MAXIMIZE THE OUTPUT OF PHOTOVOLTAIC CELLS USING DIFFERENT HEAT REMOVAL SYSTEMS

***Abed El. Mageed . H. N , **H. M. Nour and ***E. L. A. Salem**

ABSTRACT

Cooling photovoltaic (CPV) system helps in focusing the direct solar radiation on the photovoltaic module. It has been used for evaluating the performance of the CPV module with air and water cooling systems for power output and cell temperature. Also the effect of cooling air speed and water flow rate has been analyzed for performance evaluation of the CPV module. It has been found that the electrical output of the PV by water cooling is the most efficient than air cooling. It has been noticed that the output of the CPV mainly depends on the heat extraction rate and it helps in managing the cell temperature. And also the heat extraction rate from the CPV module mainly depends on the cooling air speed and also water flow rate.

Keywords: *Photovoltaic, cooling photovoltaic system (CPV), air cooled PV, water cooled PV.*

INTRODUCTION

In our world today, the problems caused by global warming and pollution effect become the important issues for research. Renewable energy sources are considered as a technological option for generating clean energy. Among them, photovoltaic (PV) system has received a great attention as it appears to be one of the most promising renewable energy sources. The renewable power generation is important to reduce the dependencies on fossil fuels. In some decades we will run out of oil and gas; coal will be in use for some centuries. In the long run energy utilities need alternative or renewable fuels to have the continuing ability to provide their products, **Teleke et al. (2010).** One of the promising applications of solar energy technology is the use of photovoltaic systems to generate electric power without emitting pollutants. Solar energy may be used to produce electricity using photovoltaic solar cells and heat in photo collectors by a photo thermal conversion process.

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Increasing efforts are directed towards reducing the installation costs and enhancing the performance of photovoltaic systems so that the system can be deployed at a large scale. **Sanusi et al. (2011)**
Photovoltaic has nonlinear internal characteristics. The voltage-power characteristics of the PV panel is varied which depends upon insulation and temperature, **Galal et al. (2011).**
The output voltage of a PV module has approximately a linear relationship to its temperature given by the thermal coefficient α. Since α is negative the output voltage of a PV module rises with decreasing module temperatures. When a certain minimal (maximum power point) MPP voltage VMPP is required for full load operation at 70-80°C, the worst case output voltage can occur at open circuit and low temperature. The module should be designed in a way that its voltage does not cross certain thresholds, **Sahan et al. (2008)**
The operating solar cell temperature also increases and therefore the solar cell efficiency decrease and the also the life time of the PV module decreases. It is important to include proper cooling system in the PV system for increasing the efficiency of solar cell by reducing the operating cell temperature. Further efficiency gains can be accomplished by including a cooling system to reduce the cell temperature. As solar cells increase in temperature, the cell efficiency decreases. This decrease can have adverse effects on the cell efficiency and therefore power output at medium and high concentration levels, **Tony and Laura (2012).**
Solar cell cooling is an integral part of the PV design. First, the solar cell efficiency is a function of cell operating temperature and lower temperatures result in higher efficiencies. Second, the solar cell must be kept below the melting point of the solder that is used to manufacture the multi-junction cells to prevent immediate cell failure. And third, the reliability of the solar cell is a function of the number of thermal cycles and the magnitude of the thermal excursion. Some experts claim that reliability or life expectancy is doubled for every ten-degree reduction in thermal excursion**, Anderson et al. (2008).**

<u>This search aims to:</u>

1- Development the performance of the photovoltaic module according to removed temperature of the PV and also increasing the PV out put through the maximum power tracking .

2- Comparison the estimate results for photovoltaic development with and without development.
3- Estimate and compare the results of the PV output according to development.

MATERIALS AND METHODS

Characteristics Of the Photovoltaic.

The Photovoltaic which used was mono-crystalline PV, Germany made. The photo of the PV is shown in Fig. (1).
The electrical characteristics is illustrate in the table (1)

Figure (1): The photo of the mono-crystalline PV.

Table (1): Electrical characteristics of the photovoltaic

Electrical Characteristics	Specifications
Voltage at peak power (Vpp)	24
Current at peak power (Ipp)	5
Open circuit voltage (Voc)	26
Short circuit current (Isc)	6

The Battery - Storage Element.

An electric battery or deep cycle battery is a device consisting of one or more electrochemical cells that convert stored chemical energy into electrical energy. Each battery consists of a negative electrode (anode) that holds charged ions, a positive electrode (cathode) that holds discharged ions, an electrolyte that allows ions to move from anode to cathode during discharge and (return during recharge) and terminals that allow current to flow out of the battery to perform work. The specifications of the battery which used are listed in table (2).

Table (2) : The specifications of the dry battery – (Gel-battery).

Characteristics	Specifications
Maximum voltage, (volts)	12
Maximum current, (Amps)	70
Number of plates:	
Dimensions: Length (cm)	24
Width (cm)	16
Height (cm)	19

PV cooling systems: In order to remove or reduce the temperature of the PV two methods of cooling were used first named water cooling, hence the DC pump was used to pressuring the tape water to heat exchanger.

Water Cooling Systems: The water cooling system includes Heat Exchanger, DC pump for pressuring water and Solenoid Valve to controlling the path of the water inside plastic tube.

Heat Exchanger: Regardless of the function the heat exchanger fulfills, in order to transfer heat the fluids involved must be at different temperatures and they must come into thermal contact. Heat can flow only from the hotter to the cooler fluid. The heat is transferred from the hot fluid to the metal isolating the two fluids and then to the cooler fluid. The heat exchanger is made from cupper.

DC Pump: The DC pump which used is Brazilian made, the pump used and placed between the heat exchanger and the reservoir, which contains tap water. Pump is used to pump the water from the tank to the heat exchanger through the hose is made of plastic with inner diameter of 10 mm in diameter. The discharge of the pump was measured according to the revolutions of the pump and that is affected by the supplied voltage.

Solenoid Valve: A solenoid valve is an electromechanical device used for controlling liquid flow. The solenoid valve is controlled by electrical current, which is run through a coil. Solenoid valves make automation of fluid. Modern solenoid valves offer fast operation, high reliability, long service life, and compact design.

RESEVOIRS: To conduct laboratory experiments to improve the performance of the photovoltaic using water, a two tank were used. The capacity was 650 liters in volume for each. The tank is made of plastic resistant to breakage, heat, and one of reservoirs is filled with tap water ,where water is flow through the plastic tube with diameter10 mm bore to heat exchanger ,while the another reservoir is receiving water with high temperature which produced from heat exchanger installer behind PV.

Air Cooling System: The second method of PV cooling is air cooling system; in this system forced air cooling was used. The DC electric fan was used to force the air against the back of the PV module. During the laboratory experiments. The component of the air cooling system consists of as follows:

Fan Blade: Three types of fan blades, it has compared them with in terms of energy consumed, fan speed and air speed to reach the best suitable fan for cooling the PV according to laboratory experiments. The photo of the three blades of the fan are shown in Figs. (2)

Fan type (A) **Fan type (B)** **Fan type(C)**

Figure (2): The photos of different types of fan blades.

Fan Blade Evaluation: The evaluation was depended on blade width, number of blade and blade length using an efficient method for evaluation. According to **Monroe (1998), Peng (2008) and Venkanna (2009).** The greatest amount of work a fan performance is done by the outer portion of the blade. Consequently, the fan solidity is critical. Solidity ratio (SR) is defined as the ratio of the sum of the blade widths to the fans circumference. The solidity ratio (SR) is:

$$SR = N_b \times F_w / 12 \pi L_b \qquad (1)$$

Where:

N_b = Number of blade, F_w = fan width (ft) and L_b = length of blade (ft).

The specifications of the fans used are illustrated in table (3). The table include fan width, length of blade and also number of blade were also listed for each fans. These data sheet for fan was aid to compare between them using the suitable and efficient equation for evaluation.

Table (3) : The specifications of the fan blade.

Specifications	Blade type (A)	Blade type (B)	Blade type (C)
Width Fan Blade	32	28	38
Number of blade	5	4	3
Length of blade	10	7.5	16

DC Electric Motor:

The electric DC motors was used to operate the previous fans. The peak power and voltage were measured in order to evaluate their performance of the PV output through hour the daylight during operation. The device offers advantages over the other commonly used fan speed control methods, also the control device designed for use with low-voltage (3 VDC to 18 VDC). However, with an open-drain tachometer output, the device is also suitable for applications that require two wires for RPM speed control and tachometer signal. The photo of the DC motor is shown in Fig. (3).

Figure (3): The photo of the DC motor

Instrumentations.

Pyranometer – Recorder L1 - 1200.

Sensors were employed to measure solar radiation, air relative humidity, using pyranometer, hygrograph, digital thermometer, auto range multimeter, and digital multimeter. A Pyranometer –Recorder LI-1200 is a 4 channel data logger designed to collect the minimum daily meteorological data set defined by the international Benchmark Sites Network for Agro technology Transfer (IBSNAT) program of the agency for international development.

Auto Range Multimeter.

Auto range multimeter was employed to measure both voltage and current output for the photovoltaic array during daylight hours and during laboratory experiments and PV applications. The apparatus measurement DC Volts (5 ranges)- auto manuals rang DC current- manual range (3 ranges) and the power supply 2x1.5v AAA, while the power consumption Approx. Dc 0.7 mA.

Thermocouple Temperature Sensor

The most popular thermocouple in the Industrial field, which is called **(Type J)** thermocouple temperature sensor). This type is Constructed from iron and Cu-Ni metals, the temperature range of this thermocouple is -180^{o}C to +750 ^{o}C , the sensitivity of type J thermocouple is 54 µV/^{o} C Type J thermocouple is generally recommended for new designs.

Variables Transformer (Variac- Foster).

A variables transformer can be obtained, allowing for very smooth control of voltage. Applicable only for relatively low voltage designs, this device is known as a variable AC transformer (often referred to by the trademark name Variac). The mention variac was used to adjust and control the rotating both pump and fan at different levels of speeds during the experiment for development the PV module.

Flow meter Device.

Flow measurement is the quantification of bulk fluid movement. Flow can be measured in a variety of ways. Positive-displacement flow meters accumulate a fixed volume of fluid and then count the number of times the volume is filled to measure flow. Flow may be measured by measuring the velocity of fluid over a known area the liquid flow can be measured in volumetric or mass flow rates, such as liters per second or kilograms per second. The digital flow meter, maximum pressure (PSI) equal 120, the flow range : 0.1 -10 m/s, while the maximum Viscosity (SSU) equal 100.

Digital Tachometer.

A tachometer, also known as a revolution-counter, is an instrument that has a purpose of measuring the rotation speed of a cooling fan. The term is usually restricted to mechanical or electrical instruments that indicate instantaneous values of speed in revolutions per minute, rather than devices that count the number of revolutions in a measured time interval and indicate only average values for the interval.

Air speed device, (Anemometer).

To measure the air speed during the experiments the thermo. Anemometer was used. The air Sensor is a thermal anemometer based on a traditional technique for measuring air speed. The technique is called the “hot-wire” technique, and involves heating an element to a constant temperature and then measuring the electrical power that is required to maintain the heated element at temperature as the wind changes.

The Applications of The Photovoltaic:

Laboratory experiments.

The aim of the laboratory experiments was evaluate different systems of the PV cooling, the first one was the cooling of the PV with forced air using three types of fan blades, the parameter of the evaluation depended on solidity ratio and also consumed energy using similar DC motor for each, while the second system was using water for removal photovoltaic temperature, through two methods for water cooling, the first one was DC water pumping while the another one was tap water cooling methods.

The Development Of The Photovoltaic Module By Water Cooling:

The water cooling system which consists of main reservoir (650 lit in volume) filled with tap water (22°C). The tank was connected with DC pump through the plastic tube with 10 mm bore; the pressuring water from the pump was pushed to the heat exchanger through plastic tube 10 mm bore. The dimension of the heat exchanger is similar of the PV module and it fitted at the back of PV module the outlet of heat exchanger was connect with another reservoir through the similar plastic tube.

In order to controlling of the DC pump speed (m/sec) at different values of the voltage requirements a variac (Variables transformer) was used. The photovoltaic temperature (back and front) and also the inlet and outlet water temperature of the heat exchanger was measured and recorded by data logger instrument. The output energy (voltage –current) from the developed module was measured by auto rang multimeter during measurement. Then another PV module without development.

The Development of The Photovoltaic out put:

(Forced air cooling):

Development of the PV module by using forced air cooling produced from DC fan. Through the laboratory experiments three types of fan blade were examined (type A , type B and type C) in order to determine the efficient fan which Produced more air cooling and consumed a little energy. The developed module consists of one fan fitted at the back of the module through the fixed frame with dimension of (1.20 m long and 0.53 m width). The operating voltage of the rotating DC fan at different levels of speed was controlled by high sensitivity transformer (Variac). The PV temperature measured (at the back of the PV) was measured and recorded by data logger device. The revaluation of the DC motor of the fan was illustrates by digital tachometer. The voltage and current output were measured by digital auto – range multimeter. The data of the laboratory experiments were measured every one hour from sun shine to sun set.

RESULTS AND DISCISSIONS

Determination the Solidity Ratio (SR).

The blade solidity is an important design parameter for the axial flow impeller and is defined as the ratio of blade chord length to pitch. The solidity ratio for three types of fan blades produces axial forced air produced form was plotted in figure (4). The (SR) of the fan blade is defined as the ratio of the sun of the blade width to the fans circumference. From the table, it can conclude that the fan type (A) gave a higher values followed by fan type (B) and (C). Also, the data indicate that, the solidity Ratio (SR) were 0.43, 0.40.and.0.19 for fan type (A), (B) and (C) respectively.

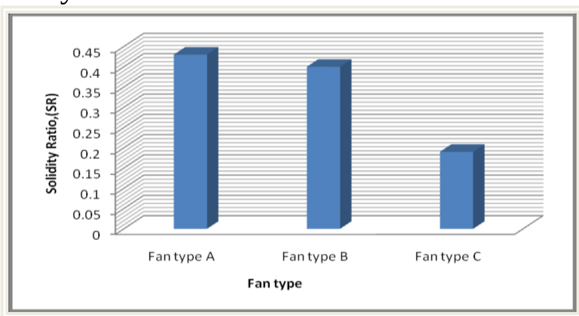

Figure (4): solidity ratio (SR) of three types of fan blades.

Power Consumed.

The energy consumed (W) for the three types of electrical fan blades are illustrated in figure (5). Increasing the applied voltage of fan leads to more energy consumption for three types of fan blades (A, BandC). The average values of the consumed energy were 33.48, 45.34 and 54.28 W/h for three types of fan blade (A) ,(B)and(C) respectively. From the mentioned figure, one can notice that the consumed energy for types (B and C) is higher than type (A) with percentage of 26.7%.

Finally the operating of the fan type (A) is better than type (B) because of consumed energy of type (A) less than consumed energy of type (B) at all speeds of the fan.

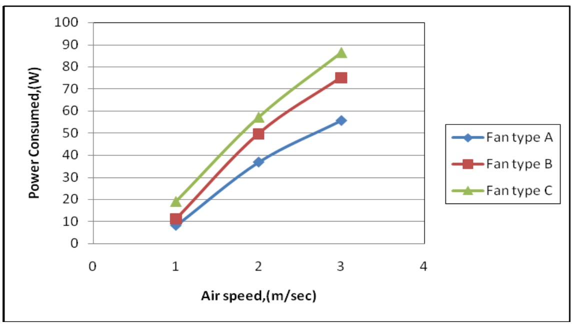

Figure (5): The relationship between power consumed, (W) for three types of fan blades and its air speeds (m/s).

Pump Power Consumed.

The operating of water pump operated by DC motor which depended on energy consumption affected by pump flow rate (Lit/min). If the flow rate of the pump increased the energy consumption must be increase.

Figure (6) indicate these phenomena, the Fig. shows that the increasing in pump flow rate increases also the pump energy consumption. The three levels of pump flow rates are 5, 7 and 11 Lit/min, and the corresponding values of energy consumption are 43.69, 61.17 and 96.12 Watt/h respectively. Also, the increasing in flow rate from 5 to 7 Lit/min, increase the energy consumption of the pump with percentage of 40%, and 57% for increasing the flow rate of the pump from 7 to 11 Lit/min.

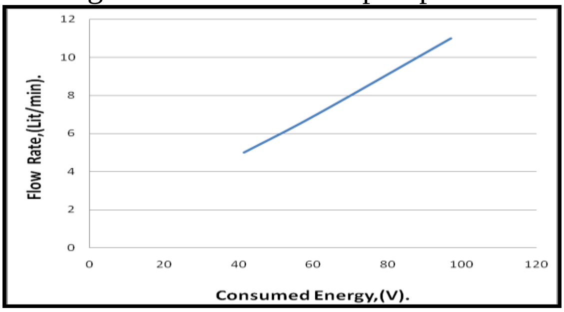

Figure (6): The relationship between consumed energy (E) and its pump speeds (Lit/min).

Effect of cooling PV module with forced air at air speed 4.5 m/s.

Fig (7) show the relationship between daily hour (h) and back temperature for two module of PV, At 10 am, the two module because hot the temperature of both reached 49.8° C. After that, the cooling system of DPV is operated till at 15 pm and the cooling system reduce the temperature from 50.5 to 30.5° C .

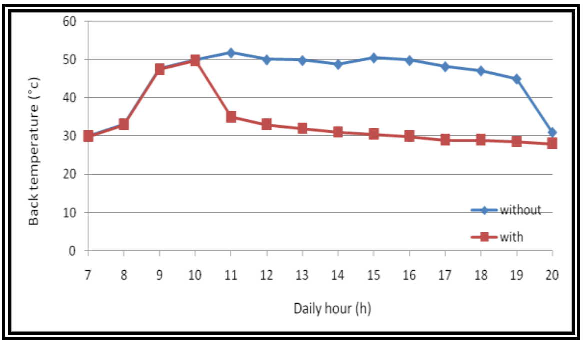

Fig (7): Variation of back temperature (°C) for PV with cooling and without cooling at daily hours.

Fig (8) illustrates the relationship between daily hour and PV energy output for tow modules of PV. The first module was with forced air cooling (DPV) while another one was without cooling system. The cooling system which used is forced air cooling system using DC fan type(3) (12 V DC). And at air speed of 4.5 m/s . Because of the maximum temperature of the media leads to increase in cell temperature then decrease in energy output. At 12 pm the energy output are 55.5 and 80.57 watt for without and with PV cooling system respectively and the developed ratio was 45.2% at the same hour.

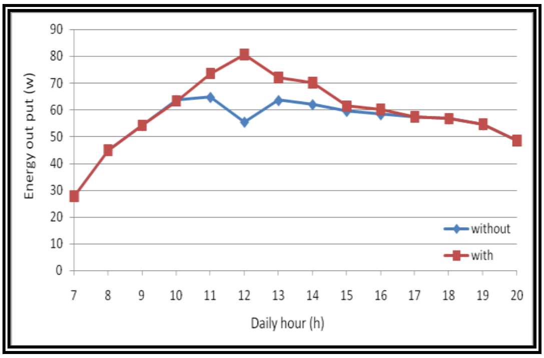

Fig (8): Variation of energy output (E) for PV with cooling and without cooling at daily hours.

DC pump cooling system:

Effect of daily hour on photovoltaic output at pump speed of 7 L/min:

During the test day, the maximum temperature difference between the PV developed module and the comparison one was lower than 18.5°C at 15 pm Fig. (9).

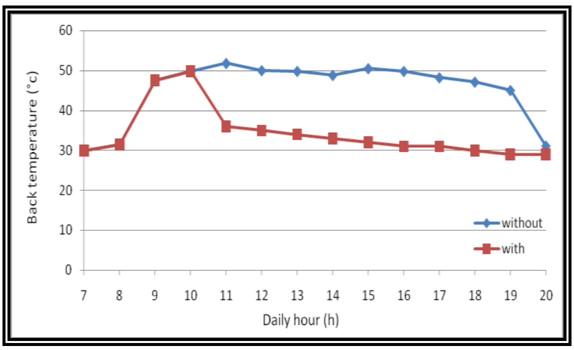

Fig (9): Variation of back temperature (°C) for PV with cooling and without cooling at daily hours.

Compared with undeveloped module, the module receives more direct solar radiation. It transfers the heat to the cells and therefore the cell temperature increases. The experimental results have shown that the temperature difference between the PV module with cooling (DPV) and the PV module without cooling (WDPV) is more specially at period from 11 am to 16 pm. The water cooling has extracted significant amount of heat which has been gained due to the temperature rise of the PV developed module. The raise percentage of the cell temperature for the undeveloped module was 49.6% than developed module.

Figure (10) illustrates the effect of daily hour (h) on performance of PV modules. The two modules were tested, the first one was developed by install cooling system use the water through DC pump at flow rate of 7 Lit/min (DPV) especially at med day, while another tested module for comparison (WDPV). At period between 11 am to 16 pm, the total energy were 363.7 W and 429.2 W for also WDPV and DPV respectively with increasing in energy percentage of 18%.

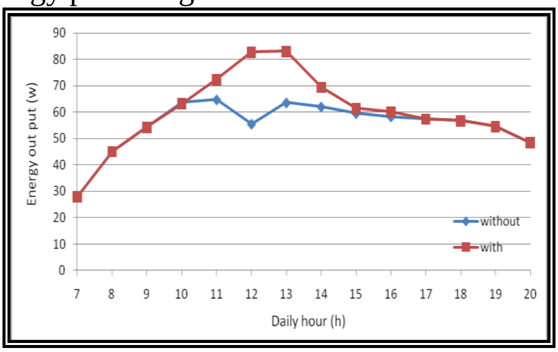

Fig (10): Variation of energy output (E) for PV with cooling and without cooling at daily hours.

<u>Cooling by tap water:</u>

The effect of daily hour on photovoltaic output at tap water flow rate of 7 L/min is illustrates in fig (11) effect of Photovoltaic module back temperature during day light of the day for the PV with cooling (DPV) and without cooling (WDPV) system. The water which used to remove the temperature from developed PV module was water flow from the tap with flow rate of 7 Lit/min. The maximum value of PV temperature reaches to 50.5 °C at 15 pm for PV without cooling, but temperature of the PV is 50.5°C and 31°C for without and with respectively at time of 15 pm, while the PV temperature at the peak of the day are 50°C and 35°C at 12 pm for without and with respectively. The total percentage of the removing temperature for with cooling was 51%.

Fig (12) shows the energy output of a PV at daily hour of the daylight for PV with and without removed temperature system. The mention figure indicate that at daily hour 11 am, the diagram of the PV with cooling system increase in energy output than the another one. The amounts of the PV energy output were 421.5 and 363.7 for PV with and without respectively at time from 11 am to 16 pm.

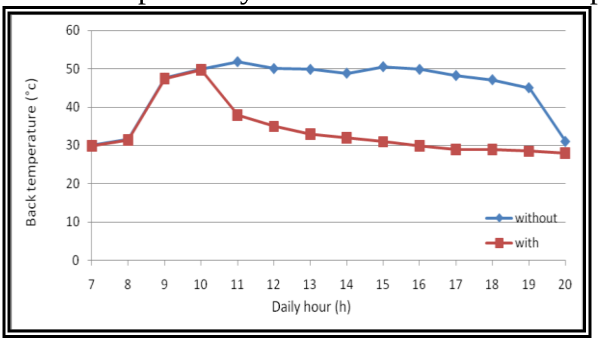

Fig (11): Variation of back temperature (°C) for PV with cooling and without cooling at daily hours.

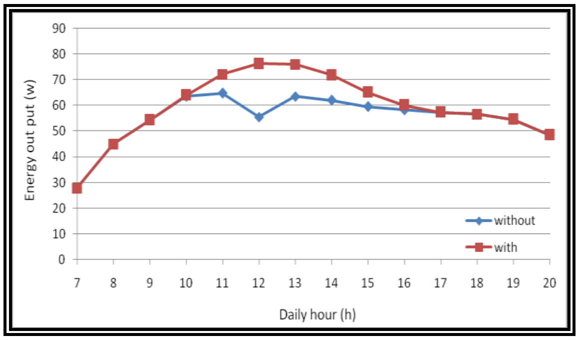

Fig (12): Variation of energy output (E) for PV with cooling and without cooling at daily hours.

CONCLUSION

The electrical efficiency of photovoltaic (PV) cell is adversely affected by the significant increase of cell operating temperature during absorption of solar radiation. From the experiment result, it shows that the effect of using the active cooling mechanism. Under the situation where no cooling was used, the operating temperature of PV module attained a value as high as 55^{o} C. Besides, an optimum flow rate was also found in this study. Air speed of 4.5 m/s is sufficient to absorb the maximum amount of heat from the PV module. Also, the cooling with pumping water gave a higher value of recovery power 63.32 watt at water flow rate of 7 Lit/min, while PV cooling with air gave recovery power of 51.65 watt.

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الملخص العربـــي

تحقيق أقصى قدر من خرج الخلايا الفوتوفولتية باستخدام أنظمة مختلفة لإزالة الحرارة

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تعتبر الطاقة التقليدية الآن هي المصدر الأساسي للإعتماد عليها في كثير من تلبية احتياجات الدول. ومن الطاقة التقليدية والتي تعرف بالطاقة الأحفورية ، والتي تتمثل في البترول والفحم والغاز الطبيعي ولما كانت هذه الطاقات ستنتهي بمرور الزمن وتنضب. لذا يجب لزاما الإعتماد على الطاقة الجديدة والمتجددة ومنها الطاقة الشمسية . وتتبلور أهمية الطاقة الشمسية في تحويلها إلى طاقة كهربائية من خلال أنظمة الخلايا الفوتوفولتيه photovoltaic power system.

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لاشك أن الخلايا الشمسية تلعب دورا كبيرا في تلبية الإحتياجات من الطاقة الكهربائية نظرا لإنتشار سطوع الشمس في ربوع الأرض كلها. وتعرض الخلايا لضوء الشمس المباشر يؤدى إلى إنتاج الطاقة الكهربائية إلا أن استمرار تعرض الخلايا يؤدى الى ارتفاع درجة حرارتها نظرا لأنها ذات لون غامق خاصة هذا الإرتفاع في درجة الحرارة يؤدى إلى انخفاض الطاقة الكهربائية الناتجة من الخلايا خاصة من الساعة ١١ صباحا إلى الساعة ٤ عصرا.

لذا يهدف البحث إلى :-

التوصل إلى المواصفات الفنية والهندسية لتصميم أنظمة مناسبة وملائمة لإزالة حرارة الخلية الشمسية ويتم تشغيلها عند إرتفاع درجة حرارتها خاصة في منتصف النهار وهذا الإرتفاع فى درجة الحرارة يؤدى إلى انخفاض الطاقة الناتجة منها. ويتم تنفيذ ذلك من خلال تنفيذ أنظمة إزالة حرارة إحداها تعمل بنظام الحث والأخرى يتم إزالة الحرارة منها بنظام التلامس بغرض زيادة الطاقة الناتجة منها وبالتالى يؤدى ذلك الى توفير مساحات من الخلايا وبالتالى يؤدى الى انخفاض تكاليف المنظومة.

وأنظمة التبريد التي أستخدمت كما يلي :-

١- التبريد بنظام الحث .

وفى هذا النظام يتم إستخدام التبريد بدفع الهواء من خلال مراوح التبريد بنظام Forced Air Cooling حيث تم تقييم عدد ثلاث ريش من ريش المراوح باستخدام ثلاثة مواتير من التى تعمل بنظام التيار المستمر وتقيمهم من خلال تقدير(solidity ratio (SR كما تم تقييمهم من خلال القدرة المستهلكة (وات) عند سرعات ١,٥ و ٤,٥ م/ث للتوصل الى افضل ريشة يمكن استخدامها فى التبريد وهى التى تكون اعلى فى قيمة SR واقلهم فى استهلاك القدرة عند السرعتين المستخدمتين.

٢- التبريد بنظام التلامس.

وفى هذا النظام يتم استخدام مبادل حرارى يثبت خلف الخليه ويتم ضخ المياه داخل المبادل لإجراء التبريد ويتم استخدام طريقتين فى هذا النظام .

- التبريد بضغط المياه Water pumping cooling .

حيث يتم إستخدام طلمبة تعمل بالتيار المستمر (DC) من خلال الطاقة الناتجة من الخليه وقد أستخدم معدل سريان داخل المبادل ٥ و ٧ لتر/ دقيقة .

- التبريد بإستخدام مياه الصنبور .

حيث أستخدم مياه الصنبور لتبريد الخلايا عند تصرف ٥ و ٧ لتر/ دقيقة .

- التبريد بإستخدام مياه الصنبور .

حيث أستخدم مياه الصنبور لتبريد الخلايا بدون إستخدام طاقة تبريد عند تصرف ٥ و ٧ لتر/ دقيقة .

وقد أجريت القياسات كل ساعة إبتداء من الشروق (٧ صباحا) حتى الغروب (٨ مساءا). وتم تسجيل درجات حرارة الخلية وخرج الخليه (فولت V ، تيار I وتم حساب الطاقة بالوات .

وتم تقدير الطاقة الناتجة من الخلية اثناء عملية التبريد وأيضا تم تقدير حساب الطاقة اللازمة لجهاز التبريد. واخيرا تم تقدير وحساب الطاقة المتبقية بعد اجراء عملية التبريد والتى يتم تخزينها

فى البطارية وتقدير النسبة المئوية للطاقة المتبقية كل ساعة من خلال أجهزة القياس الدقيقة لكل من درجة حرارة الخليه ، الجهد ، التيار .

وقد أظهرت النتائج :

من خلال التجارب المعملية :

١- التبريد باستخدام المراوح :اختيار افضل ريشة وكانت الريشه من النوع Type A ذات طول ١٠ سم وعرض ٣٢ سم وعدد الريش فيها ٥ ريشة ، و الطاقة المستخدمة لتشغيل المروحة كانت ٨,١٠ و ٣٦ واط عند سرعتى ١,٥ و٤,٥ م/ث على التوالى.

٢- التبريد باسخدام طلمبة المياه : تم تقدير الطاقة المستهلكة لتبريد الخلايا باستخدام المياه من خلال طلمبه تعمل بالتيار المستمر عند سرعتى كانت الطاقة المستهلكة ٣٤,٦٩ و ٨٨,٣٣ واط عند تصرف ٥ و ٧ لتر/ دقيقة على التوالى.

من خلال التجارب النهائية الخاصة بتبريد الخلايا .

١- نظام ازالة الحرارة باستخدام الهواء :

اظهرت النتائج ان متوسط ازالة درجة الحرارة من الخليه طوال اليوم كانت ٧٢ °م وذلك عند سرعة هواء ١,٥ م/ث ، ومن خلال تبريد الخليه عند هذه السرعة ادى الى زيادة الطاقة الناتجة بزيادة بنسبة مقدارها ١٠,١٨ % من اجمالى الطاقة الناتجة. بينما استخدام نظام تبريد الهواء عند سرعة ٤,٥ م/ث كانت النسبة المؤبة للطاقة التى تم استعادتها من خلال نظام التبريد ٥١,٦٥ وات بزيادة بنسبة مقدارها ١٤% من قيمة الطاقة الكلية الناتجة من الخلايا وهذه النسبة نتيجة تبريد الخلايا وتحسين ادائها.

٢- نظام ازالة الحرارة باستخدام المياه :

- باستخدام التبريد بطلمبة المياه : تعمل بنظام التيار المستمر اظهرت النتائج بانه باستخدام طلمبة ضخ المياه عند تصرف ٥ لتر/ دقيقة كانت الطاقة الكهربية المفقودة بفعل الحرارة والتى تم استعادتها اثتناء التبريد طول اليوم حيث كانت مقدارها ٤٦,٨٦ وات بزيادة بنسبة ١٢,٧% من الطاقة الكلية الناتجة.

اما فى حالة التبريد باستخدام ماء الصنبور عند سرعة ٥ لتر/دقيقة كانت كمية الطاقة المفقودة والتى تم استعادتها بلغت ٤٦,٨٢ وات بزيادة بنسبة مقدارها ١٢,٧%. بينما بزيادة تصرف المياه من الصنبور الى ٧ لتر/الدقيقة كانت الطاقة المفقودة والتى تم باستعادها مقدارها ٥٦,٣١ وات بنسبة مقدارها ١٥,٣%.

٣- من النتائج سابقة الذكر وبمقارنتها اتضح ان استخدام نظام التبريد بضخ المياه باستخدام الطلمبة اعطى اعلى نسبة طاقة مستعادة مقدارها ٦٣,٣٢ وات وذلك عند تصرف ٧ لتر/دقيقة وذلك بنسبة ١٧,٢% ، واتضح ايضا ان التبريد بالهواء عند سرعة ١,٥ يعطى اقل نسبة طاقة مستعادة تصل الى ٣١ وات بنسبة ١٠,١٨% .