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A wireless monitoring system for comparison photovoltaic and photovoltaic thermal characteristics

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Abstract. This paper proposes a prototype of a wireless monitoring system. It was employed to compare the electrical characteristics of two solar modules of the same type and size. One of the solar modules on the bottom side is mounted a copper pipe for circulating water (as call photovoltaic thermal). This system serves as a heat absorption on the bottom of the solar module. The experiment is conducted at the same time, place, and sunlight intensity conditions for both solar modules. The characteristics of open circuit voltage, short-circuit current, temperature upper side, temperature bottom side and the irradiation of sunlight from the two solar modules are observed. The low-cost processor, A Tmega 8535 is employed as an embedded system and Visual Basic.Net as Graphic User Interface. The collecting data is processed and displayed graphically. The wireless communication is applied to PC and ATmega 8535. The measuring data is validated to instrument standard. The test results show that photovoltaic thermal generates greater electrical power than solar modules not equipped with heat absorption.

1. Introduction

The massive utilization of fossil energy can lead to an energy crisis. One of the recent symptoms of the energy crisis is the scarcity of fuel oil, such as kerosene, gasoline, and diesel fuel. One solution that can be applied to resolve the problem is by not using the energy sources that derived from a fossil. Solar energy is an example of energy sources that are not derived from the fossil and produces clean and unlimited amounts of energy. Solar technologies exploit this energy to be consumed by customers varying from an individual, commercial, until industrial customers with many purposes such as generating electricity, lighting, running the machine, etc. The most solar technologies used by many people are heaters and photovoltaic.

The solar heater is working by converting the sunlight into heat energy and commonly used in the household to heat the water. Meanwhile the photovoltaic is known as one of the energy sources to produce electricity. This product is very popular since it can generate non - polluting energy. Previously, it was usually implemented in the area that far away from the electrical connection



utilities, but currently is widely used in many sectors of electricity network especially in the distribution network. [1].

PV converts solar energy into electricity with an efficiency between 5% to 25% [2], and unconverted energy is wasted as heat. With the amount of energy wasted into heat causes an increase in the working temperature of the PV cell. This has the effect of reducing the efficiency of electrical energy generated. In figure 1 can be shown that the higher the value of solar irradiance, the greater the power generated and the greater the temperature of the solar module the resulting power decreases. For that reason, the concept of "PV cooling" becomes consequently important in a photovoltaic generation [3-4].

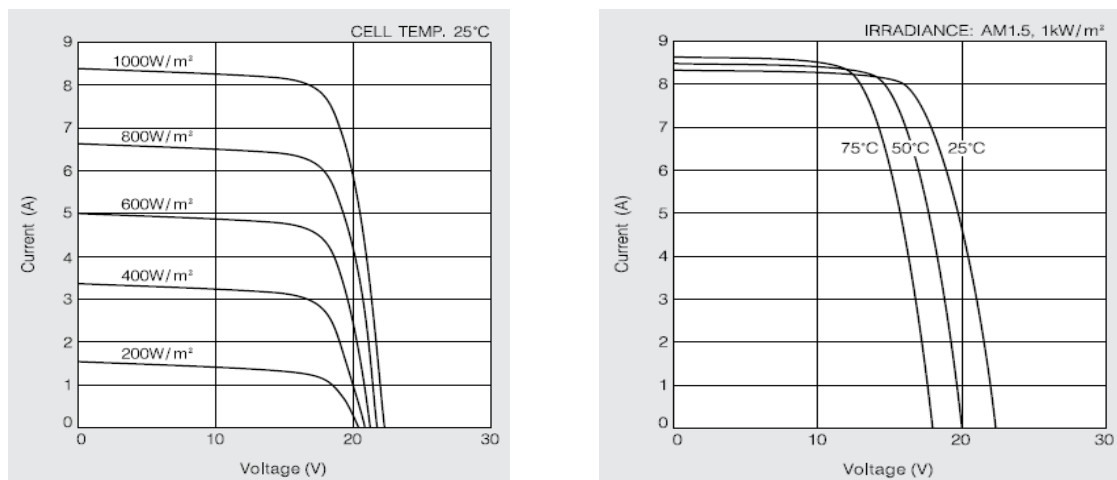


Figure 1. *I-V* characteristics of a PV cell array for KD135GX-LPU [5]

(a) for various irradiances S at 25°C

(b) for various temperatures T at 1000 W/m²

Combination of a PV module with a solar water heating module could be a perfect solution for the problem above. This method is developed to improve the characteristics of PV modules by draining the water under of the solar panel. Therefore, they not only convert the heat received from sunlight but also the heat produced by drained water. This technology is known as Photovoltaic Thermal (PVT). In this system, the use of external resources for water heaters can be eliminated, because it absorbs the heat produced around the solar modules and it also can reduce the temperature around the PV modules.

A lot of research has been carried out regarding the technologies used to develop a combination of PV modules and solar water heater due to the many benefits obtained from this technology. It can produce electricity and heat at the same time. The idea of PVT was firstly invented 1950 by [3], and then it got along reviewed. But, in the 2000s, this technology gained serious attention and got deep reviewed by [4-9] until they could develop and optimize it to be implemented in the electricity system.

In this paper, a prototype of an embedded monitoring system for characteristic comparison between the PV module and PVT module. A prototype has been designed with ATmega 8535 microcontroller and verified through experiment. The Visual Basic.Net was implied to interface between PC and user. The serial communication Bluetooth HC-05 was employed to the wireless system.

2. Photovoltaic-Thermal

PVT is well known as hybrid solar cell because of it can change the solar energy into electrical and heat energy. It is constructed by combining the PV and solar thermal modules. The PV modules are located at the upper side, and the solar thermal is put down at the bottom side. The function of the PV module is

to convert the solar energy into the electricity meanwhile the solar thermal module serves to absorb the heat produced around the module toward absorbent plate [10-11].

A liquid is employed to absorb heat. Various liquids can be implied as heat absorbance such as water, liquid nano-fluid, coconut water, palm oil, sugarcane water, etc. this liquid is drained through a copper pipe attached to the bottom of the solar module. The copper pipe is in direct contact with the solar module. Due to this direct contact, there was heat transfer from high temperature to low temperature. High-temperature solar modules provide heat to a copper tube filled with liquid that will absorb heat from the solar module [12-13].

The arrangement of copper pipes which are drained by the heat absorbing liquid can be either series or parallel connected. A pump can be added to this system to accelerate fluid circulation so that the heat absorption process is more efficient. A typical water PVT collector is shown in figure 2 [14].

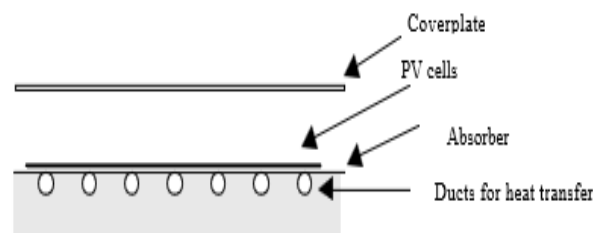


Figure 2. A typical water PVT collector

PV-actual conversion efficiency in working environments is a parameter that needs to be considered for PVT collector performance evaluation. This parameter affects the electrical energy generated. The magnitude of the potential of electric energy generated can be explained by a ratio of comparison of power generated by multiplying the amount of solar irradiance with the cross-sectional area of the photovoltaic module surface. This can be explained by the following expression: [15]

$$\eta_{MOD} = \frac{P_{MOD}}{I_t \times A_{MOD}} \quad (1)$$

Where η_{MOD} is the module efficiency; I_t is the solar irradiance on the module (W/m^2); P_{MOD} is the power generated by the module (W); A_{MOD} is the cross-sectional area of the photovoltaic module surface to the Sun (m^2).

Standard Test Condition (STC) is engaged in measuring the efficiency value of a PV module (). This is conducted at irradiance appeared in the front side of the module which is $1000 \text{ W}/\text{m}^2$, cell temperature of 25°C , and solar cell spectrum corresponding to air mass (AM) of 1.5. But this measured result () can be different if it is tested in real working conditions and open area with the real meteorological parameters are involved even though it is conducted in the same PV module.

There are several parameters used to determine the value of as follow: The incidence angle of solar irradiation on the module; the composition of solar spectrum; the operational temperature of the solar cells; and the type and material of solar cells [16].

3. PV and PVT monitoring system

The PV and PVT monitoring system is designed to collect data and display their characteristics. The data are temperature on the upper side and bottom side of PV and PVT modules, short-circuit current, open-circuit voltage, the irradiance of sunlight.

The prototype of PV and PVT monitoring system is developed using an ATmega8535 microcontroller. The ATmega8535 microcontroller plays a big role in collecting data to determine the PV and PVT characteristics. The Atmega 8535 microcontroller performs sampling of the output signal

sensor. The analog data from the output signal sensor is converted to digital through the ADC of the microcontroller. Digital data will be through the process of coding, so the data transmission of binary bits. The binary bit sequence will be sent to the Personal Computer (PC) via serial communication Bluetooth HC-05. PC through Visual Basic programming (VB) will perform data processing to be able to display the values and graphs of temperature, irradiance, voltage, current and so on the data is stored in the database.

Design of comparison PV and PVT modules experiment test can be shown in figure 3. In this figure, two PV modules put closely. They are the same brand, size, and power. The test is conducted at the same time and condition. A water pump is employed to water circulation. On initial condition, a water pump is on and flow the water to copper pipe. It conducts until all copper pipe water fulfills, then the pump and solenoid are off. In this state, copper pipe absorbs heat from PV module. When water temperature is more than 43°C , the solenoid and the pump are switched on, water flow to copper pipe.

Figure 4 shows the block diagram of the prototype PV and PVT monitoring system. A computer is used to present data and control the short-circuit current PV and PVT modules. For this purpose, the graphical user interface is developed using VB.Net, with features as graphical data display and able to save file data.

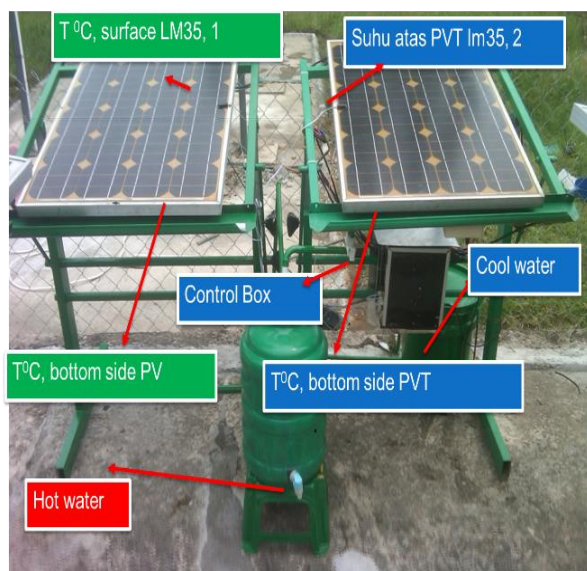


Figure 3. Design of experiment test.

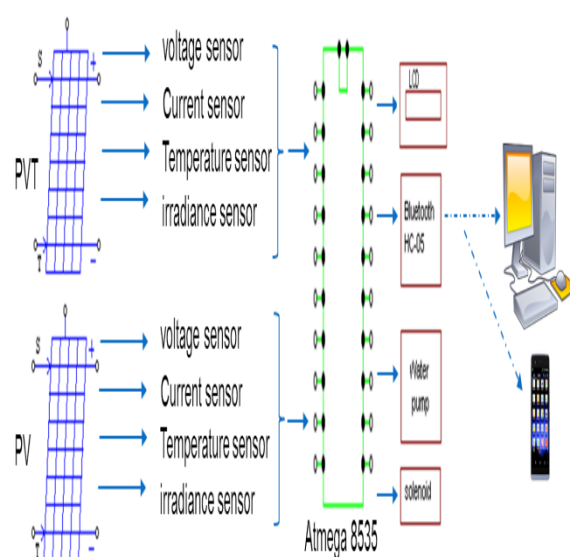


Figure 4. Diagram of PV and PVT monitoring system.

4. Experimental results

To verify the capability of PV and PVT modules monitoring system prototype is designed and tested using shell SP50 modules. These modules are mono-crystalline silicon solar cells. The electrical parameter of the shell SP50 module at STC is shown in Table 1.

Table 1: Specification of PV modules

| Specification | Rate |
|---------------|----------------|
| Pmax | 50Watt (Peak) |
| Voc | 21.6 Volt |
| Isc | 2.98 Ampere |
| Vmp | 17.6 Volt |
| Imp | 2.85 Ampere |
| Size (mm) | 835 X 540 X 28 |

Measurement results from the developed prototype are shown in the figure. 5. This form comprises graphics; the root means square of the measured parameter, a data table for the measured parameter.

To validate the measured parameter, they are compared to standard digital Voltmeter. The comparison results of the voltage sensor and Voltmeter is shown in figure 6. Comparison of open-circuit voltage for PV/T and PV module is shown in figure 7, comparison of short-circuit current PV/T and PV module is shown in figure 8. Meanwhile, comparison of irradiance, current PV/T and PV module and comparison of temperature differences (ΔT = temperature of PV/T upper side – water intake temperature) and heat transfer of the PV/T system (ΔQ) are shown in figure 9 and 10 respectively.

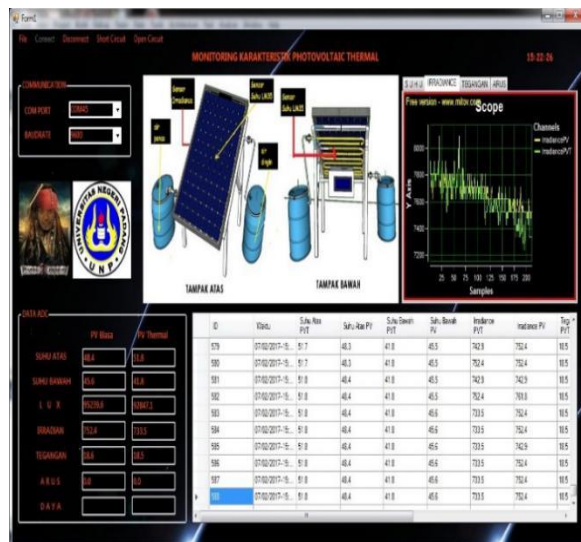


Figure 5. Interface Visual Basic of PV and PVT monitoring system

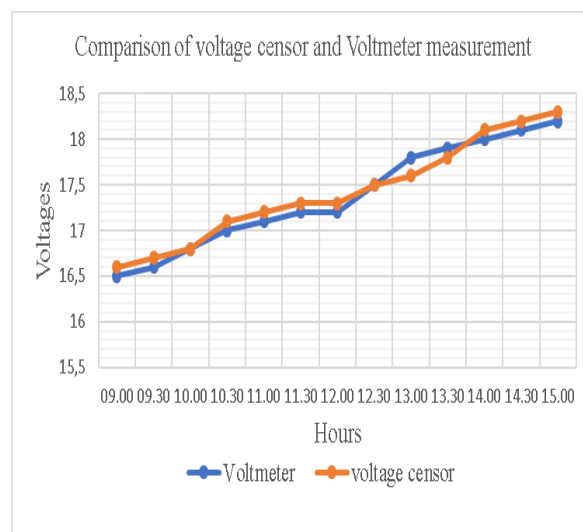


Figure 6. Comparison of the voltage sensor and Voltmeter measurement

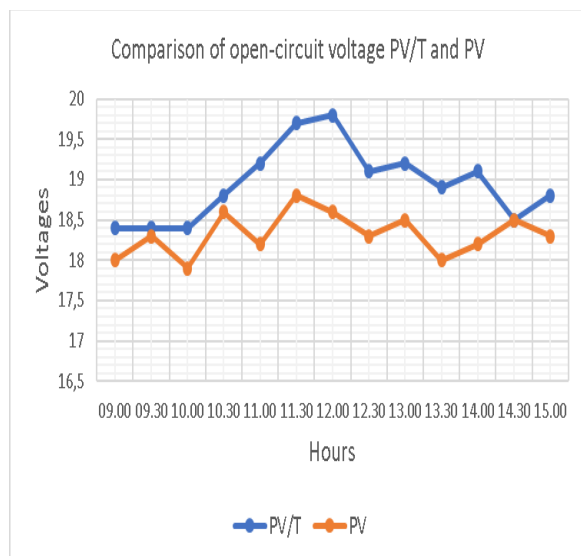


Figure 7. Comparison of open-circuit voltage for PV/T and PV module.

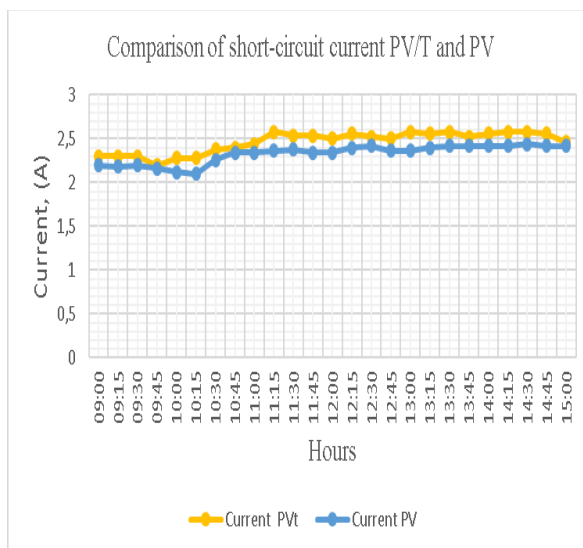


Figure 8. Comparison of short-circuit current PV/T and PV module

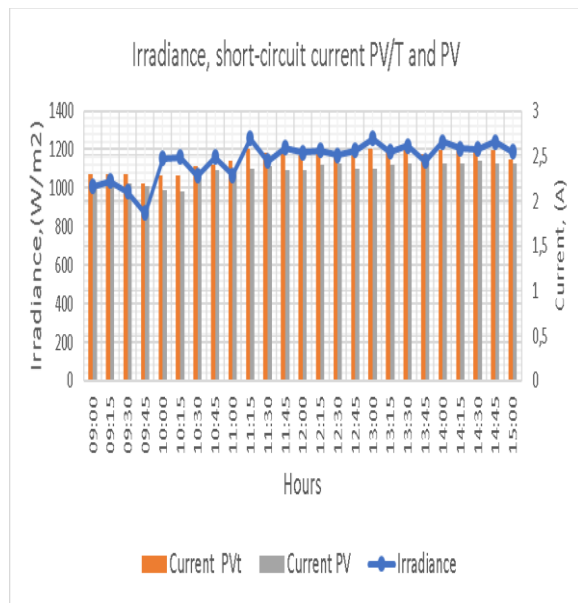


Figure 9. Comparison of irradiance, current PV/T and PV module

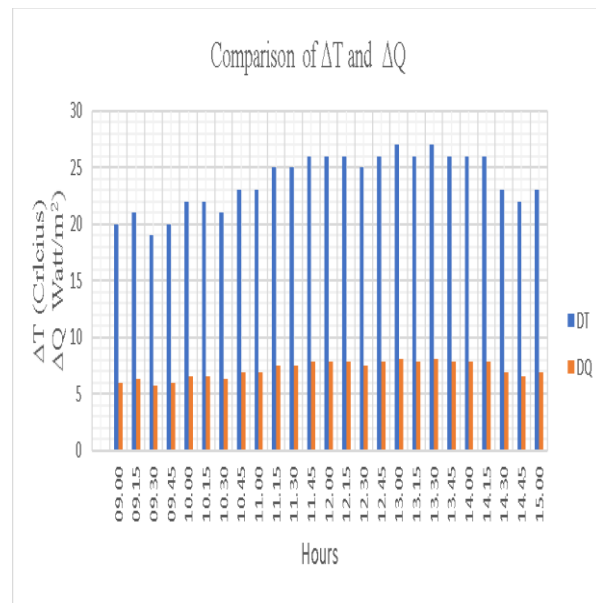


Figure 10. Comparison of ΔT and ΔQ

5. Conclusion

A prototype of a wireless monitoring system with Bluetooth has been designed and built. The low-cost processor, Atmega 8535 has been applied to collect data to comparison characteristics PV module and PVT module. The collected data are presented in software that has designed in Visual Basic. Therefore the graphic is more interactive. The programming algorithms of the monitoring system prototype have been implied in Atmega 8535. The Bluetooth HC-05 has been employed to communicate between PC and Atmega 8535. The experiment results have been verified by instrument standard that has been calibrating.

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