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Research Article

Performance Enhancement of Solar Photovoltaic Module by the Application Of Different Coolants over the Photovoltaic Module Surface

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Abstract
High temperature affects the efficiency of solar photovoltaic modules and hence the electrical power production. The study identified a suitable coolant that could best reduce the temperature of solar photovoltaic module and increase the efficiency of the solar module. The properties of several coolants were reviewed and four potential coolants selected for application on the solar photovoltaic module surface. Experiment was designed for the application of each of the four coolants. The performance of each coolant was evaluated and the best coolant was selected. The study identified sugar solution, water, Abro radiator coolant and soluble oil as the potential suitable coolants. The percentage increase in efficiency for soluble oil was 5.3% followed by 3.8% for water and then 3.5% for sugar solution whiles the Abro radiator coolant was last with 3% after the application of the coolants. Since soluble oil record the higher percentage increase in efficiency, it was identified as the best coolant for the solar photovoltaic module. However, before soluble oil coolant could be used for performance enhancement of solar photovoltaic modules, the cost-benefit analysis of application of the coolants and their chemical properties which could damage the photovoltaic module should be studied.

Keywords
Coolants, Efficiency, Performance Enhancement, Solar Photovoltaic Module, Temperature

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Contents

1. Introduction

Electricity is the key to the development of the global economy and thus, countries around the world give significance attention to the provision of electricity to their citizens [1]. However, lack of access to electricity is still a major issue in the world particularly in under developed and developing countries. It was estimated that over 1.3 billion people worldwide lack access to electricity [2]. Ghana like other developing countries faces major challenges in providing the needed electricity in a reliable and sustainable manner [3]. The electricity produced from fossil fuel amounted to 67.2% of the total electricity production in the world in 2013 [4]. However, due to the negative environmental impacts and climate change associated with the use of fossil fuels, fossil fuel pricing, social demand, depletion of fossil fuel and reduction in renewable energy pricing, the renewable energy sources have gained increasing attention of governments and other stakeholders in the renewable energy sub-sector [5].

The promotion of solar photovoltaic (PV) sources for electricity supply is one of the leading sources among the renewable energies and the trend is envisaged to continue in the coming years [6]. The Solar PV systems are cost effective in many remote applications such as lighting, water pumping and irrigation applications. Electricity generation from solar PV systems has been identified as one of the promising renewable energy alternatives because of the abundance of solar radiation, rapid reduction in electricity production cost, highly dependable energy supply and low maintenance [7-11]. The development of solar photovoltaic systems globally is gradually increasing. The total global capacity was 3.1 GW in 2005 [12], over 150 GW in early 2014 [2] and increased to 227 GW in 2015 [12]. The PV capacity in Africa has increased from 26 MW in 2000 to 1334 MW in 2014 [2] and in Ghana, utility scale solar PV electricity generation stands at about 42.5 MW which constitutes less than 2% of electricity generation capacity [12, 13].

The main factor that hinders the solar PV electricity generation is cost. Solar PV array is almost 70% of the capital investment of PV power system [14] and hence, in order to improve the cost effectiveness of PV array powered systems, the PV array should be efficiently used to pay off the high costs. Temperature is one of the significant factors in the performance of PV systems because the output power of solar PV modules is dependent on the operating temperature of the solar cells. The solar PV modules specifications are stated in terms of current, voltage and power at standard test condition (STC) temperature of 25°C [15]. However, the conditions specified in STC hardly occur in the actual outdoor conditions since solar module temperature is often higher than 25°C. The conversion efficiency of solar PV module is about 15% [16]. The residual energy is converted into heat energy which raises the operating temperature of the solar PV system and decreases the electricity generation capacity of the solar PV module. The heat energy generated also has the tendency to damage the structure of the PV module which decreases the conversion efficiency and shortens the lifespan of the PV systems. If the heat energy build-up is not dissipated, the temperature of the PV module rises and the output power of the module decreases [16]. Studies show that high temperatures reduce the efficiency of the PV array and hence increases cost of the PV array required to generate the expected electricity [17-19]. According to Gilman et al. [20], the output power of solar PV systems varies inversely with the operating temperature of the module and when the temperature of the module exceeds 25°C, the output power of the module decreases by 0.5% for every 1°C rise in temperature [21]. The decrease in the efficiency of the solar PV module tends to decrease the power production from the system and consequently, the quantity of electricity expected to be generated from the solar PV system may not be achieved. This increases the generation cost and thus, makes the solar PV systems unattractive alternative energy source.

In the quest to identify efficient cooling technology for solar PV modules, several researches have been carried out to analyse the performance of solar cells using different cooling methods. In many instances, water and air are considered as the suitable coolants for the solar PV module to increase the electrical efficiency of the module [22-24]. However, it has been found that water cooling technique is more effective than air cooling technique [10, 25]. Zubeer et al., [26] also reviewed different PV cells cooling techniques such as heat sink cooling, array air duct cooling beneath the PV panel, front surface water spray cooling and back surface water cooling to assess their effects on the performance of solar PV modules and concluded that water spray cooling technique best improved the performance of the solar PV modules. Thus, water is often used as a coolant for the PV modules to decrease the module temperature and increases the module performance [17-19, 27-30]. However, the potentials of other liquid coolants for the PV modules have not been considered. It is therefore, imperative to study the potentials of other coolants to enhance the performance of solar PV modules to ensure that solar PV systems operate reliably and efficiently. This research sought to identify the suitable coolant that would best reduce the temperature of solar PV modules and improve the efficiency of solar PV systems for sustainable power generation. When the efficiency of the PV array is increased, less PV modules are required, less space is needed and cost of power generation is reduced.

2. Materials and Methods

2.1 Selection of Coolants

A coolant is any kind of fluid which flows around or through a device to absorb the heat energy generated in the device and release it to the environment to avoid overheating. For efficient heat transfer, some of the important factors to be considered in the choice of liquid cooling technology for a particular application include cost, availability, compatibility, thermal stability, low toxicity, low corrosivity, high flash point, low freezing point, low viscosity, specific heat and high thermal conductivity [31]. The properties of several coolants were reviewed and based on the above factors the following coolants were selected for the study: water, sugar solution made of sugar/water 1:40 (wt./wt.), Abro radiator coolant and soluble oil coolant made of soluble oil/water 1:100 (v/v).

2.2 Experimental set-up

The experiment was conducted at the Department of Energy and Environmental Engineering of University of Energy and Nature Resources in Sunyani, Ghana. The experimental set-up was designed to investigate the potentials of four coolants in cooling the PV module and improving its efficiency. The set-up consists of one polycrystalline silicon module with peak power of 40W, battery, inverter, TQ TE4 photovoltaic load, solarimeter (pyranometer), Ammeter and voltmeter. The solarimeter, Ammeter and voltmeter are inbuilt and connected to TQ TE4 photovoltaic cell where the readings are recorded. The module was manufactured by BP Solar and coded BP340. The module is inclined toward south with tilt angle of 30° to the horizontal. Fig. 1 shows the set-up of the experiment conducted during the study and the reference module parameters is displayed in TABLE 1.

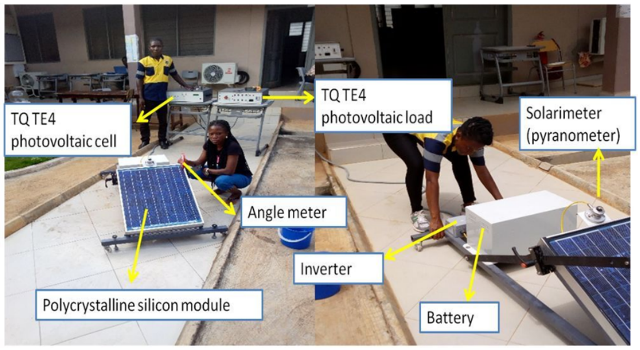

Figure 1. Experimental setup

Table 1. Reference module parameters

Parameter	Peak value
Type	Polycrystalline
Area	650mm *537mm wide
Peak power	40W
Warranted minimum (Pmax)	36W
Voltage (Vmp)	17.3V
Current (Imp)	2.31A
Open circuit voltage (Voc)	21.8V
Short circuit current (Isc)	2.54A
Minimum Bypass Diode	5A
Maximum series fuse	20A

2.3 Experimental procedure

The experiment was carried out under the same environmental condition to provide a level ground for comparison. The experiment started at 9.00am and ended at 4.00pm. The surface of the module was cleaned with clean water and allowed to dry before measurements were taken. The module was mounted in the sun as in Fig. 1 and the orientation measured with the angle meter. Before the application of the coolants, the ambient temperature was measured with the thermometer. The temperature of the module was also measured with a thermometer. The module temperature readings were taken from three different points on the module (at the ends and at middle) and the average calculated. As a precautionary measure, the thermometer was shielded from the sun to avoid the influence of the sun on the thermometer readings. The solarimeter (pyranometer) was used to measure the irradiance and the voltage, current and irradiance were recorded from the TQ TE4 Photovoltaic cell. After taken the above readings, 500ml of the coolant was applied on the surface of the module with the help of measuring cup and a brush. The module was left to cool for three minutes and the measurements were taken again. The procedure was repeated every one hour for each of the coolants.

2.4 Calculation of percentage increase in efficiency

The efficiency, η of the PV module was computed from the formula:

$$\eta = \frac{P_{max}}{AG}$$

$$P_{max} = I_{max}V_{max}$$

Where

P_{max} = is the maximum power generated from the PV module in W

A is the surface area of the module in m^2

G is the solar irradiance incident on the module in W/m^2

$I_{max} = maximumpowercurrentinA$

$V_{max} = maximumpowervoltageinV$

The percentage increase in efficiency was calculated from the formula below:

$$\frac{Changeinefficiency}{Efficiencybeforeapplicationofcoolant} \times 100\%$$

3. Results and Discussion

3.1 Measured parameters

Table 2 depicts the measured average parameters during the experiment.

3.2 Temperature and efficiency of module before and after application of coolants

The Fig. 2 shows the graph of temperature of the module before and after the application of various coolants as well as the change in temperature due to the application of the coolant. It was observed from the graph that when each of the coolants was applied, the temperature of the module reduced. The change in temperature for soluble oil was 2.1°C followed by 1.8°C for Abro radiator coolant, 1.5°C for sugar solution and 1.4°C for water. Water is a popular substance used in cooling solar PV modules and has been found to lower operating temperature of PV modules and increase power output [8, 30, 32-36]. However, this study has revealed that soluble oil record the higher percentage change in temperature than water and the other coolants as displayed in Fig. 2a. Soluble oil was therefore, identified as the better coolant for the solar PV module than water in terms of reduction in temperature.

The Fig. 3 shows the graph of efficiency of the module before and after the application of various coolants as well as the percentage change in efficiency due to the application of the coolant. It indicates the reading of the efficiency against the various coolants. It was revealed that when each of the coolants was applied, the efficiency increased. The percentage change in efficiency for soluble oil was 5.3% followed by 3.8% for water and then 3.5% for sugar solution whiles the Abro radiator coolant was

Table 2. Measured parameters

Coolant	Module temperature (oC)			cIrradiance, (W/m2)	cPower (W)	cEfficiency (%)				
	Before	After	Change	Before	After	Before	After	Before	After	Percentage change (%)
Sugar solution	39.1	37.6	1.5	609.4	617.6	25.8	26.9	12.08	12.43	3
Water	38.9	37.5	1.4	613	623.5	25.5	26.9	11.87	12.32	3.8
Abro radiator	38.5	36.7	1.8	656	667.3	27.1	28.5	11.8	12.21	3.5
Soluble oil	39.4	37.3	2.1	638.1	641.6	26.3	27.9	11.79	12.42	5.3

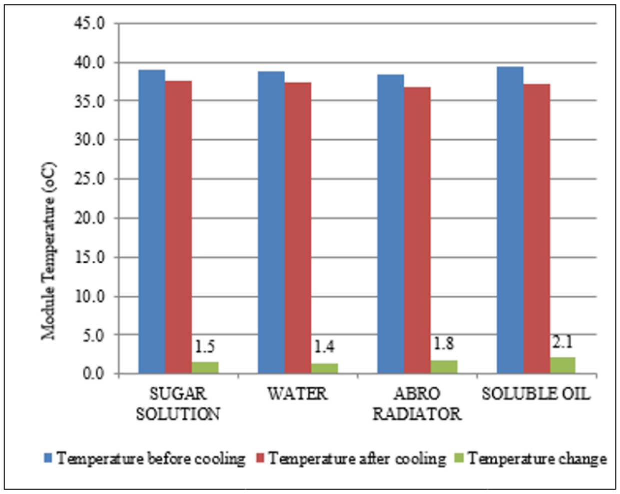

Figure 2. Module temperatures before and after application of different coolants

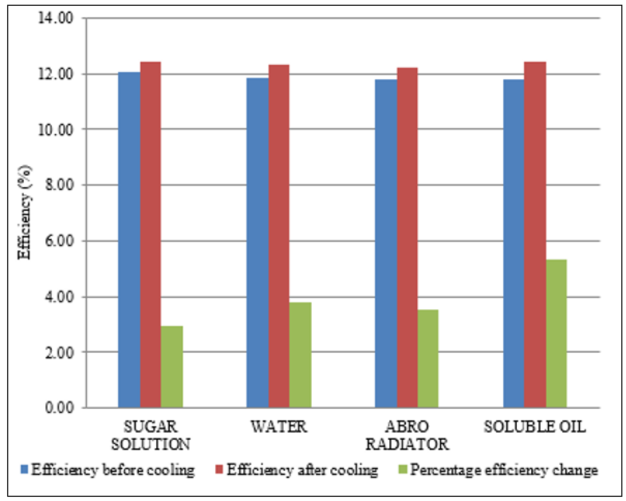

Figure 3. Efficiency of module before and after application of different coolants

last with 3%. Although Abro radiator coolant and sugar solution had higher drops in temperature that water, the percentage change in efficiency for water was higher than that of Abro radiator coolant and sugar solution. This is attributed to that sticky nature of sugar solution and the colour of Abro radiator coolant which prevented the solar radiation from reaching the module surface. Several studies show that water cooling enhances the power output and the efficiency of solar PV modules [32-34]. However, this study has revealed that soluble oil recorded the highest percentage change in efficiency compared to water, sugar solution and the Abro radiator coolant. This shows that soluble oil is the better coolant for the solar PV module than water in terms of improvement in module efficiency.

Fig. 4 displays the temperature and efficiency of the PV module against the various coolants. It shows the graph of temperature and efficiency of the PV module before and after the application of various coolants as well as the percentage change in efficiency due to the application of the coolants. It was found from the graph that when each of the coolants was applied over the module surface, the temperature of the module reduced and efficiency increased. The percentage change in soluble oil was 5.3% followed by 3.8% for water and then 3.5% for sugar solution whiles the Abro radiator coolant was last with 3%. Several studies show that water cooling reduces the operating temperature of solar PV modules and enhances the power output and the efficiency of modules [30, 32-36]. Zubeer et al., [26] reviewed different PV cells cooling techniques and concluded that water is the best coolant for improved performance of PV modules. However, this study has identified soluble oil as a substance that cools the solar PV modules and enhances its efficiency better than water. Thus, soluble oil was identified as the better coolant for the solar PV module than water.

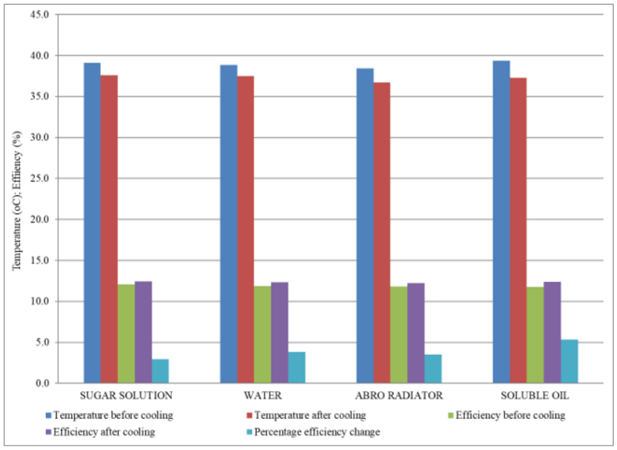

Figure 4. Temperature and efficiency of module before and after application of coolants

4. Conclusions

The study sought to identify a suitable coolant that could best reduce the temperature of PV array to improve the efficiency of solar PV systems. Four potential suitable coolants namely sugar solution, water, Abro radiator coolant and soluble oil were selected for application on solar PV module surface. The performance of the selected coolants has been evaluated by applying them over the solar PV module surface. The application of each of the coolants over the surface of the module resulted in decrease in module temperature and increase in module efficiency. The percentage increase in efficiency for soluble oil was 5.3% followed by 3.8% for water and then 3.5% for sugar solution whiles the Abro radiator coolant was last with 3% after the application of the coolants. Soluble oil was the best in reducing the module temperature and highest in improving the module efficiency. Thus, soluble oil was identified as the best coolant for improving the performance of solar PV modules. However, the cost involved in getting the coolants, how the coolant should be applied and cost of application, and the chemical properties of the coolants which could cause material damage to the module parts and subsequently damage the PV module permanently were not considered in this study. Thus, these areas need further studies before soluble oil coolant could be used for performance enhancement of solar photovoltaic modules.

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