Study on PV Panel Cooling System using IoT with ESS for Preventing Reduced Efficiency of Solar Panel

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Abstract Solar photovoltaic systems are renewable energy sources that are used around the world. However, one of the causes of reducing the efficiency of solar systems is the temperature increasing in solar panels. To prevent this phenomenon, a cooling fan can be installed on the back side of the solar panel. The solar system efficiency also decreases due to weather conditions and unexpected situations. To overcome this problem, an IoT (Internet of Things) system was used to monitor the state of the solar system and control the cooling fan. The core microprocessor used in IoT systems was Arduino. Using Arduino, an IoT system can be implemented simply and economically. Also by following the paradigm of using ESS (Energy Storage System) smartly, we can use long-lived supercapacitor to operate the fans. The entire system was designed and tested and the efficiency increased by approximately 4.7%. Although it is a small 30W capacity photovoltaic system, its efficiency is expected to be increased by applying it to a photovoltaic system of more than 1kW in the near future.

1. Introduction
Encapsulation alters the heat flow into and out of the PV module, thereby increasing the operating temperature of the PV module. These increases in temperature have a major impact on the PV module by reducing its voltage, thereby lowering the output power. Recent studies have shown that the efficiency of an amorphous silicon cell decreases by 0.05% for every 1 °C increase in temperature and in the case of a crystalline silicon solar cell, the decrease ranges from 0.4% to 0.5% [1]. As shown in Figure 1, the output power decreases with increasing temperature.

![Figure 1. Solar panel output power with temperature change](image-url)
Although the temperature differs according to the season and location, the temperature of a solar panel is usually highest in summer [2]. Various solutions have been proposed to prevent the efficiency decrease due to such a temperature rise. There are various methods to deal with efficiency problems, in this study, we choose the cooling fan method. The cooling fan is turned on and off automatically by the temperature of the solar panel. On the other hand, operating the cooling fan in the event of clouds or inverter failure is inefficient. Therefore, in some situations, real-time remote control is needed.

And if we can apply ESS in the setup (Even we haven’t yet) to operate fans, we can check the battery level in real time, in some case with needs, use electric energy from panel directly to charge it.

It will help to simplify the energy managing algorithm. And If we use supercapacitor for it, we will see the positivity even not to care about life time of all device setup cause of batteries’ long life time.

To implement such a system, an operating system based on the IoT (Internet of Things) is required. The IoT is an ecosystem of connected physical objects that are accessible through the internet. This is next generation technology that will soon be applied to society. [3] The IoT refers to the technology or environment, in which sensors are attached to transmit data to the Internet in real time. [4-5] Based on the IoT, the temperature of the solar panel can be controlled anytime and anywhere through a smart phone. In this paper, the ultimate goal is to automatically control the temperature of the solar panel using an IoT system.

2. Devices and Methods
The devices used in this experiment were divided into three parts. First, it receives the temperature data through a temperature sensor as the main control part, activates the relay through an external interrupt, and controls the overall system operation. The second is the solar panel part. This part receives the signal from the relay and activates the cooling fan installed on the back of the solar panel. The final is a smart phone application part that allows the users to monitor solar power system states and control the cooling fan whenever and wherever. The parts and mechanisms of each of these three parts have been described.

2.1. Control part
This part receives the various data values as the main control part and transmits the data to the server in connection with the internet network. This also activates the cooling fan on the back of the solar panel through an external interrupt. The microcontroller used was the Arduino Mega2560. This device was optimized to implement the IoT and is economical and can be interworked with a range of sensors. A WIFI shield (JSN270) for implementing the IoT was also used.

The power to operate the Arduino was obtained from an internal power source produced from a solar panel. The power consumed by the control part was 1.12 W. Figure 2 shows the internal view of the control box. In the center, there are the Arduino and WIFI shield as well as converters, current sensors, and relays around.

![Figure 2. Inside control box with Arduino and WIFI shield](image)

Arduino controls the system via the flow diagram below. The cooling fan turns on automatically when the temperature of the solar panel exceeds 40 °C and when there is no cloud. Figure 3 presents a flow diagram of this system.
2.2. Solar panel part
This part consists of a cooling fan and a solar panel. Four cooling fans are installed on the back of the solar panel. This is arranged in a regular Square arrangement for efficient cooling. Four cooling fans consume 360mW of power. The Arduino controls the cooling fan through the relay on/off operation. The solar panels had a 30W capacity for testing and were fixed at an optimal angle of 35 degrees, to maximize the solar energy. In addition, an infrared temperature sensor was attached to the back of the solar panel to monitor the temperature of the solar panel in real time. Figure 4 shows the four cooling fans attached to the solar panel.

![Figure 3. Flow diagram of this system](image)

![Figure 4. The back of the solar panel with four cooling fans](image)

2.3. Smart phone application part
This system does not allow people to go directly to the solar panel to turn the cooling fan on or off. The cooling fan should be controllable at anytime and anywhere. To implement this, control using smart phone application is essential. Open source software, called App Inventor 2, was used to develop apps. This is not only easy to make, but also available for free. An essential element to this application is the part that can monitor the sensor values received from the Arduino and the button part to control the cooling fan. Figure 5 presents the designed application and the source used in App Inventor 2.
3. Experimental Setup
Each component was designed and assembled to produce a model for the experiment. The experiment was carried out from 09:00 to 18:00 in clear, cloudless weather. The location was Pusan National University, Busan, Korea (31.040 N, 31.486 E), building number 207 on the roof, and the experiment date was around September 2017. The angle of the solar panel was maintained at 35 degrees, and the direction of gaze pointed to the south. An infrared thermometer was used to measure the temperature of the solar panel. A VT04A visual IR thermometer (FLUKE, Everett, WA, USA) was used. Model A without a cooling fan was compared with model B with a cooling fan. The system connected to the network for monitoring and remote control of the cooling fan. Figure 6 shows the layout.

4. Results and Discussion
The solar panel was fixed in a suitable wide area and the experiment was then conducted. At the beginning of the experiment (09:00 ~ 10:00) and at the end (16:00 ~ 17:00), the output power was similar because the temperature difference between the two solar panels was small. On the other hand, from 11:00 to 15:00, when the temperature difference of the solar panel is large, the solar panel with the cooling fan showed a higher output power than the solar panel without the cooling fan. The difference in the output power reached a maximum at 13:00 when the temperature difference in the solar panel reached its maximum. Figure 7 (a), (b), and (c) shows the solar panel temperature, ambient temperature, and output power over time.
Figure 7. (a) Solar panel temperature (b) Output power of solar panel (c) Ambient temperature

The output power graph shows that the output power can be determined using this system from 11:00 to 15:00. At that time, the increase in efficiency of the output power was approximately 4.7%. This value can change depending on the season and weather. On the other hand, it is practical to use the IoT system to control at any time and place. Moreover, a higher power may be obtained by applying it to a large-capacity PV system rather than to such a small-capacity PV system.

5. Conclusion

The solar PV system becomes less efficient as the temperature of the solar panel increases. In particular, the temperature of the solar panel increases by more than 40 degrees during the daytime (11:00 ~ 15:00). Therefore, a cooling fan was installed on the back of the solar panel to increase the output power. On the other hand, when weather and other incidents occur, the solar system efficiency becomes low. If the temperature can be checked in real time and the cooling fan can be controlled automatically, the efficiency can be improved again. Therefore, real time remote control through an IoT system was implemented to increase the solar power efficiency. The IoT system device used is a microprocessor called Arduino, which makes it possible to construct an inexpensive and simple system. This system is compatible with various sensors and can implement various functions. Finally, after designing the IoT system and solar system, a successful experiment was conducted. Using a 30W solar panel, the maximum increase in efficiency was approximately 4.7% and the power increased by 1.4W. As a result, the performance improvement of the cooling fan using IoT was confirmed. If the system is also applied to a large-capacity PV system, higher power affected by the cooling fans can be expected. Future studies will extend the system and apply it to a 1kW PV system with ESS based on supercapacitor.
6. Reference
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