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Thermoelectric Effect Based Themerature Controlled Photovoltaic System

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ABSTRACT

An intermittent nature of Solar Power Generation gets affects the efficiency of overall performance of Photovoltaic system (PV), the many reasons behind of that such as temperature of the panel, accumulation of dirt on solar panel, weather, the angle of the relative radiation to the panel and solar radiation availability etc. The temperature increment is one of the most challenging factors, that affects the performance of Photovoltaic systems (PV)which causes significant degradation in the solar cell's power output. To overcome this issue, an approach towards increasing these cells' power output is to utilize a cooling method by using thermoelectric cooling in order to reduce the cells' temperature. A cooling model has been developed to determine how long it takes to cool down the PV panels to its normal operating temperature, i.e., 30°C, based on the proposed cooling system. In this proposed model work, a thermoelectric (TEC) module with a heat sink at the back is attached to the back side of Photovoltaic panel. The role of the TEC module is used to absorb the heat generated on the surface of the photovoltaic panel in order to increase the efficiency of the system and so its power capacity. The paper also contains a formulation of Photovoltaic thermoelectric module equations referring to cooling capacity, power output at different ambient temperature and together with the electrical model of the Photovoltaic power generator.

Keywords : Solar Energy, Photovoltaic Cells, Thermoelectric Cooling, Peltier Effect

I. INTRODUCTION

Electricity consumption has increased sharply over the last two decades, mainly due to a rapid economic development, an absence of energy conservation measures and other contributing factor like rapidly growing population. Solar energy can be a major source of power, though the energy density is low and the availability is not continuous. It is now possible to utilized the energy by using photovoltaic conversion system. Solar power is the conversion of sunlight into electricity directly using photovoltaics (PV). Solar energy is coming to the forefront, global warming and state awareness are leading to more intensive use of non-polluting energies, photovoltaic solar power is in the stern. The sale of photovoltaic panels has increased by 40% a year for 10 years. The solar panels have proved their reliability. The cost of production of solar cells has also decreased. Solar energy had a second boost during the energy and pollution crisis. When the price of oil rose dramatically, photovoltaic solar panels began to be used for the first time in homes. However, the low efficiency of these cells and their high capital costs have had negative impacts on their popularity. Therefore, possible improvements to these cells' performance are widely appealing. The performance of these cells is highly dependent on cell temperature. Furthermore, it is clear that the cell temperature has a close tie with the ambient temperature. Accordingly, an innovative approach towards increasing these cells' efficiency is to utilize thermoelectric cooling in order to reduce the cells' temperature. Thermoelectric cooling can be described by the Peltier effect. This effect which occurs by heating or cooling one end of a circuit requires no operating fluids and therefore demands less maintenance and offers more reliability when compared to other cooling methods. Therefore, a combined TEC and PV design will be the subject of analyses. The combined TEC and PV system operates as a unit by converting the solar energy to electrical energy. The TEC module can either be supplied energy from an external source or utilize the energy converted by the PV module. In either case, the net power output remains the same. For this research, the latter was considered. An overall schematic block diagram of this system is presented in figure 1. The efficiency of the combined system can be influenced by various design and operation parameters. An operation parameter which can affect the performance of these systems is the windspeed. This effect can demonstrate negative or positive feedbacks on the system based on the operating conditions. Furthermore, design parameters such as the area can play a role in these combined systems' output. Moreover, the TEC current can change the efficiency of the system based on the operating conditions and an optimized amount can be calculated under certain circumstances.

In our project we are looking forward to optimize their efficiency in absorbing sun radiations. The methodology that will be used is using thermoelectric cooling (TEC) for cooling them down, to reduce the temperature at a certain degree inside the panel and therefore to work at its maximum efficiency. The challenge in this project is to solve the problem with thermoelectric cooling (TEC) used to cool down panels. This project is to develop a mathematical model responsible for detecting the temperature of the solar panel and being able to start the cooling once it exceeds the norms. But also, it does compute the appropriate time for the solar panel to be cooled down.

The project presents a solution focused on increasing efficiency of photovoltaic module by reducing losses due to warming photovoltaic cells. The solution consists in a thermoelectric effect cooling system applied to the back of photovoltaic module by using Peltier plates.

II. METHODS AND MATERIAL

1) BLOCK DIAGRAM

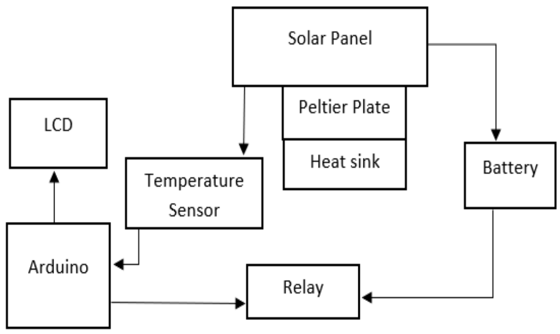

Fig. 1. Block Diagram of Proposed Model

The block diagram involves solar PV module with Peltier plates and heat sink attached at the back side of the Solar PV. The temperature sensor is connected to the Solar PV module. As the block diagram shown below we use temperature sensor and relay interface with Arduino and the status is shows on LCD. The sensor gives signal to Arduino which is programmed to get the temperature from the temperature sensor. Arduino controller is used to detect the temperature and to turn ON the relay if temperature exceeds above 30°C. If the temperature of solar PV module rises above 30°C then the Relay (which is in interface with Arduino) will turn ON by Arduino to flow the current to the Peltier plates to decrease the temperature below 30°C of the PV module. The power supply is provided by the battery which gets its power directly from solar PV.

2) SOLAR CELL

Solar cell is the basic unit of solar energy generation system where electrical energy is extracted directly from light energy without any intermediate process. A solar cell is basically a semiconductor p-n junction device. It is formed by joining P-type and N-type semiconductor material. Movement of electrons to the p-side exposes positive ion cores in N-side, while movement of holes to the n-side exposes negative ion cores in the p-side. This results in an electric field at the junction and forming the depletion region. When sunlight falls on the solar cell, photons with energy greater than band gap of the semiconductor are absorbed by the cell and generate electron-hole pair. These e-h pairs migrate respectively to n- and p- side of the PN junction due to electrostatic force of the field across the junction. In this way a potential difference is established between two sides of the cell. A semiconductor p-n junction is in the middle of these two contacts like a battery. If these two sides are connected by an external circuit, current will start flowing from positive to negative terminal of the solar cell. This is basic working principle of a solar cell. For silicon, the band gap at room temperature is Eg = 1.1 eV and the diffusion potential are UD = 0.5 to 0.7 V. Construction of a Si solar cell is depicted in Fig.1.

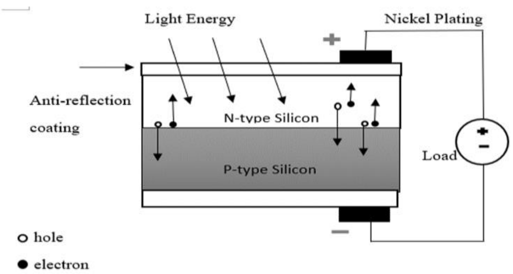

Fig. 2 : Construction of a solar cell

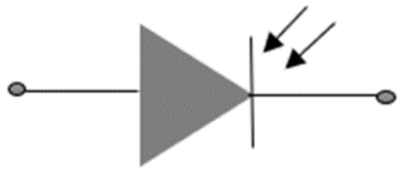

Fig. 3 : PV Cell Symbol

Solar Cell I-V Characteristics Curve diode in absence of light and in presence of light currents in the diode so that the diode law becomes:

$$I = I_0 \left[\exp\left(\frac{qV}{nkT}\right) - 1\right] - I_L$$

where I_0 = "dark saturation current"

q = electronic charge

V = applied voltage across the terminals of the diode

n = idealist factor

k = Boltzmann's constant

T = temperature

I_L = light generated current.

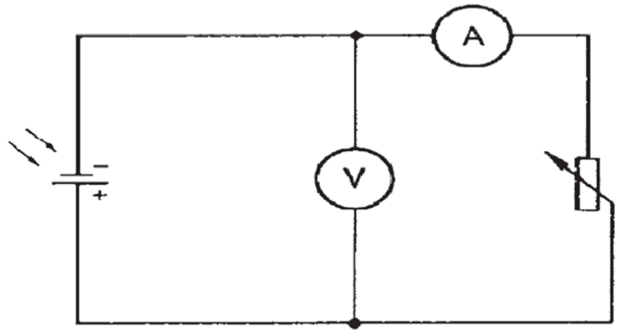

Fig. 4 : Circuit for V-I Characteristics of Solar Panel

A typical circuit for measuring I-V characteristics is shown in Fig.2. From this characteristic various parameter of the solar cell can be determined, such as short-circuit (I_{SC}), open-circuit voltage (V_{OC}) and the efficiency. The rating of solar panel depends on these parameters.

The short-circuit current is the current through the solar cell when the voltage across the solar cell is zero (i.e., when the solar cell is short circuited) is due to the generation and collection of light-generated carriers. For an ideal solar cell at most moderate resistive loss mechanisms, the short-circuit current and the light-generated current are identical. Therefore, the short-circuit current is the largest current which may be drawn from the solar cell.
The open-circuit voltage, V_{OC} is the maximum voltage available from solar cell and this occurs at zero current. The open-circuit voltage corresponds to the amount of forward bias on the solar cell due to the bias of the solar cell junction with the light-generated current.

The efficiency is the most commonly used parameter to compare the performance of one solar cell to another. Efficiency is defined as the ratio of energy output from the solar cell to input energy from the sun. In addition to reflecting the performance of the solar cell itself, the efficiency depends on the spectrum and intensity of the incident sunlight and the temperature of the solar cell.

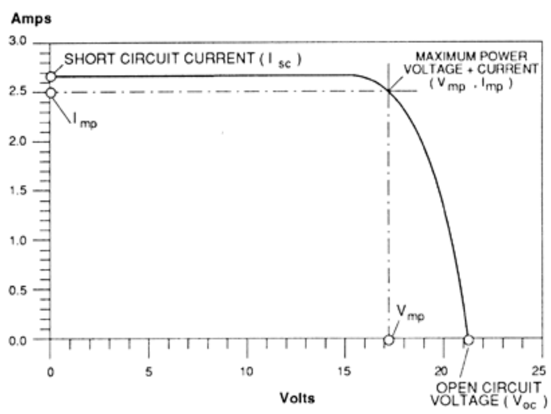

Fig. 5 : A typical I-V curve of a solar cell

3) PELTIER EFFECT

Thermoelectric coolers operate by the Peltier effect (which also goes by the more general name thermoelectric effect). The device has two sides, and when a DC electric current flows through the device, it brings heat from one side to the other, so that one side gets cooler while the other gets hotter. The "hot" side is attached to a heat sink so that it remains at ambient temperature, while the cool side goes below room temperature.

Two unique semiconductors, one n-type and one p-type, are used because they need to have different electron densities. The semiconductors are placed thermally in parallel to each other and electrically in series and then joined with a thermally conducting plate on each side. When a voltage is applied to the free ends of the two semiconductors there is a flow of DC current across the junction of the semiconductors causing a temperature difference. The side with the cooling plate absorbs heat which is then moved to the other side of the device where the heat sink is. Thermoelectric Coolers, also abbreviated to TECs are typically connected side by side and sandwiched between two ceramic plates. The cooling ability of the total unit is then proportional to the number of TECs in it.

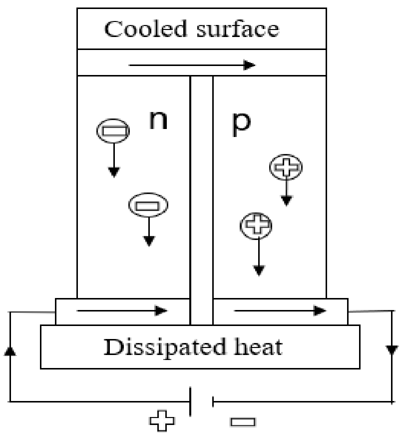

Fig. 6 : Peltier element schematic

Through the principle of Thermoelectric cooling (TEC) this research we'll be investigating through simulation, designing and experimenting on a prototype a system that will be used to; monitor the PV module's efficiency, temperature and effect of cooling down the PV modules using TEC. Thermoelectric devices mounted on the back of the PV modules will be controlled to assist in cooling down the PV module thereby reducing a decrease in the PV module's efficiency as a result of an increase in ambient temperature. A second (referent) panel is a panel without the modification which is used for comparison with modified panel, before and after the modification. That way, it can be directly shown that raise in electrical efficiency is a consequence of modification.

4) PHOTOVOLTIAC CELL MODULE

The PV cell model implemented in the calculations has a schematic as shown below. In this work, a thermoelectric module with a heat sink is considered to be attached to the back side of photovoltaic panel. The incoming irradiation from the top side crosses the glass and is absorbed by the PV cells. A percentage of the sunlight's energy is converted to electrical energy by the PV cells and the remainder is given back to the surroundings through convection and radiation.

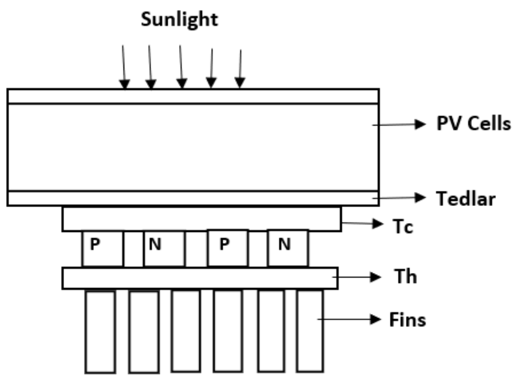

Fig. 6 : A schematic of hybrid PV cells combined with TEC modules

A TEC module is installed in the back of the model to reduce the cell temperature and increase the efficiency. As the TEC current increases, the cooling effect and also, the TEC's hot side temperature increase. In order to reach an adequate cooling for the TEC module, fins were installed as heat sinks in the back of the module to enhance the heat transfer to the ambient air.

The following equation can be represented to estimate the efficiency of PV cell with temperature variation

$$\eta=\eta_0[1-0.0045(Tcell-Tcell, ref)]$$

Where,

η_0 is the PV efficiency at reference conditions and $T_{(cell, ref)}$ is commonly assumed as 298 K. It is assumed that the power required to run the thermoelectric cooling module is provided by the photovoltaic panel itself. A TEC module can be defined by four characteristic parameters, namely, $Imax$, $Vmax$, $Qmax$ $\Delta Tmax$. The module parameters can be calculated by the following equations:

$$S_m = \frac{V_{max}}{T_a} \quad (1)$$

$$R_m = \frac{(T_a-\Delta T_{max})V_{max}}{T_a I_{max}} \quad (2)$$

$$K_m = \frac{(T_a-\Delta T_{max})V_{max} I_{max}}{2T_a \Delta T_{max}} \quad (3)$$

Where Sm, Rm and Km represent the TEC module's Seebeck coefficient, electrical resistance and thermal conductance respectively.

Q_c which is the total absorbed power at TEC's cold side can be calculated by:

$$Q_c = S_m I_c T_h - \frac{I^2 R_m}{2} - K_m \Delta T \quad (4)$$

Similarly, Q_h is the total amount of heat generated at the hot side:

$$Q_h = S_m I_c T_h + \frac{I^2 R_m}{2} - K_m \Delta T \quad (5)$$

ΔT represents the temperature difference between the hot and cold sides of the TEC module:

$$\Delta T = T_h - T_c \quad (6)$$

In order to calculate the temperature at the junction between the tedlar and the PV cells, the following equation is presented:

$$T_{tedlar} = T_c + Q_c R_{jc} \quad (7)$$

It is clear that the net power output of the combined system can be calculated by extracting the TEC power consumption from the PV cells power output:

Net output power = PV's generated power – TEC's power consumption

5) MODEL DEVELOPMENT

The model will be based on controlling the operation of the thermoelectric device to reduce the PV temperature when it tends to go beyond 30°C.

The model will also consist of two systems:

- A PV module only
- A PV module with a TEC and its associated control circuit.

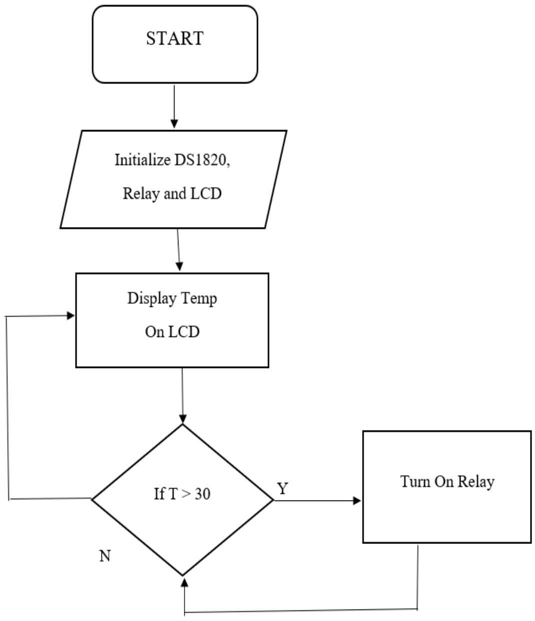

Fig. 7 : Flowchart of Maximizing PV module's power output through cooling by thermoelectric device

The differences between the net power outputs for each case were calculated in order to reach an accurate analysis. The TEC modelling and design parameter are

Parameter	Value	Unit
Vmax	15.4	Volts
Imax 6	Amps	
Area 494	mm	
Qmax	0.80	Watt

Next, the results will be presented and a comparison between cases with and without thermoelectric cooling will be conducted.

III. RESULTS AND DISCUSSION

It is observed that optimum thermoelectric cooling increases the efficiency and the effect of cooling is more realizable at higher irradiations. Furthermore, as the irradiation increases, the power generation is also increasing while the efficiency of the PV cells is reduced due to excessive heating.

Table 1 : Selected power outputs at different ambient temperatures and irradiations

Temperature (Celsius)	Power Output with Cooling	Power Output without Cooling	Percentage Increase
26.85	2.75	2.66	3.26
36.85	2.55	2.46	3.24

Clearly, the performance of PV cells is gradually reduced as the cell temperature rises Furthermore, the ambient temperature affects the cell temperature greatly. The TEC consumes power from the PV cell in order to operate and cool the panel. However, this power consumption reduces the net power output. In order to optimize the net power output based on the efficiency increase and power consumption, in this research, the maximum net output power from the PV cell while under the effect of TEC has been calculated and its respective current was used for the rest of calculations.

IV. CONCLUSION

Research has proven that maintaining a photovoltaic panel's operating temperature at approximately 30°C can reduce a decrease in the efficiency of a photovoltaics' power output. At the time of writing this paper research for using TEC had been conducted through prototype and obtained data prove that a TEC can be a practicable active cooling alternative. It is only when a TEC is used that there isn't a need for a medium to extract heat from the photovoltaic panel. The prototype's research outcomes will be compared to that of a referent photovoltaic panel to conduct a cost analysis of the PV-TEC system.

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