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Efficient Photovoltaic Module Intergrated with Automatic Cooling System using Arduino

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Abstract*: Solar photovoltaic-thermal (PVT) is an integrated system that produces both electrical and thermal energy simultaneously consist of PV module with heat extracting media for example water or air. The performance of the photovoltaic (PV) module depends upon the operating temperature of the PV module. The problem of non-uniform cooling of PV module can be solved by controlling the operating temperature of PV module systematically therefore, an automatic cooling system using Arduino integrated with PV module has been proposed. A theoretical model in term of heat transfer process analysis and simulation was developed to predict overall thermal-electrical conversion performances of Photovoltaic-Thermal (PVT) water system. The experimental validation of the used thermal and electrical model has been carried out by measured data. The result shows there is a good agreement between experimental and simulated results. This paper presents the electrical and thermal performance evaluation of Photovoltaic Module Integrated with Automatic Cooling System Using Arduino and comparing its performance with conventional solar PV system.

***Index Terms*: Solar Energy Photovoltaic(PV), Automatic cooling system, Arduino, Photovoltaic-thermal(PVT)**

I. INTRODUCTION

Nowadays, solar energy is considered as one of the important main sources of renewable energies. Photovoltaic (PV) systems and solar collectors are well known as systems used to utilize solar energy [1]. With the concern of global crisis on utilization of energy resources, photovoltaic-thermal (PVT) has gain more attention and become an important for research and development. The integration between solar photovoltaic (PV) and solar thermal systems are known as a solar photovoltaic-thermal (PVT). PVT systems are capable of converting solar energy into electricity and heat simultaneously. Conventionally, high electrical output is produced as high in incident solar radiation on PV module.

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However, the efficiency of the module is decreased as high incident also caused the temperature of the solar cells to increase [2]. Depending on type solar-cell at standard temperature and pressure, a solar cell can converts solar radiation to electrical energy with peak efficiency in the range of 6-15%. With increase of 1°C in temperature there is reduction of photoelectric conversion efficiency by 0.5% [3].

Depending on the medium used for collecting thermal energy, there are two types of PVT collector which is air-based and water-based. The water-based system are the air-based and water-based system are the combination of PV module with solar collector called as photovoltaic-thermal (PVT) water collector. PVT water collector have an important advantage over PVT air collector, as the latter requires a high volume of air flow to obtain good thermal efficiency. A PVT collector also provides several advantages over solar water collector where PVT doesn’t required external electrical power to circulate water. On the other hand, in a solar water collector, an external electrical power is required to pumping water. Combining both systems provided great advantages, such as transfers the additional heat of PV module to water.

With that background, the performance evaluation of a PVT water collector is important for utilization of PVT water collectors. The climatic, operating and design parameters including ambient temperature, solar radiation intensity, solar cell temperature, back surface temperature, inlet and outlet water temperature, inlet water flow rate and the length and width of PVT water collector will affect the performance of a PVT water collector depends on. The extracted water from PVT water collector can be utilized as a hot water that can be used for bathing and cooking [4].

A lot of research has been conducted regarding the performance of water-based PVT collectors. [5-8] study focused on such collectors, involved various designs of PVT water collectors; these were designed and their overall electrical and thermal performance was evaluated.Other studies [9-12], various types of PVT water collectors were also explored for improving the performance of PVT system. These included such adding an insulated material as a cover at the back in order preventing thermal losses to the surrounding. In addition, a study of PVT water collectors with numerical calculation dealing with the modeling and simulation of PVT water collector were presented in order to determine the effect of parameter such as temperature inlet of water, water flow rate and design of absorber. Fig. 1 shows the cross-sectional view of a PVT water collector.

In this paper a photovoltaic (PV) module integrated with automatic cooling system using Arduino was designed, and its electrical and thermal performance was analyzed through the validation of experimental results with simulation result.

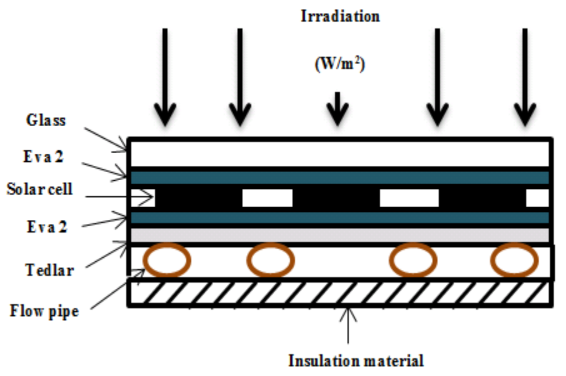

Fig. 1 The cross-sectional view of a PVT water collector

II. THEORETICAL ANALYSIS

In this paper, theoretical analysis is divided into two sections consist of thermal analysis and electrical analysis which has been discussed in mathematical model . By getting the performance result of thermal and electrical, the overall performance can be achieved.These analysis are then were validated using experimental works as explained in next section.

Thermal analysis

The thermal performances are evaluated from input data of solar radiation intensity (G), the inlet water temperature (Ti) and ambient temperature (Ta). In order to achieved maximum heat transfer rate between PV module and absorber pipe, the inlet water temperature must be keep below ambient temperature and the absorber pipe must be cover with insulated material, preventing heat loss to surrounding.. The thermal efficiency is calculated as a ratio of the incoming solar radiation on the PVT collector (Q1) and heat gain energy from PVT collector (Q2). The steady state efficiency is calculated by the following equation:

Q1=Apvt x G (1)

Q2=mCp(To-Ti) (2)

ɳth=Q2/Q1=mCp(To-Ti)/Apvt x G (3)

ɳth thermal efficiency [-]
Apvtcollector area [m2]
To collector outlet water temperature [°C]
Ti collector inlet water temperature [°C]
m mass flow rate [kg/s]
Cp specific heat [J/kg K]
G irradiance on the collector surface [W/m2]

The thermal efficiency of PVT collectors was conventionally calculated as a ratio of the temperature convection to surrounding (ΔT) and solar radiation intensity (G). The details equations are shown as following:

Tm=Ti-(To-Ti)/2 (4)

ΔT/G=(Tm-Ta)/G (5)

From the equation (5), Tm and Ta are the PVT collector mean temperature and ambient temperature respectively, and G is the solar radiation intensity on PV module. The transient thermal efficiency, nth is then expressed as:

ɳth=ɳ0-α1(ΔT/G) (6)

where ɳ0 is the thermal efficiency at zero-reduced temperature, and α1 is the heat loss coefficient. This research involve in selecting the type of absorber design. The different type of absorber design provides different performance. The Oscillatory flow design coil as shown in Fig. 2 is being used in the PVT water collector.

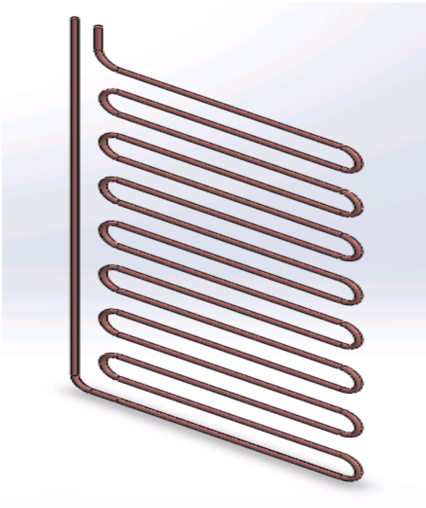

Fig. 2 Oscillatory flow design coil

Electrical analysis

The electrical performance of PV module is determined based on the operating temperature and incoming solar radiation. Measuring electrical output from PVT system is easy since the output can be use directly to the device and storage usage is optional. It is calculated with the following equation:

ɳel=ImVm/ApvtG (7)

where, Im and Vm are the current and voltage of PV module at maximum power.

For temperature-dependent, PV module electrical efficiency can be expressed as:

ɳel=ɳr(1-βT(Tc-Tr)) (8)

ɳel electrical efficiency
ɳr reference efficiency of PV module
βT temperature coefficient (0.0045°C)
Tc temperature of solar cells
Tr temperature

Overall analysis

The overall performance of PVT system can be expressed by combination of the thermal efficiency, ɳth and efficiency of electrical, ɳel. As PV module absorbs and converts the solar irradiation into electrical energy, fraction of it forms heat energy that will decrease the power output since the heat produce raise the PV temperature. The total efficiency, ηtot is used to express the overall efficiency of the PVT system:

$$\eta_{tot}=\eta_{th}+\eta_{el} \quad (9)$$

where ηth is the efficiency of thermal and ηel is the electrical efficiency. Overall performance of PV module strongly depends on the irradiation, operation temperature, working condition or weather and the module characteristics itself.

III. EXPERIMENT SETUP

The experiments setup has been carried out in a field area and consists of two PV modules, which being used for automatic cooling System and without automatic cooling system at the same time. Both PV modules are placed directly toward sunlight. The water-type PVT collector controlled using Arduino was constructed as shown in Fig 3(a)-(b). It was installed at the orientation of due south and a tilt angle of 40°. The PVT collector was made with a mono-crystalline PV module of 100W. Table 1 shows the technical specification of Solar PV module used in the experiment.

Fig. 3 (a) Front view of PVT water collector

Fig. 3 (b) Back view of PVT water collector

Table. 1 Technical specification of solar PV module

Subject	Specification
Maximum power (Pmax)	100 Wp
Voltage at maximum power (Vmpp)	18.17 V
Current at maximum power (Impp)	5.51 A
Open circuit voltage (Voc)	21.6 V
Short circuit current (Isc)	6.06 A
Power tolerance	+/- 3 %
Panel Dimension (H/W/D)	1196x541x35 mm
Cell Type	36 pcs , 125x15, Monocrystalline
Max. Operating Voltage	1000 V
Standard Test Condition	1000 W/m2, AM1.5 , 25°c

PV module able to generates electricity and absorbed the heats simultaneously causing the absorber to increase its temperature, this due to the PV cells in PV module are exposed the sun. At the moment, the water fluid passing inside the absorber pipe is heated due to the contact underneath the PV module. The water tank is fed with water that is flows along the absorber pipe. Water which is used as cooling agent flows at 0.01 kg/s continuously inside the hollow tubes.

The inlet and outlet at opposite end of the hollow tubes equipped the absorbers to ensure the trapped air in the absorber can be releases. The fresh and cooler water enters the hollow tubes is heated continuously which is considered to be a closed loop system. Hence,reduces the temperature of the PV cells and simultaneously increasing it efficiency.

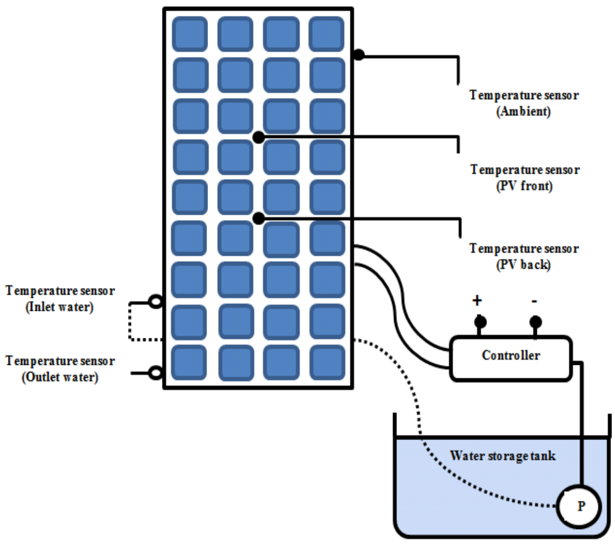

Fig. 4 The schematic diagram of experimental setup[13]

For this experimental set up, Arduino mega is used as a microcontroller for the automatic cooling system. Its function is to collect data from the temperature sensor and next process the data to start the AC water pump and start the cooling system accordingly to the temperature that has been set. The Arduino is to be programmed to set the minimum value of temperature to cut off the automatic cooling system and the maximum value of temperature to start off the automatic cooling system.

AC water pump is used as a mechanism for the PV cooling system.

The AC water pump is placed below the PV module to supply water to the cooling coil. When the temperature sensor detect the changes of heat from the PV within the range of 36°C and above that has been set, the pump will run automatically according to the maximum temperature that has been set. After that, when the temperature sensor detects the changes of heat within the range of 36°C and below, the water pump will automatically cut off and disconnecting it from the cooling system. The detail view of schematic experiment setup of controller with cooling system is shown if Fig. 4.

The module temperature, ambient temperature, water temperature, ambient radiation and open circuit voltage (Voc) and short circuit voltage (Isc) were recorded and analyzed. The experiment was carried out starting at 10.00 AM to 5.00 PM. The data were recorded every 1-hour cycle. The open circuit voltage (Voc) and short circuit (Isc) are measured using a Multimeter, as the module temperatures is measured using an Infrared thermometer and the ambient radiation is measured by using a data-logger. The instruments used to measure the value of parameters are shown in Fig. 5.

The table 2 shows the technical specification of instrument used in experiment.

Fig. 5 Instrument used in the experiment

Table. 2 instrument used in experiment

Instrument	Accuracy	Range	Model	Parameter measured
Solar power meter	±5 %	0– 2000 W/m2	TES-1 333R	Global radiation
Digital multimeter	±1 %	0-10V 0.01-10 A	Fluke 175	Voltage and current
IR thermometer	±2 °C	-18 to 275°C	Raytec MT2	Front and back temperature of panel

A 100W monocrystalline silicon PV module is being used as PVT water collector by integrated with thermal collector and controlled automatically using Arduino. In order to evaluate the energy gain, the concept of energy saving efficiency has been used on the PVT water collector. The following parameters have been chosen for the solar cells: ηref=0.15, βT=0.0045 °C-1, Tref=25 °C.

IV. RESULTS AND DISCUSSION

The outdoor test results of monocrystalline PV modules, the electrical and thermal performance was analysed and the results for the PV and PVT collector were compared.There are several factors that affect the overall performance of PVT system such as intensity of solar radiation, wind speed, mass flow rate, inlet and outlet temperature, ambient temperature, and tilt angle of PV module. Fig. 6 shows the variation of front and back module temperature of PV with automatic cooling system and PV without automatic cooling system with ambient temperature. From the graph, it is noticed that operating temperature of PV module plays a vital role in electrical and thermal performance.

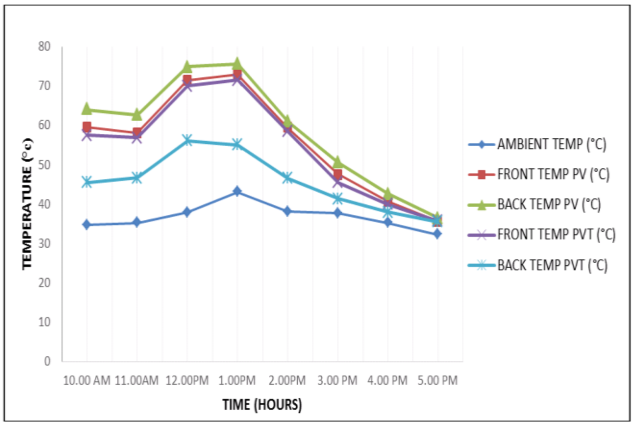

Fig. 6 Module temperature variation with automatic system and without automatic cooling system

It can be seen that the PV module temperatures also greatly affected by ambient temperature. The data of important parameter was recorded every one-hour cycle. The graph further shows between 12.00pm until 1.00pm, PV on with automatic cooling system is much cooler rather than the temperature of the PV without automatic cooling system. It is noted that the automatic cooling system does bringing an effect to the PV module. The back temperature of PV with automatic cooling system varies between 45°C-55°C and front temperature of PVT varies between 55°C-75°C.

Figure 7 shows the variation of inlet and outlet water temperature with ambient temperature. The thermal performances of PVT system are greatly affected by inlet water temperature (Ti) and mass flow rate (m). The cooler inlet water temperature will provide more heat gain by outlet water and low mass flowrate will extract heat from PV module into the water more efficiently.

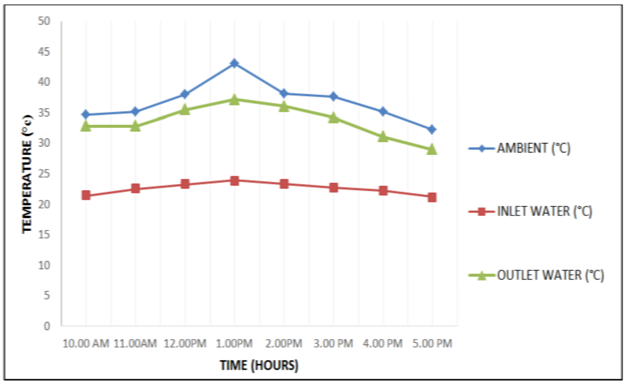

Fig. 7 Variation of inlet and outlet water temperature

The variation of electrical efficiency of PV with and without automatic cooling system is shown in figure 8. The data was collect at the time around 12.00pm until 1.00pm was the highest solar radiation gain, shows that PV with automatic cooling system produce more electricity rather than the PV without automatic cooling system. It is prove that electrical efficiency was affected by operating temperature and the intensity of solar radiation.

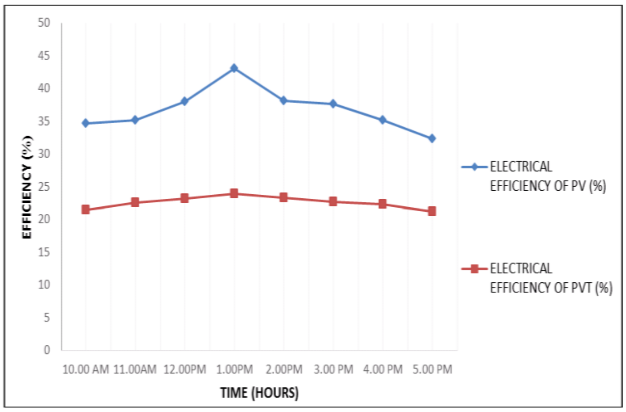

Fig. 8 Electrical efficiency variation of PV with and without automatic cooling system

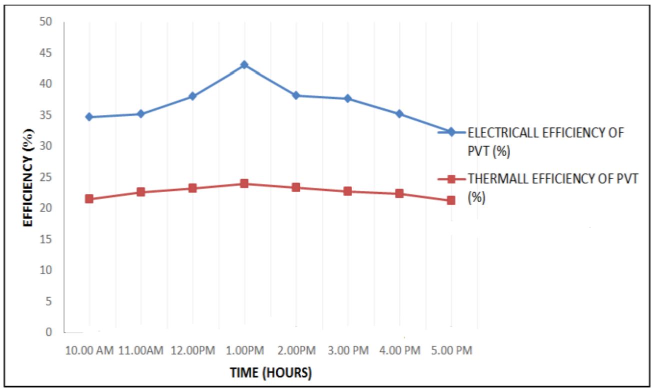

Fig. 9 Overall efficiency variation of PV with automatic cooling system

When PV module absorbs solar irradiation, its operating temperature increases which in turn affected the performances of PV module. Applying heat extracting media such as flowing fluid on the back surface of PV module can solve this non-uniform cooling. Design parameters of PVT thermal collector have been taken into account in this study such as solar irradiation intensity, mass flow rate, inlet temperature and type of coolant. These parameter are important in order to investigate the electrical and thermal performance of PVT water collector. As the solar radiation intensity increase gradually, results in the increasing of PVT water collector electrical efficiency. Later it remains constant after receiving solar radiation intensity of about a maximum point.Power output of PV and PVT decrease as operating temperature increase.

V. CONCLUSION

In this paper, the performances of PV and PVT water collector had been tested on outdoor environment. The comparison analysis show that there are good agreement between numerical simulation results with the experimental works.The effect of design parameters in outdoor environment toward electrical efficiency and temperature efficiency were successfuly discussed and proved.

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