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Efficiency Improvement in polycrystalline solar panel using thermal control water spraying cooling

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Abstract

The increasing demand for electricity generated from main grids has necessitated the use of multiple microgrids, which serve as subsystems of the utility power. More recently, solar farms are being utilized for electricity generation, since solar irradiation is a green and sustainable renewable energy source. This energy source has witnessed high global growth figures, as more countries explore this alternative power source in the fourth industrial revolution. Solar panels are exposed to high temperatures due to the heat absorbed from the sun and this heat negatively impact its thermal control that lags its power generation. The excessive heat absorbed from the sun limits energy generated by the solar cells. Colling of solar panels is essential, especially on concentrated Photovoltaic (PV) systems. The paper focuses on an optimization option of an automated water spraying method that has effectively addressed a major gap experienced by the solar panel under hot weather conditions. The Introduction of a microcontroller-based thermal control water spraying system using an Arduino board was found to improve the efficiency of the solar cells. In the study, a solar collector cooling algorithm was designed and developed using a thermal control feedback system, which increased the efficiency of the solar panel array by 16.65%.

Keywords: polycrystalline; solar panel; water cooling; heat removal; efficiency

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1. Introduction

The demand for electricity supply for industrial, commercial, and domestic purposes is increasing due to the economic growth and expansion of facilities and infrastructural development. In other power domain, the demand is higher than the amount of power generated by the utility company, which lead to unreliable service delivery. Electricity generation and availability are regarded as the main source of industrialization in the 4^{th} Industrial Revolution (4IR). It is important to supply reliable electricity to customers for improving their living standards associated with micro-economy, education, and healthcare. The rise in global prices of fossil fuels is continually increasing the prominence of green energy generation thereby contributing to solar energy demand [1]. The utilization of renewable energy sources was preceded by the application of fossil fuel. Due to the environmental sustainability drive, governments, and industries are saddled with the responsibility of protecting the environment through dependence on alternative energy sources. Independent analyses have shown that cost-effective energy efficiency improvements could reduce electricity use by 27% to 75% of total national use within 10-20 years without impacting the quality of life or manufacturing output [2]. Solar energy system operates as a separate controllable system and they can be connected to power utility grid as back-up systems.

Solar energy is free but the process of absorbing radiant energy is challenging due to undesirable natural elements. Excessive heat absorbed from the sun by the solar panels has been identified as one of the most contributory factors to the poor efficiency of solar absorbers. In 2016, Sargunanathan et al [3] stated that “to overcome these effects and to maintain the operating temperature of the PV cells within the manufacturer specified value, it is necessary to remove heat from the PV cells by proper cooling methods” [3]. The solar cells generally operate effectively on the temperature range between 15 and 35 degrees Celsius to produce maximum efficient energy [4][5]. The Maximum Power Point (MPP) varies with solar insolation and seasons, and absorbing maximum solar irradiation is imperative for an efficient system [2][6]. Much researches have been conducted to enhance the efficiency of photovoltaic generated. Generally, increasing the number of cells within an array is the quickest method often considered when energy demand increases [7]. The study involved the development of low-cost microcontroller-based water spraying solar system using temperature detection and Arduino board. The poor adoptions of solar cooling devices have been largely linked to the placement location and the high cost of purchasing solar cooling systems. As such, a major objective of the study was to improve solar PV array efficiency at a low cost. The focus of the paper is to discuss the approach that was adopted for improving the efficiency of the solar panel array as tested on the Light Emitting Diode (LED) domestic light system. However, the use of a microcontroller-based automated thermal control water spraying system enables more energy to be generated by the solar panel [8]. The designed microcontroller based thermal control water spraying system detects the high temperature on the solar panel and releases a certain amount of water to cool the glass. The system helps the solar not to exceed a certain temperature that impacts its efficiency.

Nomenclature

A	Thermal control

2. Background of the problem

During the daytime, there is a big variation in the power generated by PV solar panels especially in the first six hours and the last five hours of the day due to temperature variation [9]. In an attempt to increase solar power generation, the number of solar panels is often increased which increases the system cost and the overall land space consumption. The output power produced by the high-concentration solar thermal and photovoltaic (PV) system is directly proportional to the amount of solar energy acquired by the system which is a major reason why cooling solar panels. Lower cost of acquisition and maintenance of the microcontroller-based water spraying cooling system will increase the adoption of solar cooling systems. According to the graph of local solar time shown in figure 1, there is a gradual increase in solar insolation from 06:00hrs to 12:00 hours and a decline from noon to approximately 19:00 hours. The solar panel has a problem of not producing its maximum energy due to high environmental temperature.

In this study, a microcontroller-based water spraying cooling method was used to improve the efficiency of the solar panel.

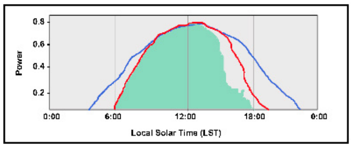

Figure 1: Example of solar power generated against time (duration) of capture [5]

The power generated by the solar cell is counter proportional to the temperature. An increase in cell temperature leads to less power generated. Figure 2 shows the relationship between output power and temperature of the solar cell.

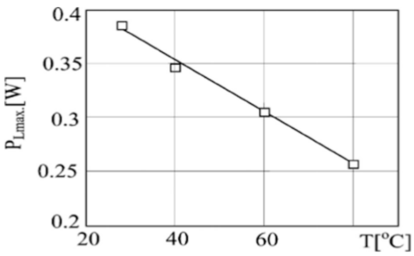

Figure 2: Temperature dependence of the maximum output power [10]

3. Literature review

Many studies and experiments have been conducted in a bid to improve the efficiency of solar systems. A problem associated with solar panels is a variation of environmental temperature, which determines the temperature of the surface of the solar panel. Another challenge is associated with solar panels maintaining a vertical position relative to the sun's position during daylight irradiation conditions. There are different hypotheses regarding achieving efficiency improvement in solar panels. Generally, many solar-powered grids simply improve efficiency by multiplying the number of cells, tracking the sun's position, cooling the solar panels amongst other measures. In this paper, one of the many cooling methods has been selected to improve the efficiency of solar panels.

Various studies have been conducted on cooling Photovoltaic (PV) systems as a method of enhancing the efficiency of the solar cells. Meneses-Rodriguez et al. (2005) utilized the cooling method to investigate the possible improvement in the electrical energy efficiency of the solar panel [11]. In 2005, Royne et al. discussed a cooling methodology that meets the desirable uniform temperature across all the cells of the solar panel [12]. Solar panels can be cooled using radiator (fins) methods, air compression, water immersion, and water spraying technique. Hussain et al [13] recommended the use of water and air as the best medium of cooling PV cells [13]. However, there is much ongoing research on other cooling liquid that will optimize the cooling process and retain the fluid properties for a long recycle life. A problem with the solar panel is associated with a low level of wind, so the blowing will be very minimal for cooling the solar. In this paper, water is regarded as the medium to be used in the cooling process of PV. In 2012 Tinaa et al, found that submerging the energy-generating PV with water heating solar system module is one of the most significant means to overcome excessive heat generated on the solar cells [14]. This submerging system gives the advantage of multi-function, but is not applicable for electricity generation, as there is no need for hot water use. In 2004, Krauter replaced the front glass surface of the solar panel with the water that covers the top surface of the PV panel by 1mm that improved the system efficiency by 8 to 15% [15]. In 2013 Chinamhora et al used a water immersion method on both top and bottom surfaces of solar panel to improve the efficiency of the PV module [16]. The water immersion method has problems associated with water evaporation that will leave solar cells exposed to the sun directly, especially when there is no routine inspection of the solar panels. A major contributory factor that impacts the efficiency of solar panels, is the glass cover that absorbs more heat [8]. The excessive heat generated on the solar panel glass has negative impacts on the system life span of solar cells due to system cell degradation. The increase in atmospheric temperature is inversely proportional to the efficiency and output power of the PV module [4]. Cells degradation of solar panels can be avoided by using water spraying as cooling method on high concentrated PV system glass [17]. Mehrotra et al [18], conducted experiments using water Immersion method to control the cells temperature to range between 31-39 degrees Celsius under real climateconditions which improved the efficiency of energy generated by 17.8%. Despite the efficiency improvement, water immersion is not a practical method to adopt in solar arrays wired with all associated components and peripherals.

In this paper, an automated water spraying method adopted in the study for cooling the high temperature generated on the glass of solar panels is being discussed. It is important to check the solar panel temperature specifications on each nameplate to understand the minimum and maximum operation efficient temperature of cells. Under the hot atmospheric temperature condition, the temperature of solar panels can be regulated using the adopted cooling methods. According to Mehrotra et al [18], the efficiency of solar panel can range around 95% and above at a temperature between 31 and 40 degrees Celsius. In this paper, only the automated water spraying method will be used to optimize the efficiency of solar panels.

3.1. Designing thre automated water spaying Cooling System Operation

Solar panel water spraying system was designed into the panel surface corners as a device for artificially releasing a stream of water jet to reduce the temperature of solar panel glass at a flow rate of 80ml/s of water for cooling with an automatic control system that detects the excess temperature at desired set limits. The automated water spraying system kicks in once the temperature of the solar panel glass exceed set limits, and sprays water on the panel surface until it drops to an allowable lower limit. The microcontroller based algorithm uses an electronic Resistance Temperature Detector (RTD) method to sense the high temperature of the solar panel and the pump start spraying water on the panel until it cools down within the required temperature range of 31 to 40 degrees Celsius or as set during configuration.

3.2. Working mechanism of the components within the automated water spraying system

Automated water spraying system was designed using a combination of hardware components and Software to control systems. The setup comprises of RTD, comparators, microcontroller, pump circuit, pumps and spraying pipes and sprinklers. The system is attached to the top of solar panels to release water for cooling. The RTD detect high solar temperature on the panel glass. The comparator measures if the temperature exceeds the required value, and if in excess, the microcontroller commands the pump circuit to release the water until the appropriate temperature is achieved. Figure 3 shows the schematic diagram of how the spraying process operates.

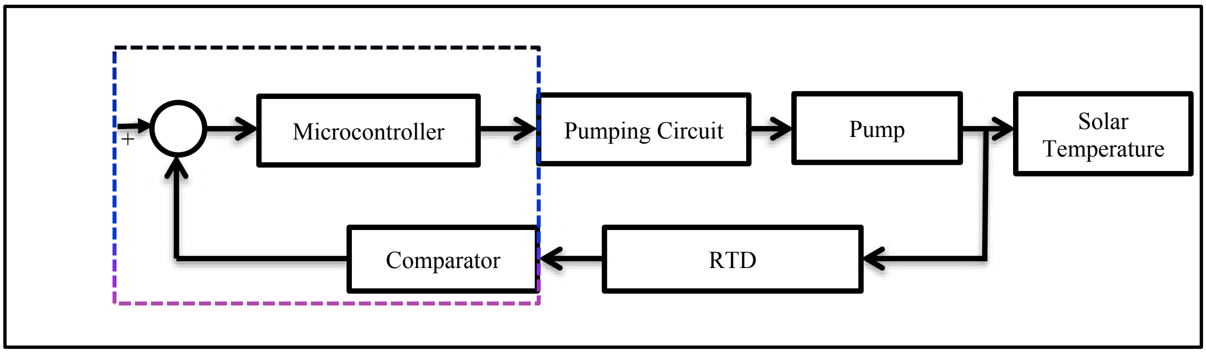

Figure 3: Water cooling system control

3.3. Components explained

I. Resistance Temperature Detector (RTD)

RTD detects the higher temperature of the solar panel and the comparator circuit compare the temperatures within the required range. The micro controlled based water spraying system use one RTD of which is attached to the panel. The resistance value of RTD is direct promotional to the temperature. Increase in temperature will generate higher resistance of the sensor. The relationship between the temperature of the solar cell and the resistance of the sensor is linearly related.

II. Comparator

The comparator circuit compares the temperature difference on the solar panel. The comparator uses the voltage divide rule to compare the voltage generated by each Resistance Temperature Detector (RTD). The RTDs are connected to the analogue input of the Arduino circuit board on the pin 23 to 26. The Arduino microcontroller (ATMega328P) has its internal comparator that is used to compare the difference of inputs voltages generated by the RTDs. The comparator has both the Non-inverting and inverting amplifies used for the comparison of voltage generated by RTD. Figure 4 and figure 5 below shows the schematic diagram of both inverting and non-inverting operational amplifies. When inverting reads 1, then non-inverting reads 0. When the temperature of the solar panel exceeds 35 degrees Celsius, the RTD detects it and comparator record 1, and when is below, it records 0. The truth table 1 below shows the spraying process of operational amplifier of comparator.

Table 1: Spraying Truth table

Inverting	Non-Inverting	Output
0	0	No Spraying
1	0	No Spraying
0	1	Spraying
1	1	No Spraying

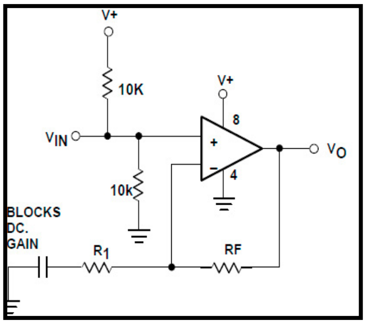

Figure 4: The non-inverting comparator

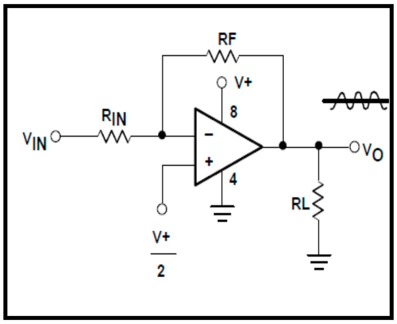

Figure 5: Inverting Comparator

The inverting comparator has input voltage connected to the inverting pin of the comparator and the reference voltage is connected to the non-inverting pin of the comparator. The non-inverting comparator configuration has the input voltage connected to the non-inverting pin of the comparator with the reference voltage connected to the inverting pin of the comparator.

III. Microcontroller

Microcontroller (ATMEGAR328) Arduino stores and runs the program memory for the operation of the solar water spraying system. The microcontroller has the analogue inputs that connect the thermometers to the circuit, and the outputs that give the pump circuit how much water is needed to cool the panel to the required temperature. The microcontroller has 14 digital input/ output of which six (6) was used as Pulse Width Modulator (PWM) and are analogue inputs. It operates at the frequency of 16MHz. One of the main advantages of the Arduino microcontroller circuit is that its circuit design has connections on both inputs/outputs connections which enable the program installation to perform the required duty. This microcontroller circuit is cheaper and minimizes time and electronic circuits construction costs. The two (2) thermometer are connected to any of the six (6) analogue inputs pins used as comparators and the pump drive circuit is connected to the output pins of the microcontroller. Figure 6 below shows the Arduino board.

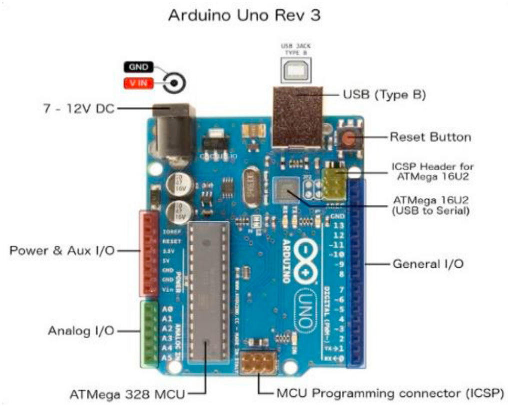

Figure 6: Schematic of Arduino Board.

IV. Water tank and pump

The tank store water for cooling the solar panel. It is equipped with the water pump inside for spraying water to the surface of the panel. The tank have input pipe supplying water into the tank and output pipe spraying water onto the panel. The water tank has control system that maintain water level all the time to avoid shortage and loss.

V. Water spraying pipes

Water spraying pipe is connected to the pump of water tank. The water praying pipe is attached on the top and beginning of solar panel to release water for cooling the panel. It has small pots for spraying water down the surface of the panel.

3.4. Experiment carried out

In this experiment, two solar panels where positioned together in the same direction and angle to measure their efficiencies. One panel is equipped with a microcontroller-based water spraying cooling system and the other one without a cooling system. In the experiment, voltages and currents were measured to determine the power generated by each solar panel and their efficiency.

In the experiment, 4 watts 300/400 mm red polycarbonate traffic light Emitting Diode was used to measure the efficiency of the solar panel. The lights operate at the rated voltage of 12 dc. The solar panel of 17-Watts 12V dc was used to measure the efficiency under hot atmospheric weather conditions. The solar panel was positioned Northwest direction at an angle of 30 degrees to the sky.

A. Solar panel without a cooling system

Table 2: Data gathered from the solar panel “WITHOUT” water spraying system.

Data of Solar panel (WITHOUT water spraying system)			
Time	**Input (Photovoltaic panel)**		
	Voltage (V)	**Current (A)**	**Power (W1)**
05:00	6.2	0.011	0.0682
06:00	20.2	0.22	4.444
07:00	18.2	0.33	6.006
08:00	17.9	0.42	7.518
09:00	17.9	0.46	8.234
10:00	17.1	0.51	8.721
11:00	17.8	0.48	8.544
12:00	17.9	0.48	8.592
13:00	17.4	0.47	8.187
14:00	17.4	0.41	7.134
15:00	17.7	0.37	6.549
16:00	16.9	0.25	4.225
17:00	16.9	0.12	2.028
18:00	13.9	0.024	0.3336
19:00	3.6	0.011	0.0396

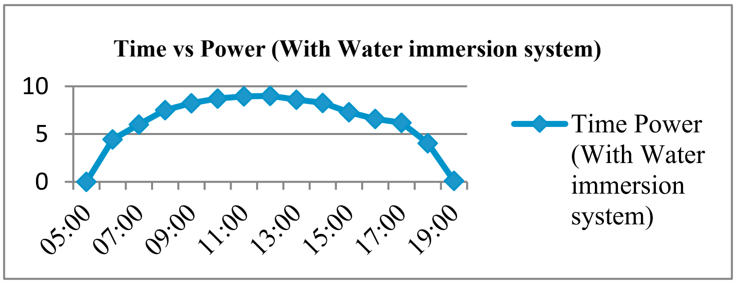

Figure 7: Solar panel equipped with the cooling system

B. Solar panel with the cooling system

Table 3: Data for automated microcontroller based water spraying cooling system for the solar panel.

Data of solar panel (With an automated Water spraying system)			
Time	Input (Photovoltaic panel)		
	Voltage (V)	Current (A)	Power (W)
05:00	6.2	0.011	0.0682
06:00	20.2	0.22	4.444
07:00	18.2	0.33	6.006
08:00	17.9	0.42	7.518
09:00	17.9	0.46	8.234
10:00	17.1	0.51	8.721
11:00	17.9	0.5	8.95
12:00	17.3	0.52	8.996
13:00	18.7	0.46	8.602
14:00	17.6	0.47	8.272
15:00	18.7	0.39	7.293
16:00	17.8	0.37	6.586
17:00	17.2	0.36	6.192
18:00	18.4	0.22	4.048
19:00	17.4	0.006	0.1044

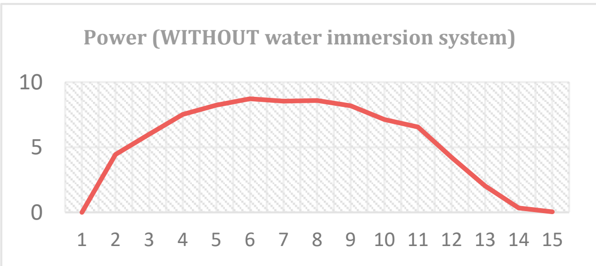

Figure 8: Graph of solar panel “equipped with” automated water spraying system

3.5. Measuring the solar efficiency

The efficiency of the solar panel is measured by a comparison of power generated by both solar arrays equipped with and without an automated water spraying system. Mathematically, efficiency is the percentage of the ratios of output power to the input power. In this case, the power generated by the solar panel without a water spraying system was considered as the reference to measure the efficiency. The comparison was made based on table 4 below. The graph presented in figure 9 was used to compare the power generated by each solar system. The automated water spraying system have its own energy source to supply its requirement. In efficiency calculations, the power consumed by the water spraying system is not considered.

Table 4: Comparison of the power generated with and without solar panel cooling

Time	Power (Watt) With Water spraying system)	Power (Watt) Without water spraying system)
05:00	0	0
06:00	4.444	4.444
07:00	6.006	6.006
08:00	7.518	7.518
09:00	8.234	8.234
10:00	8.721	8.721
11:00	8.95	8.544
12:00	8.996	8.592
13:00	8.602	8.187
14:00	8.272	7.134
15:00	7.293	6.549
16:00	6.586	4.225
17:00	6.192	2.028
18:00	4.048	0.3336
19:00	0.1044	0.0396

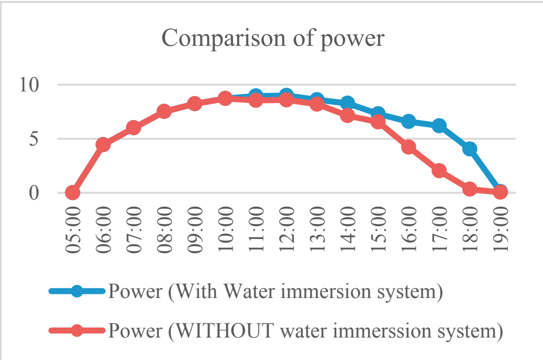

Figure 9: Graphical representation of table 4 (with and without water cooling)

The water sprayed solar panel has improved the power efficiency of the solar panel. It is mathematically expressed as:

$$Efficiency = \frac{(P_{with} - P_{without})}{P_{without}} \times 100\%$$

$$= \frac{(6.264 - 5.37)}{5.370} \times 100\%$$

$$Efficiency = 16.65\%$$

4. Conclusion

From the results of water sprayed solar algorithm, there is a considerable improvement in power generated by the solar panel with a significant increase in efficiency by 16.65 %. It is very important to ensure that solar panels do not exceed their operating temperature to improve the light absorption. Controlling the temperature at suitable range is necessary to improve sun absorption and power generation. This design has a major advantage of space saving when compared to adding more solar panels to improve energy generated. The use of a micro-controlled system reduced the construction cost and space. This design can be adopted by improving the prototype to achieve a commercially viable product.

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