A Combination of Maximum Power Point Tracking and Water Cooling System to Improve Performance of PV Panel

Le Hong Lam*, Vo Quoc Huy, Tran Anh Tuan, Nguyen Huu Hieu

Abstract— *In the present, concentrator photovoltaic was used to integrate the extraction of radiance and thermal energy. However, the temperature and the fluctuation of solar radiation have a negative impact on the PV panel since it reduces the performance of the PV panel. Therefore, a combination of the Maximum Power Point Tracking algorithm and the water-cooling system proposed in this study provides an effective solution to remove heat and track the maximum power of a PV panel. The experimental results were subsequently analyzed and compared to the power generation efficiency of the examined PV panel. The combination of a Maximum Power Point Tracking algorithm and a water circulation cooling system improves the power capacity of photovoltaic by 3% to 16%, even after accounting for the energy consumption of the cooling system. As a result, environmental protection energy savings, and increases in the efficiency of sunlight utilization can be achieved.*

Keywords— **Photovoltaics, maximum power point tracking, water cooling system, saving energy.**

1. INTRODUCTION

Recently, renewable energy systems have experienced rapid growth throughout the world and a number of renewable energy industries such as solar and wind power have grown at a steady rate about 20% per year or more. The addition of renewable energy diversifies energy sources and helps address climate change. Therefore, renewable energy provides important alternative energy sources to promote sustainable development. In recent years, due to the volatility of international oil prices as well as the rapid increase in coal prices, the development of renewable energy has attracted widespread attention in many countries and has become the focus of the international energy sector. Currently, many developed countries, including Vietnam, have invested in research and development of renewable energy sources. The development of renewable energy sources promotes energy security, reduces environmental pollution and minimizes energy depletion.

In fact, there are two main issues which can impact on the power generation of a PV panel: (i) the sudden variation of solar radiation, and (ii) temperature.

Here, in order to overcome the sudden variation of the solar radiation, many Maximum Power Point Tracking (MPPT) algorithms has been proposed such as Constant voltage [1], Perturb and Observe (P&O) [2], Incremental Conductance [3], and Temperature based [4]. In Table 1, the summarize of some main points of these algorithms is presented.

Table 1. The summarize of MPPT algorithms

MPPT algorithm	Main points
Constants Voltage	- One voltage sensor; - Simple; - The accuracy extremely depend on the temperature.
Perturb and Observe	- Two sensors (voltage and current); - Low tracking speed; - Wrong tracking in rapidly changing atmospheric conditions.
Incremental Conductance	- More complicated than Perturb and Observe; - Fast tracking speed and independent with environment; - Very low oscillation around Maximum Power Point (MPP).
Temperature based	- The output photovoltaic voltage is proportional to the temperature; - The current sensor is replaced by a temperature sensor; - Unifying the simplicity of implementing constant voltage method with Incremental Conductance tracking speed and accuracy; - Only the temperature is taken into account here, so the rapid change of radiation is taken out of the algorithm and the monitoring tends to become more stable.

From the Table 1, the two MPPT algorithms which need to be investigated and compared are Perturb and

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Observe (P&O) and Temperature Based (TB) because they are easy to implement, thus the real application is potential. However, the basic idea of two algorithms are different since one (P&O) depends on voltage and current sensors, and the other needs temperature and voltage sensors. Therefore, in this paper, two algorithms are investigated in terms of different level of solar radiation.

One of the main issues of PV panel is the effect of temperature leading to the reduction of electrical performance [5]. Many researchers have considered centralized modules as an approach to improve the generation efficiency of photovoltaic [6]; however, the use of centralized devices that drastically increase the temperature of the photovoltaic affects the effectiveness of photovoltaic power generation or damages the solar cell and associated power generation systems. In paper [7], the primary study of the cooling system for the PV panel is presented. Moreover, paper [8] summarizes and compares different types of cooling systems used in a photovoltaic system such as air-based cooling systems, liquid-based cooling systems, heat pipe-based cooling system and PCM (Phase Changed Material) based cooling system. The conclusion of this study proved that the water-cooling system is the best among those cooling systems. Moreover, this conclusion is proofed by paper [9] when making a comparison between three cases: (i) air-cooling system, (ii) water-cooling system, and (iii) combination between air and water cooling system.

Eventually, the main contribution of this paper is that comparing two different MPPT algorithms in term of different level of solar radiation, and then a combination of MPPT algorithm and water-cooling system was used for centralized photovoltaic cooling to enhance their generation efficiency and reduce damage to solar cells and system generation. The study is experimented in the Vietnam environment condition and shows the efficiency of the cooling system in enhancing the power generation with different temperatures of the environment.

The paper is organized as follow: Section 2 presents the mathematical part of two MPPT algorithms, Section 3 will show the cooling system and the algorithm to cool down the temperature of PV panels. The results of the test will be shown and discussed in Section 4 with different temperature ranges.

2. MATHEMATIC MODEL OF P&O AND TEMPERATURE BASED MPPT ALGORITHMS

2.1 Mathematical equation of PV

Mathematically describes the I–V characteristic of the ideal PV cell is

$$I = I_{ph} - I_0\left[\exp\left(\frac{V + I.R_s}{V_T}\right) - 1\right] - \frac{V + I.R_s}{R_p} \qquad (1)$$

where:

I_{ph} - the light-generated current or photocurrent (A)

I_0 - reverse saturation current (A)

$V_T = \frac{N_s.k.T_{PV}.a}{q}$ - the thermal voltage of the array with N_s cells connected in series

a = 1.2 - the ideality factor Si-mono

$q = 1{,}6.10^{-19}$ (C) - the electron charge

R_s and R_p are the series and shunt resistors of the cell

The generated photocurrent I_{ph} is related to the solar irradiation by the following equation:

$$I_{ph} = \left[I_{SC}^{STC} + K_I\left(T_{PV} - T_{PV}^{STC}\right)\right]\frac{\lambda}{\lambda^{STC}} \qquad (2)$$

where:

I_{SC}^{STC} - short-circuit current of PV in standard conditions(STC 25°C, 1000W/m^2)

K_I - Temperature coefficients of I_{SC}

T_{PV} and T_{PV}^{STC} are operating temperature of PV and temperature in STC

λ and λ^{STC} are the irradiation on the device surface and the irradiation in STC

The saturated current of the PV varies with the temperature of the photovoltaic cell

$$I_0 = I_{0n}\left(\frac{T_{PV}}{T_{PV}^{STC}}\right)^3\left[\exp\frac{E_\lambda\left(\frac{T_{PV}}{T_{PV}^{STC}} - 1\right)}{V_T}\right] \qquad (3)$$

I_{0n} - the nominal saturation current (A)

$E_\lambda = 1{,}12$ (eV) Band gap of the mono-crystalline Si at 25°C

2.2 Perturb and Observe Algorithm

P&O algorithm in Fig. 1 works based on taking the value of the voltage and current sensor and comparing the two values of P and V compared with the previous time to find MPP.

The MPPT controller will measure the values of current I and voltage V, then calculate the deviations ΔP, ΔV and check:

• If $\Delta P.\Delta V > 0$ then increase the value of the reference voltage V_{ref}.

• If $\Delta P.\Delta V < 0$, the value of the reference voltage V_{ref}. decreases.

Then update the new values instead of the previous values of V, P and conduct measurements of I and V for the next working cycle.

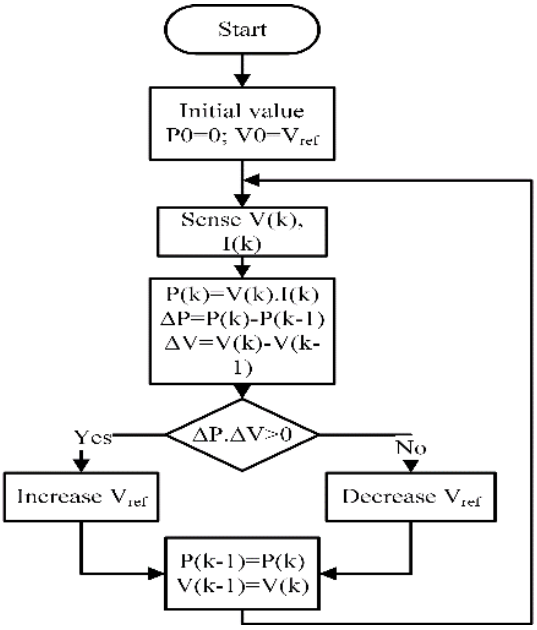


Fig. 1. P&O algorithm diagram.

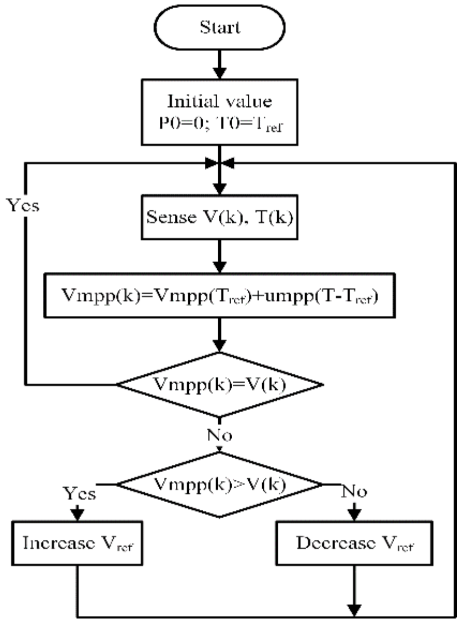


Fig. 2. Temperature based algorithm diagram.

2.3 Temperature based

The TB algorithm in Fig. 2 does not use a current sensor instead of a temperature sensor. After taking the value of the voltage sensor and the temperature then calculating V_{mpp}.

The position of the MPP is establish through equation

$$V_{mpp}(T) = V_{mpp}(T_{ref}) + u_{mpp}(T - T_{ref}) \quad (4)$$

where:

$V_{mpp}(T)$ - Maximum power point voltage at a given temperature

$V_{mpp}(T_{ref})$ - Maximum power point voltage at the reference temperature T_{ref}

u_{mpp} - Temperature coefficient of V_{mpp}

T - Measured temperature

T_{ref} - Reference temperature

The MPPT controller will measure the values of voltage V and temperature T, then calculate the V_{mpp} and check:

- If $V_{mpp}(T_{ref}) > V(k)$, then increase the value of the reference voltage V_{ref}.
- If $V_{mpp}(T_{ref}) < V(k)$, the value of the reference voltage V_{ref} decreases.

Then update the new values instead of the previous values of V, P and conduct measurements of I and V for the next working cycle.

3. A COOLING SYSTEM FOR PV PANELS

3.1 Introduce method of cooling the PV panels by water

First of all, cold water is automatically pumped into the inlet tank. The water in the inlet tank is then pumped through plastic pipes into the water circulating system of the photovoltaic. After absorbing heat from the photovoltaic panel, hot water from the cooling system flows back to the return tank through the plastic tube. The water level in the returning tank will continuously increase until it meets the threshold of the circulation pipe between the inlet and the return tank. The whole process forms a water-cooled system.

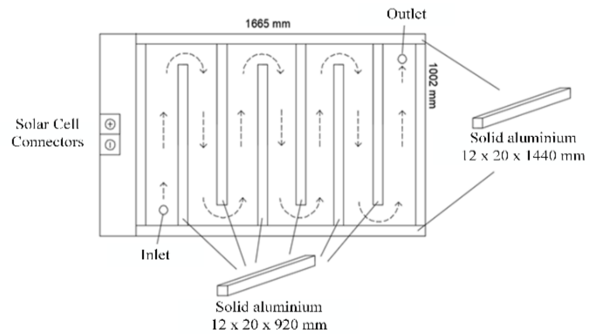
Fig. 3. Cooling system.

3.2 Diagram of the structure of the cooling system components

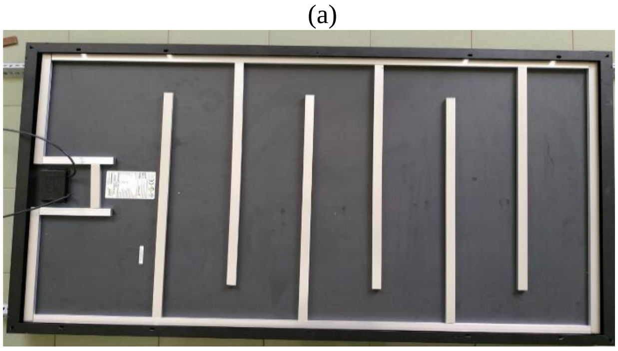
The cooling system is shown in Fig. 3 and the structure diagram consists of two main parts: (i) the converter box is the main controller of power distribution, sensors and the main operation of the entire system; and (ii) the cooling system contains the storage tanks, including the inlet and back tanks. Here, a motor is used to pump water from the inlet tank, circulating through photovoltaic panel. After cooling PV panel, the hot water returns to the tank again.

Regarding the flow operation of the cooling system, it can be divided into 2 parts, including: (i) circulation and (ii) pump/drainage components:

- **Part 1:** Recirculating components: Temperature Setting (TS) of contact temperature controller, input tank, and return tank are set, and the cooling system is started. The Actual Measured Temperature (AMT) is compared to the setting temperature. If AMT > TS, the water pump will be turned on, start circulating water cooling. Water flows through the PV panel and is transported to the tank again. Works continuously to remove heat from the PV panel;
- **Part 2:** Pumping/Draining components: The solenoid inlet valve is connected to a hose to facilitate water entering the system. When this valve is turned on, water is automatically pumped into the inlet tank. If the water level in the input tank is higher than the ball float of the water level switch of the inlet tank, the water level switch of the inlet tank will automatically turn on to stop the solenoid valve supply and to prevent further pumping of water into the head tank. to enter. If the rod temperature sensor in the tank detects that the PV of the tank is higher than the SV, water with sufficiently high temperature has been collected, the electromagnetic solenoid valve will be opened to automatically flush the tank.



(a)



(b)

Fig. 4. Flow diagram on the back of PV panel: (4a) design and (4b) real device.

3.3 Flow diagram of the water behind the PV panel

A cooling device is installed on the back of the PV panel in Fig. 4 to make installation easier. Aluminum rods are fixed on the back of the panel to control the direction of water ow, to allow water to ow evenly across the PV panel when pumping water.

3.4 Proposed cooling algorithm

The temperature of the PV panel is taken from the panel via a thermal sensor attached to the underside of the PV panel and transfer signals to the control system. Depending on the ambient temperature and the temperature of the water from time to time, we can flexibility adjust how much the temperature will activate the cooling system and stop the cooling system. In this algorithm, we choose the threshold when the panel temperature (AMT) reaches the value of TS, then starting the cooling system.

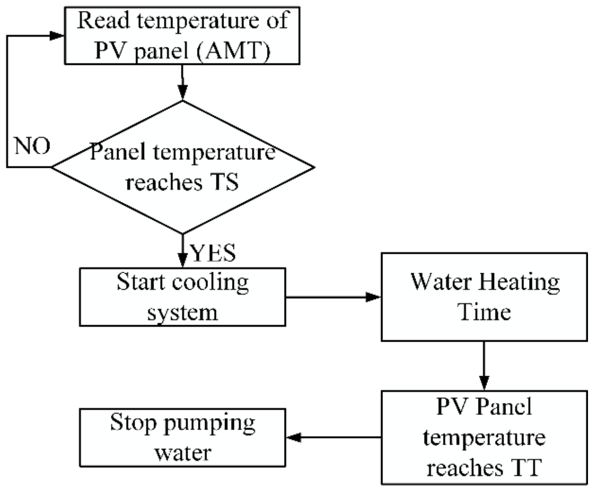


Fig. 5. The algorithm flowchart of cooling system.

The water heating time can also be calculated by the Average Pump Speed (APS) of the water pump because the Total Volume (TV) of water in the water-cooling system is known in advance. Therefore, the time required for water to enter the water-cooled system, ow through the system, and exit the system can be calculated as follows:

$$\frac{TV[l]}{APS\left[\frac{l}{min}\right]} = t[mins] \tag{5}$$

Explaining the algorithm: The temperature of the panel is measured through the temperature sensor that transmits the signal to the control system. If the panel temperature is greater than or equal to TS, the cooling system is started, after approx. time about t minutes is the time for the water pump to fill the back of the panel, then stop pumping, after the temperature of PV panel reaches the Threshold Temperature (TT), the commune has absorbed the heat, the heat exchange takes place will reduce the temperature of the PV panel, until the temperature of the panel rises to TS, the cooling system is restarted.

4. SIMULATION AND EXPERIMENTAL RESULT

First of all, the model of MPPT algorithm based on P&O and TB is developed in MATLAB [10] to compare two these algorithms. The basic blocks in the simulation diagram is shown in Fig. 6:

- The block creates the solar radiation and the input temperature of the PV panel;
- PV panel;
- Buck converter before the panel is connected to the load;
- Maximum Power Point Tracking algorithm. Here, the model is using P&O and Temperature Based algorithm.

The model is tested with a PV panel with a data-sheet in Table 2, then the real PV panel with the same data sheet is used for an experimental test in the real application. First of all, a comparison between the MPPT algorithm based on P&O and TB is investigated. Next, the impact of the cooling system is simulated in MATLAB/Simulink and a real MPPT and cooling system are implemented for an experiment test within Vietnam environment condition.

Table 2. Data sheet of the PV panel

P_{max}	315 W
V_{mpp}	33.2 V
I_{mpp}	9.49 A
VOC	40.7 V
I_{sc}	10.04 V
NOCT	45 ± 2^0C
Temperature range	-40^0C ~+ 85^0C

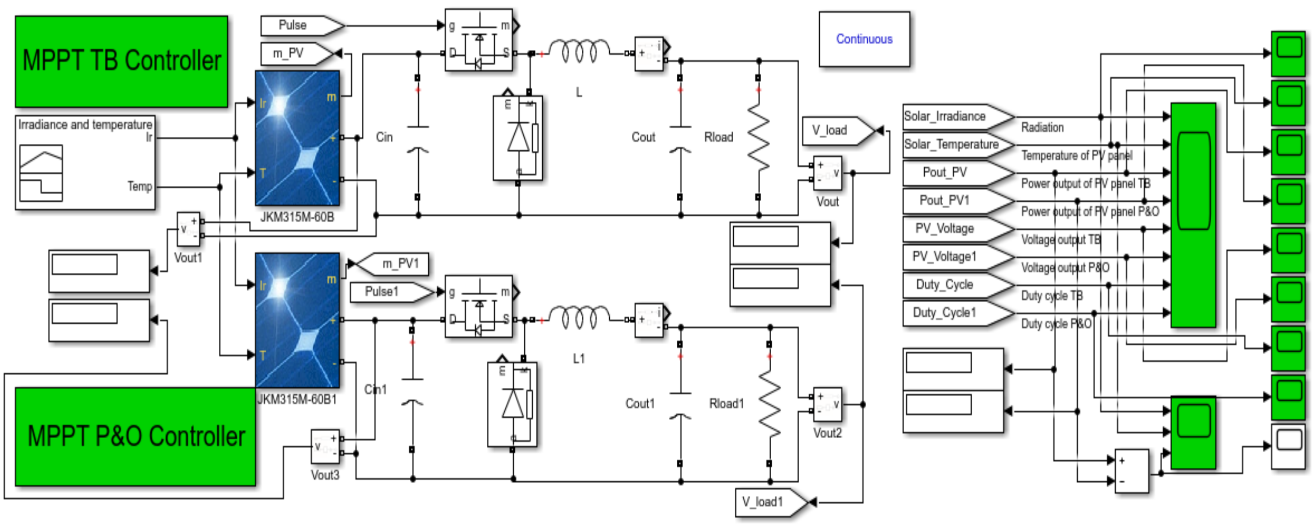


Figure 6: Modules to Comparative of MPPT algorithms based on TB and P&O.

4.1 Compare the TB algorithm and the P&O algorithm by simulation in MATLAB/Simulink

In this simulation, the input data of PV is shown in Fig. 7 including solar radiation in Fig. 7a and temperature in Fig. 7b as following:

- From 0s – 1,5s: 1000 W/m^2
- From 1,5s – 2s: 1000÷200 W/m^2
- From 2s – 3,5s: 200 W/m^2
- From 3,5s – 4s: 200÷1000 W/m^2
- From 4s – 5,5s: 400 W/m^2
- Temperature data taken from a performance test measurement of PV is in the range of 51.56-51.69°C

Simulation results comparing the difference between the output power of 2 MPPT algorithms (TB and P&O) are shown in Fig. 8.

In Fig. 8 shows that when the radiation is stable at a high level (1000 W/m2), the TB algorithm given average output power higher than the P&O algorithm but not significantly about 0.5W. When the radiation is stable at a low level (200 W/m2), it is easy to see that the P&O algorithm provides an average output power higher than the TB algorithm of about 1W. During the transition period when changing from high radiation level to a low radiation level, the average difference line tends to decrease and equals about 520 W/m2, indicating that the TB algorithm does not correctly identify MPP with low radiation level.

From the simulation results, there is no big difference between the output power of the two algorithms. TB algorithm tracking MPP at higher radiation levels better than the P&O algorithm but not significantly. But conspicuously they give lower output power when at low radiation levels. So the P&O algorithm is used in later studies.

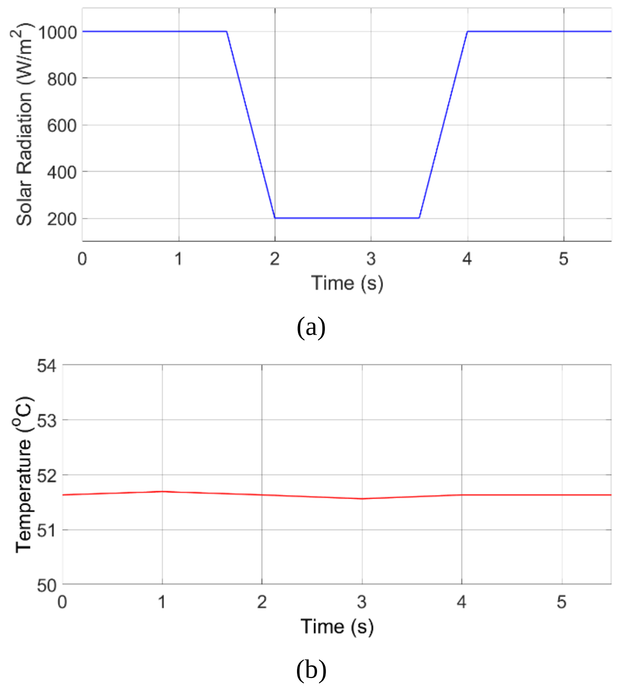


Figure 7: The input data of the simulation: (a) Solar radiation and (b) Temperature of the PV panel.

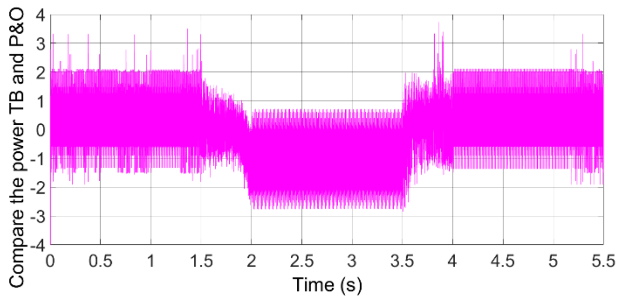


Figure 8: Simulation results compare the output power of 2 algorithms TB and P&O.

4.2 Result of the cooling system simulation

In order to evaluate the impact of temperature on the PV panel, the paper selects the radiation intensity of the sun remains constant at 1000 (W/m2) in Fig. 9a. Here, the change of temperature of the PV panel is shown in Fig. 9b, leading to the change of voltage and power in Fig. 10a and Fig. 10b. Here, TS of the cooling system is selected as 40^0C.

Temperature values change based on time in three ranges:

- **From 0s - 4s:** the time when the temperature of the PV panel (not cooling case) reaches 60°C;
- **From 4s - 8s:** the time when the temperature of the PV panel decreases from 60°C to 40°C after the cooling system is turned on;
- **From 8s - 16s:** the time when the temperature of the PV after cooling reaches the value of 40°C.

The PV Panel's temperature is inversely proportional to the output voltage, the higher the temperature, the lower the voltage.

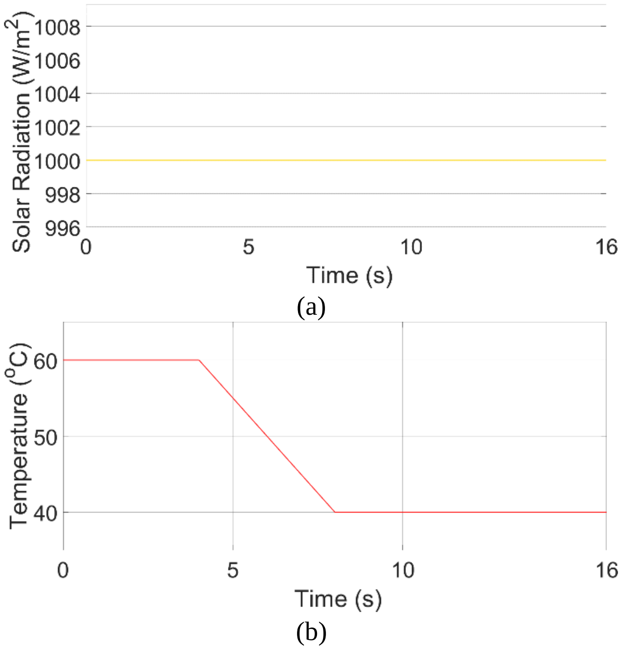


Figure 9: The input data of the simulation: (9a) Solar radiation and (9b) Temperature of the PV panel.

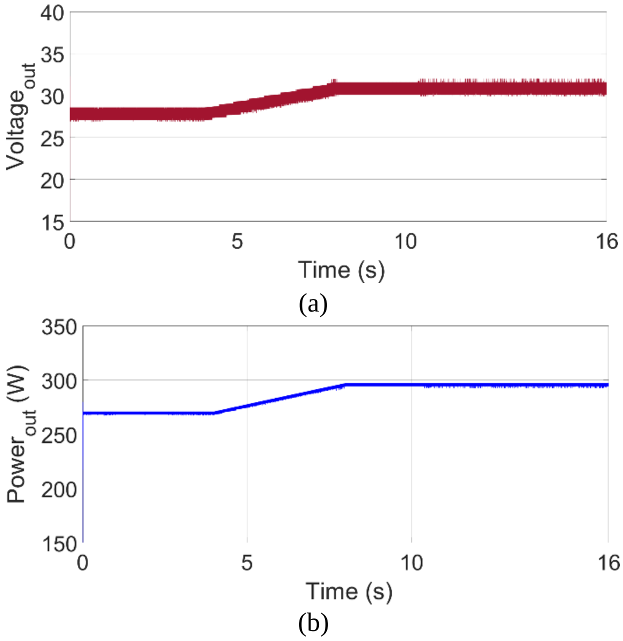


Figure 10: The output data of simulation: (10a) Voltage, and (10b) Power.

- **From 0s - 4s:** the period when the panel has not been cooled, corresponding to a temperature of 60oC, the output capacity of the battery is only 270W (85,714%);
- **From 4s - 8s:** the stage of the panel is in the process of cooling, because of the complexity of this stage, it will not consider the output capacity of the panel in this period;
- **From 8s - 16s:** the period when the panel operates stably after cooling, the panel temperature reaches 40oC, the output capacity of the panel reaches 294W (93.333%).

$$\frac{93{,}333\% - 85{,}714\%}{20°C} = 0{,}38\%/°C \quad (6)$$

4.3 *Actual experimental result*

The model is tested on 20th of December 2019, thus the temperature was not too high in comparison to summer. The maximum temperature of the PV panel was around 50ºC, then the paper uses the FORECAST function in Excel to estimate the performance of the cooling system with the temperature at 60ºC and 70ºC.

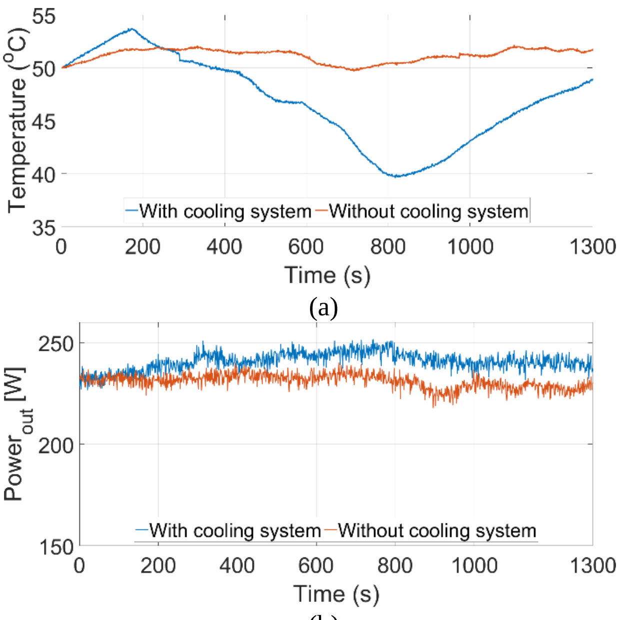


Figure 11: Temperature and generation power of two PV panels with and without cooling system: (11a) Temperature, and (11b) Generation Power.

Data collected during the period of one pump cycle 1358 seconds (about 22.6 minutes) from the time that the water pump starts operating once to before the water pump starts to run the second time. There are differences in the temperature display of the two panels:

- **From 0s - 240s:** The time when the water pump is full of PV panels;
- **From 240s - 1358s:** The time when water absorbs heat and is removed from the PV panel, the temperature of the cooling plate decreases sharply compared to the temperature of the non-cooled panel.

The formula is used to calculate the total power obtained:

$$A_1 - A_2 - A_{pump} = A_{save} \quad (7)$$

Where A_1 is the energy obtained from a panel with the cooling system:

$$A_1 = \sum P_i \times t_i = P_{eq}^1 \times \frac{t}{3600} = 240{,}6 \times \frac{1358}{3600} = 90{,}76[\text{Wh}]$$

and A_2 is the energy obtained from a PV panel without the cooling system:

$$A_2 = \sum P_i \times t_i = P_{eq}^2 \times \frac{t}{3600} = 230{,}7 \times \frac{1358}{3600} = 87{,}02[\text{Wh}]$$

A_{pump} is the energy obtained from a PV panel without the cooling system:

$$A_{pump} = P_{pump} \times \frac{t}{3600} = 15{,}6 \times \frac{240}{3600} = 1{,}04[\text{Wh}]$$

From these calculations, the energy saving with the cooling system is taken into account:

$$A_{save} = 90{,}76 - 87{,}02 - 1{,}04 = 2{,}7[\text{Wh}]$$

The performance of the PV panels is improved:

$$H = \frac{A_{save}}{A_2} \times 100\% = \frac{2{,}7}{87{,}02} \times 100\% = 3{,}1\%$$

So, in a cycle of operation of the system, it takes 1358 (s), the efficiency of the PV panels is improved by 3.1%.

From the date of temperature and energy of 2 cooling and non-cooling panels, extrapolation of FORECAST function in excel, we calculate the energy value of the non-cooling panel when the temperature reaches 60ºC, 70ºC is 218.34 [W] and 204.28 [W] in Fig. 12, respectively. We calculated the performance improvement at the temperature range of 60ºC, 70ºC, respectively: 8.93% and 16.4% in Table 3.

Table 3. Performance evaluations

Temperature	Efficiency
50^0C	3.1%
60^0C	8.93%
70^0C	16.4%

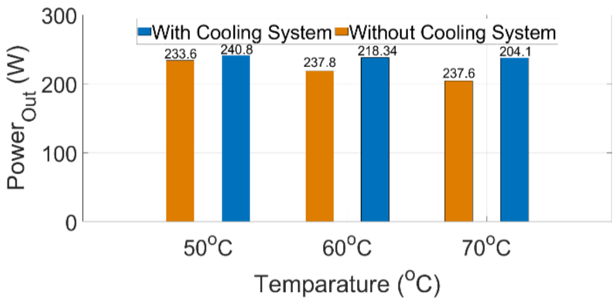


Figure 12: the generation power obtained with and without cooling system for each temperature range.

5. CONCLUSION

The paper found a way to solve the issue that occurs during prolonged operation of photovoltaic concentration under the sun which leads to a continuous increase in surface temperature. This increment in temperature reduces the efficiency of photovoltaic power generation or damage to PV panels and other aspects of the power generation system. Therefore, a cooling system based on water circulation was used to cool the heated surface of the PV panel and the hot water was stored in a storage tank. This approach maintains the generating efficiency of photovoltaic by cooling the solar cell which prevents the reduction in generating efficiency caused by the rapid rise in temperature in photovoltaic systems. The cooling system also reduces the amount of damage to PV panels and power generation systems due to rising temperatures. Advantages of the system:

- The reduction of the panel temperature in high temperature environments has significantly increased the photoelectric conversion efficiency;
- Contribute to increasing the life of the battery;
- Minimize risks for related electrical systems;
- Environmental friendliness.

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