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Power Parameters Monitoring and Temperature Dependent Performance Analysis of Photovoltaic Panels

Uğurcan Şan [a], Mehmet Ersin Aytekin [b], Ali Yüce [c,*]

[a] Tarsus University, Department of Energy Systems Engineering, Mersin Türkiye – 33400
[b] Tarsus University, Mersin Tarsus OSB Vocational School of Technical Sciences, Department of Electronics and Automation, Mersin Türkiye – 33400
[c] Malatya Turgut Ozal University, Department of Electrical and Electronics Engineering, Malatya Türkiye - 44210

*Corresponding author

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ABSTRACT

Photovoltaic (PV) efficiency can be defined as the ability of solar cells to generate electricity at the highest rate from light energy. Today, there is a rapid transition from energy production based on fossil fuels, which have irreversible effects on the environment, to energy production with renewable energy sources. The discovery of photovoltaic systems in semiconductor technology and their use in energy production makes energy production with solar energy indispensable. However, the efficiency of PV panels is highly affected by environmental factors. In particular, overheating of the panels reduces the panel efficiency considerably due to the nature of the semiconductor material. On the other hand, another challenge in PV systems is to analyze the performance of the PV system under varying load conditions by considering many parameters such as sunlight intensity, direction/tilt, weather conditions, temperature, and panel at the same time. Therefore, in this study, an Internet of Things (IoT) based PV panel performance test system is designed to facilitate data collection for efficiency analysis of PV systems. Thanks to this system, remote monitoring of PV system performance is realized with IoT. The contribution of the cooling fans placed at specified locations on the panels to the efficiency of the PV panels was investigated. Overheating of PV panels is prevented by using cooling techniques. At the same time, performance data of both the system with and without cooling system were stored in the cloud environment. Thanks to the IoT application, the current, voltage and power values of the PV panel were monitored instantaneously. The data collected in the cloud in the uncooled and active cooling state of the PV panels were analyzed graphically. In the findings, it was observed that there was a 4.7% performance increase in PV panel efficiency using active cooling system.

Keywords: Photovoltaic cooling; Photovoltaic efficiency; Remote monitoring of photovoltaic panels; Internet of Things; Arduino

1. Introduction

As a result of the use of fossil fuels as a source during the energy production phase in traditional power generation plants, greenhouse gases are emitted into the atmosphere, which cause irreversible damage to nature [1]. For this reason, energy policies have been developed globally and the use of environmentally friendly renewable energy sources has started to be popularized. Among these sources, solar energy is an infinite and renewable energy source that can be used in a wide area [2]. Humanity has been able to widely use energy from the sun since ancient times. In addition to being the first technological development in the use of solar energy for heating purposes, energy production with photovoltaic effect as a result of the development of semiconductor technology is one of the research topics used today and research and development studies are continuing to achieve high efficiency. Systems that convert the energy of the photons coming from the sun into electrical energy with photovoltaic (PV) panels are very important for green energy production and are widely used in renewable energy production.

Photovoltaic systems create electric current as a result of the formation of an electric field of different polarity by combining different types of semiconductor systems (N-type or P-type). The energy of the photons coming from the sun is absorbed by the electrons of the photovoltaic cell to generate electric current [3]. With this mechanism,

* Corresponding author. e-mail address: ali.yuce@ozal.edu.tr
ORCID : 0000-0002-4642-6272

the energy of the photon coming from the sun is converted into electrical energy in photovoltaic cells.

Today, while energy is produced in photovoltaic panels, the efficiency achieved is approximately 17.4-24% [4]. In addition to generating energy in photovoltaic systems, it is also important that the system is efficient. Photovoltaic efficiency is the ability of solar cells to generate electricity at the highest rate from light energy. With the developments in photovoltaic technologies, the efficiency of solar panels has increased by up to 24% [5].

There are two important factors that cause the efficiency to decrease in P-N junction PV cells. These are the inability to absorb photons with low energy in the forbidden band energy region and the conversion of excess energy in photons with high energy into heat [6]. New generation PV solar cells aim to utilize this unusable lost energy and increase efficiency [7]. In photovoltaic systems, temperature, dusting, snow, shading, AC and DC cable losses are the factors that reduce efficiency. On the other hand, factors such as photovoltaic material quality (incompatibilities in panels, inverter losses, etc.) can also cause efficiency decreases in PV panels.

Today, environmentally friendly alternative energy sources are used in energy production due to the harmful gases released as a result of combustion in power generation facilities where electricity is produced as a result of the combustion of fossil fuels. PV panels, which are among the alternative energy sources, have a very high place in energy production today. In the future, it is aimed to increase this ratio even more. Therefore, it is very important to find systematic approaches to increase PV efficiencies and improve the power generated. In addition, the conditions that affect the performance of a photovoltaic system are shown in Figure 1. As can be seen in the figure, the most important factor affecting PV system performance, which is summarized in the literature, is the temperature increase in the panel system [8]. The increase in PV operating temperature reduces the efficiency of the cells [9].

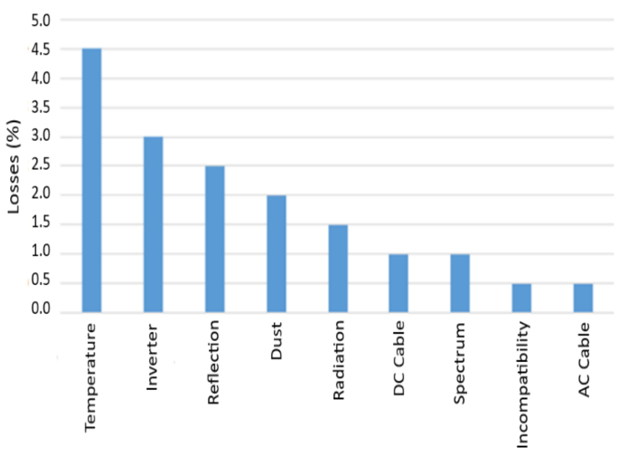

Figure 1. Losses in the PV system

The PV panel cooling system has a thermal absorbing structure with electrical energy. In other words, electrical power and heat are produced together. Generating electricity is the main goal in PV systems. It is important to keep the temperature of PV modules low to keep PV efficiency at a high level. PV panel systems according to cooling mode: air cooling, water cooling, refrigerant cooling [10] . Although using air as a coolant is not as effective as liquids, this type of cooling has some advantages such as minimum material usage and low cost [11]. In air cooling, air is circulated through a mechanical device such as an engine. Sajjat and his colleagues conducted a study to improve the performance of the PV module using air cooling technique and achieved better efficiency than uncooled systems [12].

It is understood from the literature that efficient studies using cooling techniques in PV systems are effective. However, in efficiency studies of PV systems, a lot of data of the system needs to be collected. It is very important to collect, store and analyze big data smoothly. For this reason, Internet of Things (IoT) technology was utilized in the cooling system test hardware for PV panels developed in this project for live data collection and storage. With IoT, countless objects surrounding us can be connected to the internet with specific hardware [13]. IoT can be called the future technology that will enable machine-to-machine (M2M) communication.

Nowadays, it has become important to apply the Internet of Things (IoT) platform to PV systems. IoT provides a suitable environment to monitor, store and analyze the current, voltage and power values of photovoltaic systems instantaneously from an internet-connected device. In this way, the performance of PV systems can be easily monitored and analyzed visually via internet-connected devices. IoT technology is used in the PV system test rig proposed in this paper. With IoT technology, it will be possible to remotely control and monitor the panel cooling system and other electronic equipment on the PV system.

2. Material and Method

In this section, the methodology of the air-cooled PV system test rig will be explained in order to increase PV system efficiency. When the literature on PV cooling methods is examined, the efficiency increase in air cooling system is relatively low [14]. However, in this study, realizing the air cooling by using a simple fan ensures that the system cost is low. In addition, the use of remote monitoring technology (IoT) in PV panel efficiency monitoring and analysis studies adds a distinct innovation to this study.

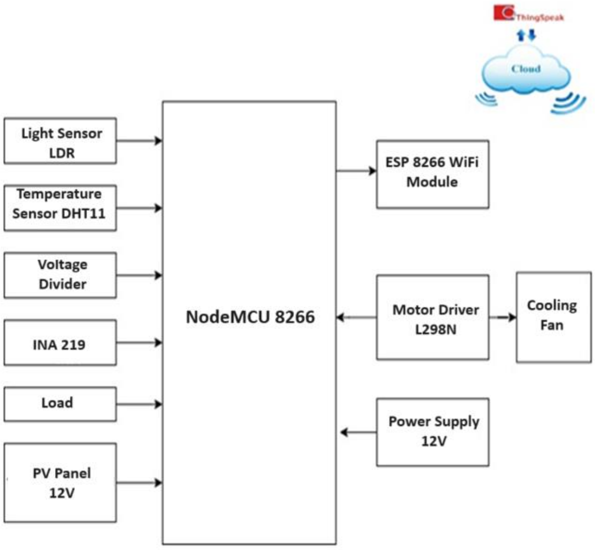

Figure 2. Block diagram of PV panel air cooling test system

The proposed block diagram of the system and their interconnection is shown in Figure 2. Arduino UNO microcontroller and ESP8266 Wi-Fi module are used in the system. All data associated with the PV panel is controlled by the microcontroller. A voltage and current sensor module are used for energy analysis of the PV module. Arduino UNO also acts as a data collector in the system. In this way, the voltage, current and power values obtained on the PV panel are detected by the Arduino processor. The ambient temperature of the PV system is detected by DHT11 and the amount of light intensity falling on the PV system is detected by LDR sensor. All measured sensor data is sent to the ThingSpeak server application via the NodeMCU ESP 8266 Wi-Fi module.

ThingSpeak records PV performance data on the cloud server. The performance data of our test equipment based on cooling in the PV panel is recorded on the cloud server and the data can be monitored instantly. At PV panel temperatures that will cause performance degradation, the cooling fan is activated by the processor via the L298N motor driver integration. Thus, the temperature of the PV panel is reduced by the cooling fan. Thus, the PV panel is kept at a stable temperature to ensure optimum performance.

Figure 3 shows the flowchart of the program running on the processor. Figure 4 shows the model of the developed solar energy monitoring and cooling system. The system includes Arduino UNO microcontroller, ESP 8266 Wifi, ACS712 Current sensor, LDR light sensor, DHT 11 temperature sensor, L298N motor driver and battery. It also includes a solar panel where we will track and analyze performance data. The data collected from the sensors is sent to ThingsSpeak and Bylink cloud programs with the ESP8266 wi-ifi module on the NodeMCU. These measured values are transferred to the ThingSpeak application over Wi-Fi.

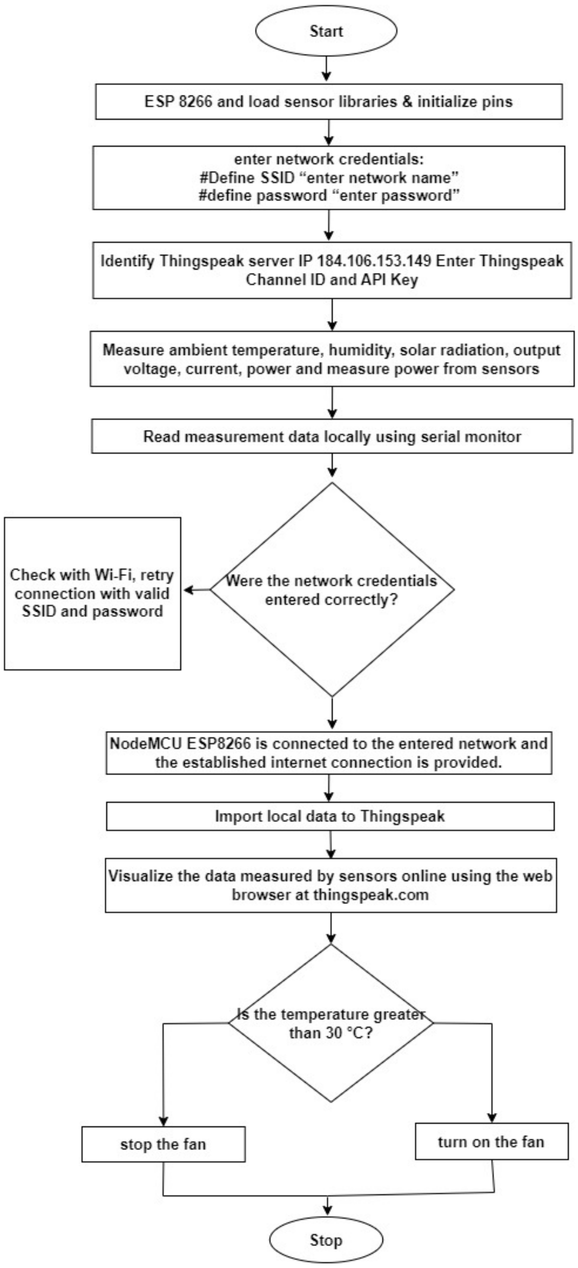

Figure 3. Flow chart of PV cooling and monitoring system

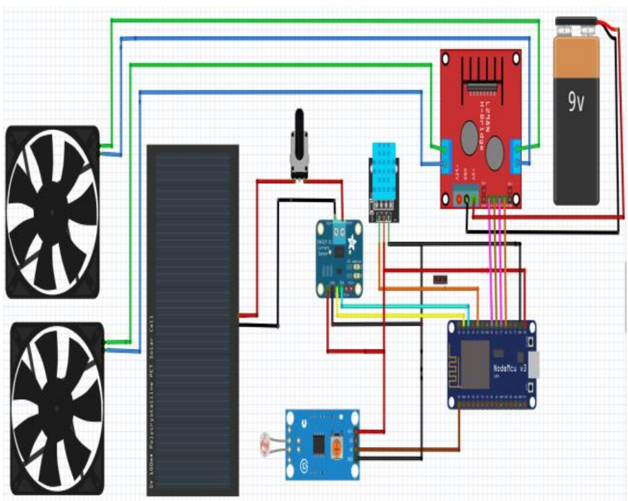

Figure 4. PV system cooling and performance analysis test rig model

In the system, when the temperature sensor is above 30°C, it sends a signal to the L298N motor driver card connected to the NodeMCU through the code written in the Arduino IDE platform. Thus, the PV cooling fan motors connected to the board are started.

In the literature, PV air cooling systems are generally designed with either front-side or rear-side cooling. In this study, the PV panel is air cooled from both the front and the back of the PV panel with a simple fan for effective cooling. The main objective of the study is to investigate the effects of cooling technique on system efficiency. For this reason, the feeds of the monitoring and control systems are not used through the PV system.

Figure 5 shows the actual front view of the developed test system. In order to cool the front part of the panel, a fan is placed at the front. Cooling is provided by providing air flow with this fan. Figure 6 shows the real view of the rear part of the test system. Thanks to the fan placed at the back of the panel, cooling is realized from the back side. For simple fan cooling, 2 12V 0.4A brushless DC motors were used.

Figure 5. Actual hardware of the designed PV panel monitoring and cooling test system (front view)

Figure 6. Actual hardware of the designed PV panel monitoring and cooling test system (rear view)

3. Results and Discussion

The data produced by the PV panel test system was taken between 09.00 and 18.00 hours in Adana province. When the system is operated, sensor data is recorded from 8 channels on the ThingSpeak application. The time-dependent curves of temperature, humidity value, shunt voltage, load voltage, bus voltage, bus voltage, current, power, and brightness data uploaded to the ThingSpeak interface are visualized in the ThingSpeak cloud system and given in Figure 7.

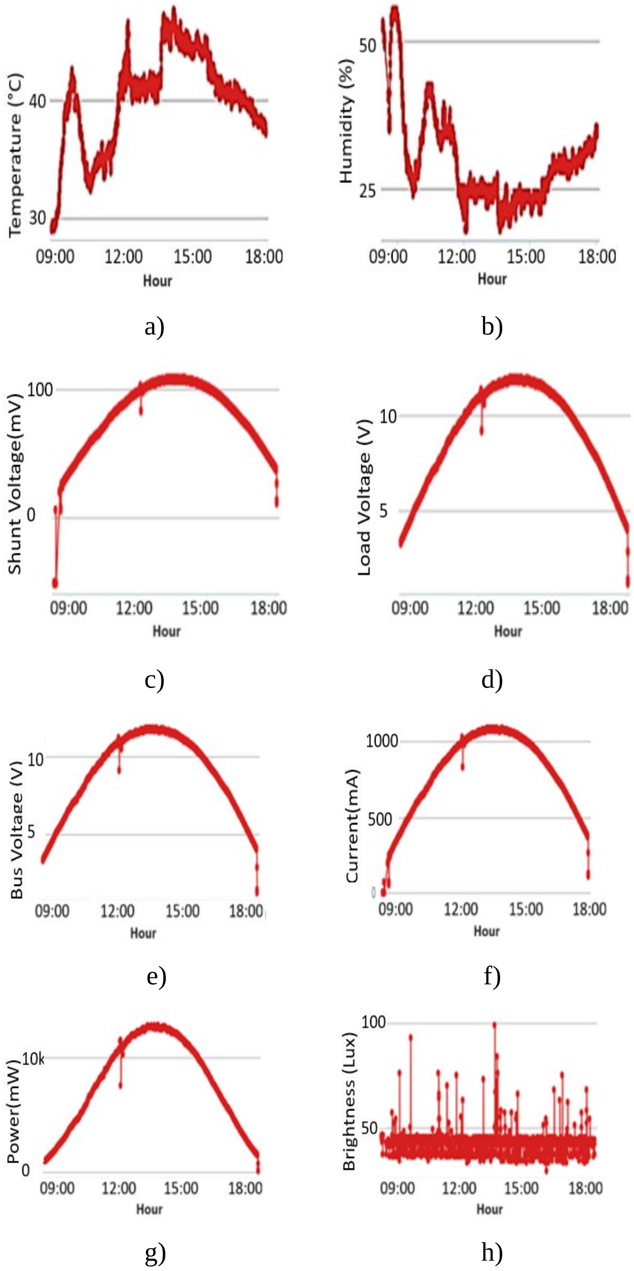

Figure 7. Photovoltaic data visualized on the ThingSpeak screen: a) Temperature value (°C), b) Humidity value(%), c) Shunt voltage(mV), d) Load voltage(V), e) Bus voltage(V), f) Current(mA), g) Power(mW), h) Brightness(Lux)

Figure 8 shows the relationship between PV panel temperature and the power generated. In Figure 8, the blue-colored curve indicates the PV panel temperature while the orange-colored curve indicates the electrical power. Here, it is seen that there is a decrease in PV output power due to the temperature increase of the panel. The effects of the cooling system integrated into the system are observed with the power decrease. Reducing the panel temperature increased the power performance.

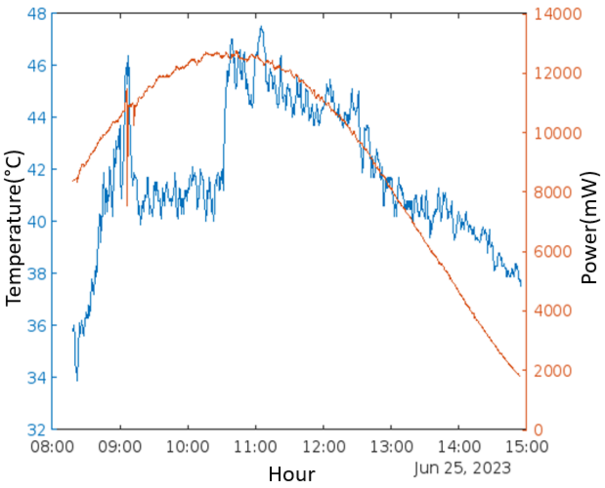

Figure 8. PV Panel temperature (°C) vs electric power value (mW) comparison curve

Figure 9 shows the relationship between the current and voltage of the PV panel. In the graph in Figure 9, the blue color shows the voltage and the orange color shows the current. Here, current and voltage increase, or decrease go in parallel. In other words, when the current increases, the voltage also increases. It is also seen that the current and voltage values of the PV panel reach the highest levels at noon due to solar radiation.

The variation graph between solar brightness and PV power is given in Figure 10. In the graph in Figure 10, power is shown in blue, and brightness is shown in orange. As the solar brightness increases, the power generated increases.

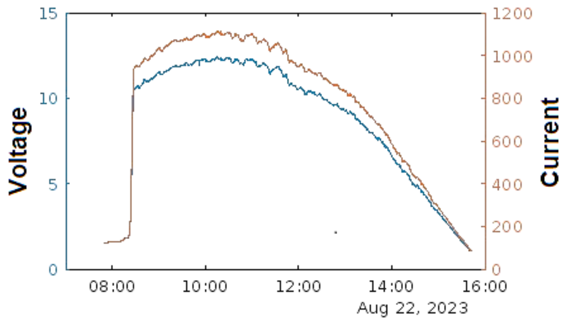

Figure 9. The graph between the current produced by the PV panel and the voltage

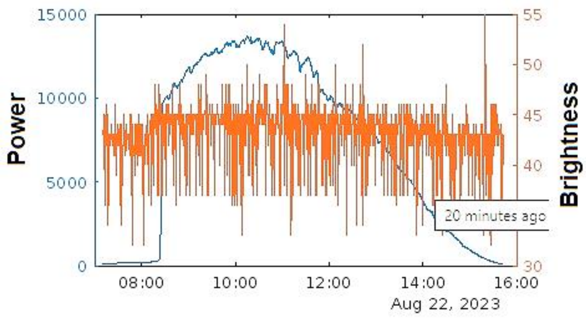

Figure 10. Graph of variation between solar brightness and PV power

Table 1 shows the electrical power data of the uncooled and cooled systems. The data in the table and the electrical power-time curve provided by the PV panel with and without active cooling are presented in Figure 11. According to the data in the graph, the output power increased between 10.00 and 15.00 hours when the PV cooling system was active and the solar radiation and temperature were high.

Table 1. Uncooled and cooled system electrical power data

Hour	Uncooled system power (W)	Cooled system power (W)
08.00	0.82	0.84
09.00	1.73	1.77
10.00	4.03	4.07
11.00	7.50	7.81
12.00	10.57	11.05
13.00	12.35	12.93
14.00	12.53	13.12
15.00	11.05	11.37
16.00	7.97	9.25
17.00	4.59	4.64
18.00	1.62	1.65

Looking at the values in Table 1 and the power values (W) of both systems in Figure 11, the data of the PV-cooled system and the uncooled system were compared between 10.00 and 15.00 hours when the radiation and temperature were high. According to the findings, the highest power values for both uncooled and actively cooled systems are observed at 14:00. When the values are analyzed, it is seen that while the power value is 12.53 W in the case without a cooling system, the power value increases to 13.12 W in the case with the active cooling system. Thus, it was observed that the power performance value of the PV panel with an active cooling system increased by approximately 4.77%.

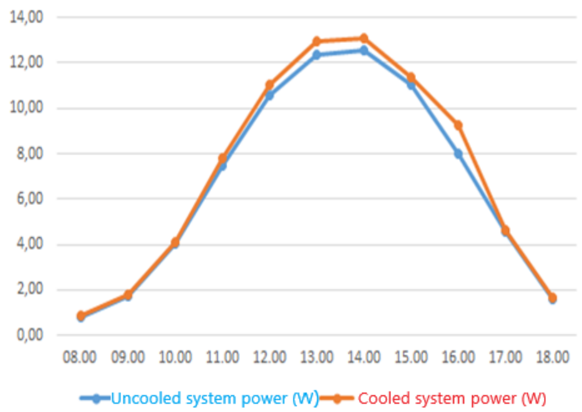

Figure 11. Graph of PV-cooled system power and uncooled system power

As another parameter in the designed system, the front fan was disabled and its effects on the system were investigated. In this case, another research was carried out by operating only the rear two fans. The electrical power data for the uncooled and cooled system with the front fan disabled were obtained as shown in Table 2. Using this data, the PV electrical power-time graph was plotted as shown in Figure 12. With this experimental study, the effect of the front fan of the PV panel on the cooling system was investigated.

Table 2. Data for PV panel cooling only from the rear by disabling the front fan

Hour	Uncooled System Power (W)	Front Fan disabled Cooled System power (W)
08.00	0.6810	0.708
09.00	1.4510	1.458
10.00	3.7030	3.763
11.00	0.2010	0.212
12.00	0.1902	0.197
13.00	11.704	12.172
14.00	13.377	13.915
15.00	10.028	10.410
16.00	7.651	7.942
17.00	3.676	3.821
18.00	0.872	0.902

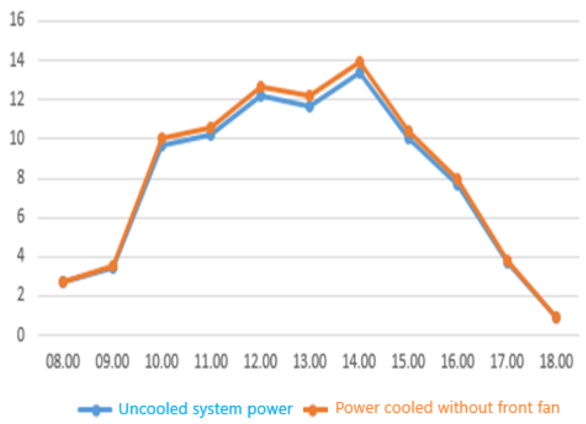

Figure 12. Uncooled system power compared to cooled power without using a front fan

Figure 12 shows that the effect of the front fan on the system efficiency is around 4.01%. While 4.77% efficiency was measured when the front fan was included in the system, 4.01% efficiency was measured when the front fan was disabled. According to the data collected, it is observed that the front fan also contributes to the efficiency increase of the system.

4. Conclusions

In this study, the effect of the fan cooling system on the power parameters of the photovoltaic system, which is widely used in power generation plants as an alternative energy source today, was investigated. In addition, PV panel data were printed to the cloud system and the system was analyzed and the necessary reports were provided over the cloud using IoT (Internet of Things) technology. In this sense, it has been shown that appropriate monitoring, installation, and operating conditions increase the efficiency of solar power plants. With the help of IoT and Thingspeak, instantaneous monitoring and live tracking of solar panel parameters have a beneficial effect on the power performance of the system. In the findings, an increase of approximately 4.77% in PV efficiency performance was observed with the tests involving air cooling with a fan. 4.77% may be relatively lower than the values in the literature, but the simplicity and low cost of the designed hardware are important in terms of the efficiency achieved. As a result, the designed system offers an innovative approach by being integrated into the Internet of Things can be monitored remotely, and provides an increase in panel power efficiency.

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