Analysis of the influence of temperature on the operating mode of a photovoltaic solar station

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Abstract. In this paper, the influence of overheating on the performance of photovoltaic modules was evaluated. The experimental observation was carried out on the basis of a 20 kW photovoltaic station with 60 photovoltaic modules. It was found that an increase in the number of solar cells with overheating in the photovoltaic module leads to an increase in output power losses. The temperature of the Feb is one of the main factors that determine the electrical parameters of the Feb and its efficiency in General. An increase in the SE temperature leads to a decrease in the band gap, which gives a slight increase in the photocurrent due to the expansion of the photo-response spectrum into the long-wave region. However, this increase in photocurrent does not compensate for the decrease in Uoc and the filling factor of the load characteristic FF due to an exponential increase in the saturation current with increasing temperature, which leads to a significant decrease in efficiency with increasing temperature. The width of the band gap of semiconductors decreases with increasing temperature, and the absorption edge shifts to the region of lower energies. Continuous analysis of the presence of "hot spots" and replacement of defective modules during the initial period of operation can increase the output power and shelf life of the photovoltaic system.

1. Introduction

It is known that the service life of a photovoltaic battery (PVB) depends on the temperature conditions of its operation. First, the solar energy conversion efficiency of the PVB decreases with increasing temperature [1-4]. Second, a PVB system consisting of materials with different temperature coefficients of expansion, due to a strong temperature gradient (repeated heating during the day and cooling at night), the PVB is likely to destroy both the commuting buses and the PVB as a whole. Therefore, purposefully cooling the temperature of the PVB, you can increase the time of its operation. One of the methods of cooling the PVB is cooling using thermoelectric devices [5-7].

The paper presents the results of experimental studies of the parameters of a thermal power device (PTED) cooled by a thermoelectric battery. The temperature was measured by five copper-constantan thermocouples and one chromel-alumel thermocouple located on the front side of one of the SC. A thermocouple measuring the temperature of the PVB on the back surface and the temperature of the" hot " side of the TEB was located between the EVA and the ceramic protection of the TB. The cold junction was placed in a thermos with ice, at a temperature of 0 °C.

Aging and degradation of photovoltaic modules significantly depend on climatic and environmental conditions, such as ambient temperature, relative humidity, solar radiation, and dust [1-4].
In [5-7], the influence of temperature on the main parameters of the PVB is also studied. It is noted that in the sharply continental climate of Central Asia, in particular Uzbekistan, in the hot period of the year (May-September), due to an increase in its own temperature to 45-60 °C, the efficiency of PVB decreases, i.e. "overheating" occurs in PVB. "Overheating" is a discrepancy between the declared parameters of the PVB tested under STC conditions (standard testing conditions) [8-10]. Due to the decrease in Uoc, the charging current of the battery in the electric energy storage system is significantly reduced.

2. Methods and Discussion of Results

One of the most common defects in photovoltaic modules is "hot spots". This phenomenon occurs when the current generated by this cell (element) is less than the current generated by the other elements of the module [11-13]. A defective (with reduced parameters) cell in a chain of sequentially connected cells is inversely displaced and dissipates energy in the form of heat instead of generating electricity. In addition, a similar phenomenon occurs when local shading or when elements are heated locally. As an example, we present data on the assessment of the influence of temperature [14, 15] on the operating energy parameters of PVM type SPP1.1.

| Energy parameter                  | Temperature, °C |
|-----------------------------------|-----------------|
| No-load voltage Uoc, V            | 22.4, 20.5, 17.8 |
| Short circuit current I_sc, A     | 2.93, 2.98, 3.05 |
| Current at the point of maximum power SC, A | 2.71, 2.76, 2.83 |
| The maximum power of the PVM, W   | 50.8, 45, 37.8  |

Thus, hot spots can also occur in fully functional modules. Therefore, it is necessary to assess the stability of various types of modules to the occurrence of hot spots.

**Figure 1.** Dependence of the electrical efficiency of various types of SC on the operating temperature [8]

When thinking about building your own solar power plant, everyone dreams of completely abandoning wired electricity. In order to analyze the reality of this idea, we will make a small calculation.

It is easy to find out the daily electricity consumption. To do this, just look at the invoice sent by the energy company and divide the number of kilowatts indicated there by the number of days in the
month. For example, if you are offered to pay for 330 kW h, it means that the daily consumption is 330/30=11 kW·h.

The calculations should take into account the fact that the solar panel will generate electricity only during daylight hours, and up to 70% of the generation is carried out in the period from 9 to 16 hours. In addition, the efficiency of the device depends directly on the angle of incidence of sunlight and the state of the atmosphere [16, 17].

Different types of SC have different characteristics depending on the temperature. Elements made of amorphous silicon, for example, have output characteristics that are less affected by temperature compared to SC made of crystalline silicon, which is associated with a larger band gap. Thin-film cadmium-sulfide SC retain high efficiency up to a temperature of 100°C [18, 19]. Gallium arsenide elements maintain their effective operation at very high operating temperatures (up to 150 °C).

Hot spots can occur in a photovoltaic module when the solar cells do not match in parameters or have certain defects, or when one or more elements in the module are partially shaded or poorly glued to the substrate. A mismatch in the current of an individual element can occur due to any mechanism that can cause a decrease in the short-circuit current of this element compared to other elements included in series in the module. The heat release in a hot spot for any faulty or shaded cell depends on how the elements in the module are connected. In General, increasing the number of elements sequentially increases the power dissipation, and increasing the number of elements in parallel reduces the power dissipation of the "hot" cell.

The possibility of using thermal imaging to detect hot spots in the module was considered. To detect hot spots, the module's leads were shorted, and an IR-image was obtained from the back of the module. The characteristics of the photovoltaic module are shown in Table 2.

| Table 2. Technical characteristics of photovoltaic modules (average values) |
|-------------------------------------------------|
| Efficiency of the module | $\eta_m$ | % | 13.09 |
| Voltage at the point $P_{\text{max}}$ | $V_{\text{mp}}$ | V | 29.5 |
| Current at $P_{\text{max}}$ | $I_{\text{mp}}$ | A | 7.20 |
| No-load voltage | $V_{\text{oc}}$ | V | 36.0 |
| Short circuit current | $I_{\text{sc}}$ | A | 7.80 |
| Temperature coefficient $V_{\text{oc}}$ | $\beta_{\text{Voc}}$ | %/°C | -0.37 |
| Temperature coefficient $I_{\text{sc}}$ | $\alpha_{\text{Isc}}$ | %/°C | 0.06 |

FLIR E6 allows you to get an accurate and detailed heat map of any surface. Each pixel of the resulting image contains temperature data. The infrared matrix based on the microbolometer has a sensitivity that allows you to determine temperature differences between adjacent pixels of only 0.06°C. The FLIR E6 thermal imager is equipped with a full-focus lens, which makes it easy to control it by pressing a single button. The MSX function provides maximum detail of the resulting images.

The design of these temperature measuring devices resembles that of pyrometers. They have a hybrid chip as a receiving element of the infrared radiation flow. With its photosensitive epitaxial layer, it senses the IR stream through a highly alloyed substrate. The device of the thermal imager receiver with a hybrid chip is shown in the picture [20, 21].

The temperature at different points of each photovoltaic module was obtained from color visualization of IR images.

An infrared image of the back of the module with hot spots is shown in Figure 2.

Photovoltaic modules were studied during 2018, which is described below. In the passport data, PVM indicates the temperature coefficients of current and voltage, usually within the range of $+10 \div +80^0\text{C}$. However, in real conditions of a hot climate, the decrease in efficiency due to an increase in temperature is more than 50% of the passport value. According to world standards, photovoltaic modules are assembled from 36 solar cells approximately equal to 18-20 V (0.50-0.56 V / cell) at 25°C. This voltage margin is not enough to compensate for the decrease in the operating voltage when the module is heated (by solar radiation) – the temperature coefficient of the idle voltage for silicon is 0.4%/degree, and the temperature coefficient of the current is positive (0.07%/ degree) [22,23,24,25].
Thus, under the conditions typical for the regions of Uzbekistan in the summer, PVB made from 36 SC can not work effectively due to a decrease in $U_{o,c}$. The temperature of the PVB was measured on the front surface and the back side of the SC at different values of the ambient temperature. Measurements carried out in July-August 2008 at a wind speed of 1-3 m/s, showed that the temperature reaches 72 °C (at a temperature in the shade of 45-48 °C). This leads to a decrease in $U_{o,c}$ from 21.5 (passport value) to 16.4-16.5V in real conditions [26-35].

![IR image of the module](image)

**Figure 2.** IR image of the module

The paper analyzes the performance of a 20 kW photovoltaic plant consisting of 60 photovoltaic modules. The total array was divided into two sub-arrays. One had hot spots, the second array had no spots. Modules with hot spots were identified by thermal imaging control and the results are given in Table 3 and Figure 3 respectively.

| Parameter                              | Array without hot spots | Array with hot spots |
|----------------------------------------|-------------------------|----------------------|
| Efficiency ratio, PR                   | 0.78                    | 0.65                 |
| The rate of degradation, DR (%/year)   | 1.49                    | 3.15                 |
| Maximum temperature of the module cell, °C | 78.6                    | 122.2                |

**Figure 3.** Comparison of power generation from different arrays (shown in module 1)
3. Conclusions

The paper evaluated the effect of a cell with hot spots on the performance of an array of photovoltaic modules. The experimental observation was carried out on the basis of a 20 kW photovoltaic station consisting of 60 photovoltaic modules divided into two groups - an array without a hot spot and an array with a hot spot. We analyzed (1) PR – efficiency coefficient, (2) DR – degradation rate and (3) temperature of the studied photovoltaic modules. A high DR of 3.15% / year was observed in a photovoltaic array with a hot spot.

It was found that the presence of "hot spots" of solar cells in the photovoltaic module leads to an increase in output power losses. The average PR is significantly reduced (from 0.78 to 0.65) due to the presence of hot spots in the photovoltaic modules. Therefore, it is important to choose materials for the production of solar cells that have high thermal stability. Obtaining infrared images of modules will help increase the power output and lifetime of the photovoltaic system by detecting hot spots early. Thus, the use of concentrated solar radiation in photovoltaic installations can improve the energy performance of photovoltaic modules not only by increasing the specific power, but also by stabilizing the temperature conditions of solar cells in photovoltaic modules.

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