Effect of Temperature on Electrical Parameters of Photovoltaic Module

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Abstract: In this study, the temperatures of the front glass, back sheet, and solar cell (SC) in the rear electrical contact of the PV module during heating, and the open circuit voltage and short circuit current corresponding to these temperatures were experimentally investigated. Measurements were conducted in the city of Termez in conditions of an air temperature of 30ºC and solar radiation intensity of 850-950W/m². Two mono c-Si PV modules with the same electric power were selected for the experiment. Three K-type chrome and alumn combined thermocouples were used to measure the temperatures in the layers of the first PV module. During the observations, it was found that the temperature of the PV module glass differs from the back sheet temperature by ~20ºC, and from the temperature of the back electrical contact of the SC by ~25ºC. Also, according to the temperature difference, the open circuit voltage of the PV module decreased from 21V to 19.3V, and the short circuit current increased from 0.65A to 0.75A. During the experiment, the values of electric power changed by ~11-11.6W.

1 INTRODUCTION

Solar energy is going to play an important role in the main supply of electricity in the future. The use of PV modules in the usage of solar energy is the most promising type [1]. The temperature of the PV module is an important parameter that changes the electricity production of PV systems. In addition, it also depends on several parameters such as the thermal properties of the materials used in the manufacture of PV modules, the types of SC, the installation angle of the PV module, and the climatic conditions [2]. However, there are no global monitoring stations to measure such climate conditions and other meteorological parameters, including solar radiation intensity [3]. Despite the advantages of using PV modules, there are disadvantages due to their changing characteristics from time to time. This may affect the performance of the consumer's system. Therefore, an accurate PV module power forecast is required [4].

It is known that an increase in the intensity of solar radiation causes a rise in the SC temperature. Several studies have found that high temperatures can reduce PV module efficiency by up to 12% [5]. Nouar Aoun researched several methods to evaluate the effect of temperature on a PV module [6]. Due to the effect of temperature, only 15-20% of the solar energy in the PV module is converted into electrical energy [7]. Including that part of the solar radiation energy is returned from the surface of the PV module [8]. In addition, dust falling on the surface has a negative effect on the PV module's working potential [9]. A large amount of dust on the surface of the PV module causes it to heat even more [10]. However, the main factor affecting the reduction of PV module output power is high temperature [11]. This is due to the properties of the crystalline silicon semiconductor, a temperature increase of 1ºC leads to a decrease in SC efficiency by about 0.5%. Figure 1 shows the relationship between the efficiency and temperature of a silicon-based PV module [12].

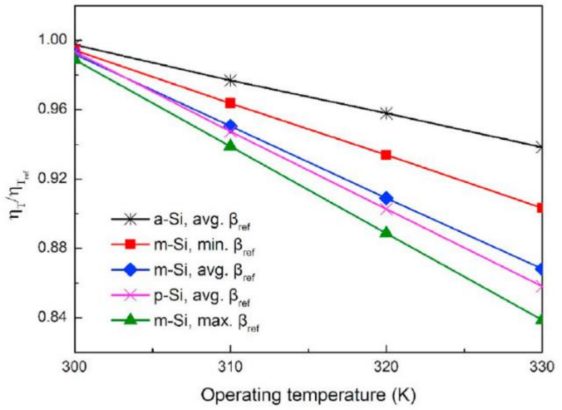

Figure 1: Temperature dependence of PV module efficiency [13].

Malaysian scientists studied the effect of temperature on the PV module by conducting experiments using K-type thermocouples in indoor and outdoor environments [13]. The authors of the study [14] measured the temperature of floating and ground-mounted PV modules using thermocouples and investigated the change in PV module efficiency. Also, Ahmed Amine Hachicha et al. compared the temperatures and electrical parameters of a PV module and a photovoltaic-thermal system using a PT100 thermocouple [15]. A paper by Yogeswara Rao Golive et al., measured the temperature of the SC, ethylene-vinyl acetate (EVA), front glass, and back cover of a c-Si PV module during heating and cooling using T-type thermocouples. In this case, the difference between SC and the back cover was 2.35ºC [16].

It is important to measure the temperature distribution in the parts that make up the PV module due to the decrease in the efficiency of the PV module under the influence of high temperature. This article describes the results of experimental measurements of temperatures and electrical parameters in the PV module structure in hot climate conditions.

2 METHODS AND MATERIALS

This research work differs from the works in the literature mentioned above. Two identical mono c-Si PV modules were used in the experiment. The electric power of PV modules is 15W and consists of 36 SC. The PV modules are mounted on a support device that has a two-axis twist at the same angle. The base device also has a place for measuring instruments (Figure 2).

In the study, the temperatures of the front glass, back sheet, and rear electrical contact of the SC of the first PV module were measured using K-type thermocouples (Model: PeakTech 3340 DMM, measurement range: -20°C to +760 °C). The open circuit voltage and short circuit current of the second PV module was measured using a Multimeter (Model: CHY VC-9205AL, measurement range: 200m V to 1000V, 2mA to 10A). The radiation intensity was recorded using a digital Solar Power Meter (Model: CEM DT-1307, measuring range: up to 1999W/m^2).

Figure 2: Experimental devices for the experiment.

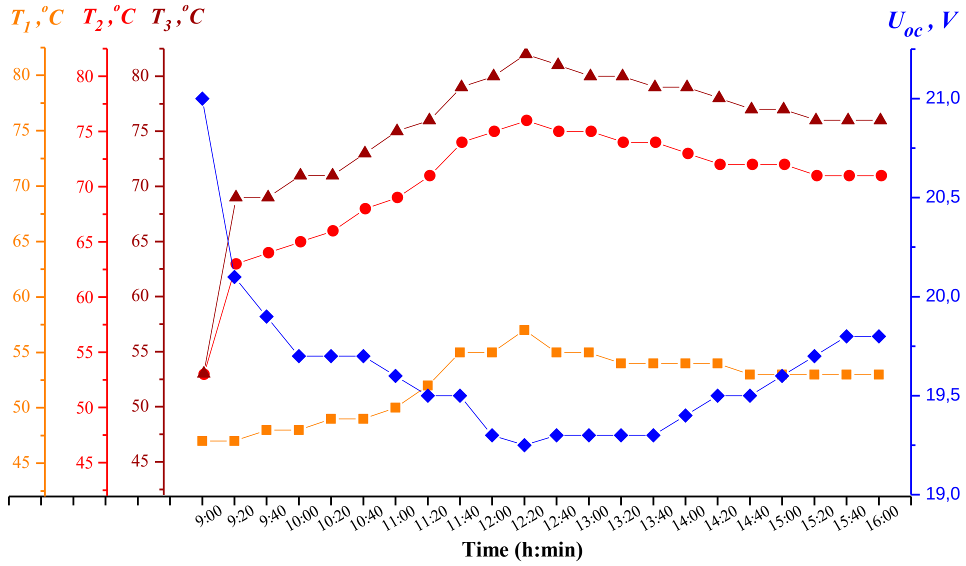

Figure 4: Dependence of PV module open circuit voltage on temperatures of SC parts.

The experiments were conducted in the open air on the territory of Termez State University, at 37°13′27″ north latitude, 67°16′42″ east longitude. The data were measured on October 4, 2022, with an air temperature of 30ºC and solar radiation intensity of 850-950W/m^2, between 9:00 a.m. and 4:00 p.m. During the measurement, the position of the PV modules in the device was changed from 34º to 68º (in tracker mode) with a south orientation.

Three K-type chrome and aluminum combined thermocouples were placed as shown in Figure 3 to determine the temperatures in the components of the SC.

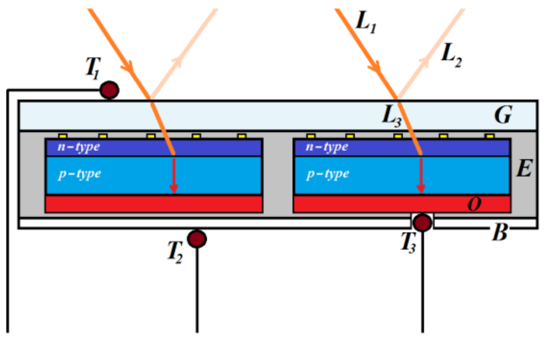

Figure 3: Installations of thermocouples in the PV module. T_1, T_2, T_3- thermocouples, L_1 - falling radiation, L_2 - returned light, L_3 - absorbed light, *G* - front glass old, *E* - EVA, *O* - rear electrical contact, *B* - back sheet.

In the experiment, the temperature of PV module parts and corresponding electrical parameters were measured at 20-minute intervals. In the results, the dependence of the PV module open circuit voltage on the temperatures in the SC parts, and the dependence of the short circuit current on the intensity of solar radiation were studied. Another goal of the outdoor experiment is to determine the optimal installation angle of the PV module and the zenith point of the sun for the conditions of Termez.

3 RESULTS AND DISCUSSION

The temperature of PV modules depends on the value of the incident solar radiation intensity. When the radiation passes through the front glass of the PV module, some of it is reflected, but most of it is absorbed by the semiconductor material. As a result, the temperature of the SC increases and the heat accumulates in the rear electrical contact of the SC. Therefore, the temperature of the glass of the PV module differs by ~20-25ºC from the temperature of the back sheet and the back electrical contact of the SC (Figure 4).

As you can see, the temperature of the PV module increased between 9:00 AM and 12:20 PM and then decreased again after the solar zenith point. Measurements were made at equal times before the zenith point of the sun (3.5 hours) and after the zenith point (3.5 hours). Nevertheless, SC temperature did not approach the initial value. This process can be explained by the retention of heat in SC for a certain period. It can be seen that the PV module open circuit voltage initially decreased by ~1.75V as the temperature increased, and then increased by ~0.55V after the zenith point of the sun. However, it is not difficult to understand that the PV module does not reach its initial value due to the heat accumulated in the module.

The increase of short circuit current in a PV module under the influence of temperature is a less useful process, and the change of short circuit current mainly depends on the intensity of solar radiation (Figure 5).

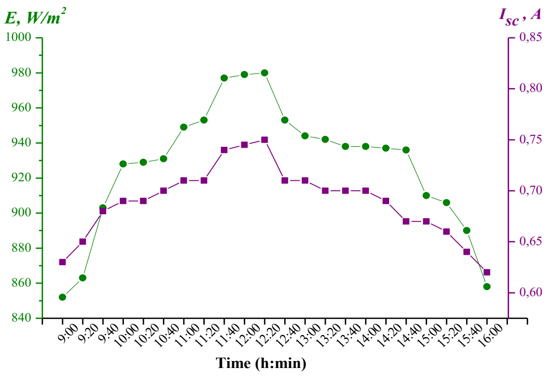

Figure 5: Dependence of short circuit current on the intensity of solar radiation.

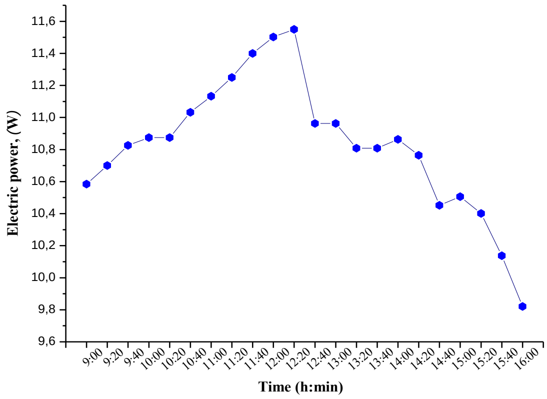

Figure 6: Dependence of electric power on time of day.

It can be seen in Figure 5, the intensity of solar radiation starts from 852W/m^2 at 9:00 and the maximum value reaching the solar zenith point is 980W/m^2. It can be seen that the value of the PV module short circuit current also increased from 0.63A to 0.75A according to the intensity of solar radiation.

Based on the above information, it was observed that the electric power increased from 10.5W to 11.5W (Figure 6). At the end of the experiment, the electric power decreased to 9.8W. This is a very bad indicator for a PV module with a maximum power of 15W. Such a decrease in electric power can be explained by the depletion in the open circuit voltage due to the heat accumulated in the PV module and the fading of the intensity of solar radiation.

4 CONCLUSION

It is a necessary task to study the causes of electrical losses in PV modules. The main factor that reduces the efficiency of PV systems is high temperature. In this study, the influence of high temperature on the performance of PV modules in the conditions of the city of Termez, which is located in the southernmost point of Uzbekistan, was studied. In the study, temperatures and electrical parameters of two PV modules attached to a two-axis support device were measured in the tracker mode. Based on the results obtained from the experiment, the following conclusions were made:

1) The increase in the temperature of PV modules depends on the intensity of solar radiation falling on its surface, and the heat generated by the infrared field of radiation is collected in the back electric contact SC. Therefore, the temperature of the SC can be higher than the temperature of the front glass;

2) The increase in short circuit current in the PV module under the influence of high temperature is not enough to significantly contribute to its power value;

3) Due to the high temperature mainly reducing the open circuit voltage of the PV module, its electrical energy loss reaches ~35%.

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