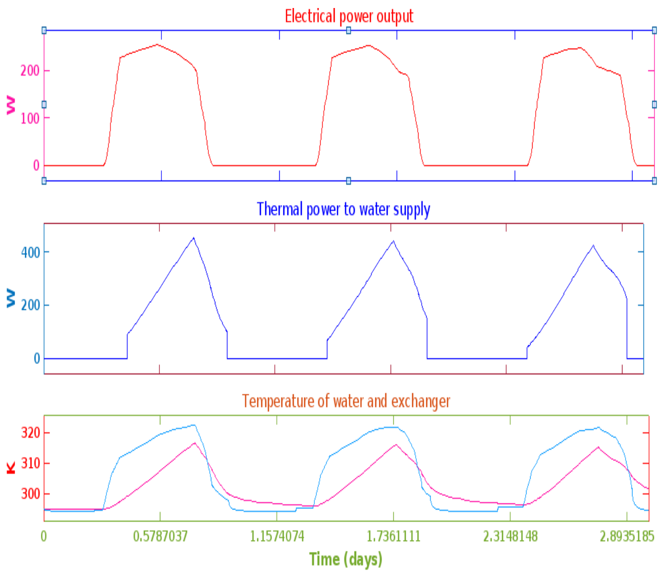

Figure 15. PVT System of electrical power output, thermal power to water supply, the temperature of water, and exchanger

From the outputs, it is possible to calculate the electrical, thermal, and total efficiency of the panel and it is shown in Table 3.

Table 3. Parameter and output specification of the PVT System

S.No	Parameter Specification	Ratings
1.	Total solar energy intake over the period	43.7845 kWh
2.	Daily average of the sun's energy input	14.5948 kWh/day
3.	The total amount of energy delivered to the load	7.5336 kWh
4.	Daily supply of energy on average	2.5112 kWh/day
5.	Total thermal energy in the water that is provided to the user	26.4349 kWh
6.	Total source-derived absolute thermal energy in the water	16.5049 kWh
7.	Total thermal energy utilized (source-sink)	9.93 kWh
8.	Average daily thermal energy usage (source-sink)	3.31 kWh/day
9.	Electrical efficacy	0.17206
10.	Thermal efficacy	0.22679
11.	Total efficacy	0.39885

Conclusion

It is possible to draw the following conclusions from the examination of solar panels operated in both normal circumstances and partial shading and PVT system. Under usual circumstances, solar panels generate 298.50 W, 92.93 W, 135.73 W, and 54.34 W for each sample. In partial shading situations, solar panels' output power is 75.34 W, 39.92 W, 141.13 W, and 43.14 W. The results have demonstrated that partial shade can lower the amount of output power produced by solar panels compared to ideal circumstances. Successful implementation of a revolutionary heat exchanger design for solar PV and thermal hybrid systems. The PVT system's performance test in contrast to a standard solar PV panel reveals that the novel heat exchanger design effectively transfers heat to the moving air. Thus, solar PV panels' open circuit voltage and output power have significantly improved. Voltage has improved overall by 0.97 V, while output power has improved overall by 2.5 W.

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