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Modeling and Calculation of Energy Losses in Solar Panel Systems Under Various Installation Conditions

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Keywords: The paer search was conducted using the keywords: solar battery, efficiency, energy losses, assumptions, modeling, tilt angle, tracking system to refine results.
Publication Timeframe: The articles considered were published between 2017 and 2024. Research Focus: This study models and analyzes energy losses in solar panel systems under different installation conditions to identify key factors affecting efficiency and optimize system performance.

Abstract: Calculating energy losses in solar panel systems is a highly relevant topic given the growing interest in renewable energy sources. Under different installation conditions, such as orientation, tilt angle, shadows, and atmospheric conditions, you may notice significant variations in the efficiency of solar panels. Research in this area can help determine the optimal placement of solar panels to maximize energy benefits. This includes studying the influence of geographical location, climatic conditions and battery specifications on their performance. Understanding the energy loss in solar panel systems under different installation conditions allows the design of more efficient systems that can be applied in different climate zones and operating conditions. This is important to improve the availability of solar energy as a clean source of renewable energy and reduce dependence on traditional energy sources. The work describes the process of entering some assumptions, followed by calculating energy losses in the entire system of generating electrical energy using a solar panel, under these assumptions. As assumptions, both situations dependent on the experimenter and situations not dependent on him are indicated. An example of such a case would be situations where errors occur during the tracking system or the horizontal installation angle. Subsequent assumptions are also introduced, but the result remains uniform and unchanged.

1 INTRODUCTION

The main problem of modern energy, in addition to the depletion of fossil fuels in individual countries, is its threat to the global environment. Accelerated industrialization and population growth in Uzbekistan (according to UN forecasts, by 2030 the country's population will increase to 37 million people) can significantly increase the economy's need for energy resources and narrow the possibilities of their use as raw materials. The prospect of using solar energy in Uzbekistan is one of the key topics for the development of alternative energy. Increasing the efficiency of using solar energy in economic sectors is one of the urgent tasks of the development strategy of the Republic of Uzbekistan. At present, the design, creation and operation of a solar photovoltaic power plant (SPPP) in order to save primary energy resources requires solving many scientific and technical problems. Increasing the efficiency of using

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SPPP in the regions is a very urgent problem, the solution of which will improve the technical and economic characteristics of solar energy equipment, optimize its energy parameters and operating modes, taking into account the changing load of solar radiation energy.

In addition, the benefits of using solar technologies include energy independence, creation of employment opportunities, acceleration of electrification of rural communities in isolated areas, and diversification and security (stability) of energy supply.

Currently, various experimental studies are being conducted to improve the efficiency of the developed solar batteries (solar panels (SP)). In this case, researchers conduct studies using various methods and techniques for installing SP. Some researchers use cooling systems to improve the efficiency of SP. To improve the efficiency of photovoltaic modules (PVM), in (Skoplaki, Palyvos, 2009; Siecker, Kusakana, Numbi, 2017), the solar panel (SP) is cooled using an air flow, where an air gap is made on the back of the solar panel, through which a fan blows air. Also in (Agyekum, PraveenKumar, Alwan, Velkin, Shcheklein, 2021), the efficiency of two-sided cooling of a solar battery was studied. With the help of this design, a temperature difference of 23 °C was achieved, which led to an increase in the energy generated by the solar converter by 1.53%. In (Sharaf, Yousef, Huzayyin, 2022; Suherman, Sunarno, Hasan, Harahap, 2020; Tozhiboev, Sultonov, 2021), similar work is described in detail.

But the main methods are tracking systems of various designs. Solar electric systems with tracking systems have been well studied experimentally. Mathematical modeling of the process of changing the efficiency of energy production of the SP, when installed in different positions relative to the sun, has not been sufficiently considered. The mathematical model makes it possible to calculate the optimal angle of installation of the SP horizontally and vertically, which reduces production costs for the installation of the SP. Therefore, the development of mathematical calculations (models) is relevant.

2 METHODS

Initially, the problem itself is as follows. Let there be a solar battery with an output power of 100 A, an output voltage of 12 V and a current of 8.3 A. This solar battery is installed on a certain area without any obstacles for the sun's rays falling on its surface. And let this battery ideally move in the direction of the sun, and the sun's rays fall perpendicularly, depending on its own latitude and time of day. It is known that to determine the output energy or, more precisely, the work performed during the generation of electric current, it is necessary to use Einstein's equation for the photoelectric effect (1).

$$h\nu = A + \frac{m_e v^2}{2}, \qquad (1)$$

where h is the plank constant equal to 6,626 • 10^{-34} J • s: A- work function of an electron leaving its orbit, for silicon 4.3 eV; ν- frequency of incident photons; m_e- the mass of an electron is equal to 9,1• 10^{-31} kg; v- speed of electron.

To calculate the energy loss in solar panels, let us first focus on the sun's own incident energy, which falls on 1 m^2 of the earth's surface under normal daily illumination. To do this, it is sufficient to use the change in the solar constant for the entire year. As is known, the Earth moves in an ellipse, due to which 1.412 kW of energy falls on m^2 of the surface at the beginning of January, and 1.321 kW at the beginning of July with a linear change, without taking into account the movement of other space objects and weather conditions. That is, from this we can conclude that it is possible to calculate this energy for a certain day of the year from (2).

$$E_s = E_{1.2} \mp \frac{E_1 - E_2}{181} * d = \begin{cases} E_1 - \frac{E_1 - E_2}{181} * d \\ E_2 + \frac{E_1 - E_2}{181} * d \end{cases} \qquad (2)$$

where, E_s- daily value of constant luminosity; E_1- luminosity in early January; E_2- luminosity in early July; d- number of days from the beginning of the year.

In (2) in the fraction itself the difference in energies is calculated, which increases due to the number of days. Since from January to the beginning of July there are 181 days and there is a decrease, the first equality is used, and then the second.

Next, when the daily energy is determined, it can already be substituted into (3), where the dependence on the zero meridian of latitude is used, that is, the distance from the equator. In this case, the module is set in the direction, both for the northern and southern latitudes, and due to the difference in time, that is, the difference relative to midday, when the Sun is at its maximum.

$$E_t = \frac{|t_{12} - t|}{t_{12}} * \frac{E_s}{2} + \frac{|\alpha_0 - \alpha|}{\alpha_0} * \frac{E_s}{2} \qquad (3)$$

where, t_{12}- constant equal to 12 hours, that is, noon; t- present time; α_0– zero latitude (equator), 90 degrees; α– the latitude at which the collector is located (south or north does not matter).

When the hourly energy in watts was finally calculated, it was safe to say that all that was left was to apply the efficiency of the panel itself (4).

$$E' = E_t \eta = E_t * 14\% \quad (4)$$

Now, it can be specified that with the error-free movement of the panel towards the Sun and the indication of the angle of inclination relative to the located latitude, as well as the absence of any other interference, the outgoing energy will be as follows (4).

And when the ideal case is precisely defined, the following assumptions can be introduced:

1. The installed solar panels do not have sensor systems for monitoring the movement of the sun, but the angle of latitude and other parameters are precisely specified, that is, the absence of sensors is the only difference from the ideal case;
2. When turning towards the sun, the solar battery is behind by 5 degrees;
3. Dependence of the angle of inclination on the latitude.

To describe the first assumption, it is enough to indicate that the energy received by the solar battery is calculated according to (5), while in order not to have the condition that the opposite vectors are reduced with the primary ones, only 1 quarter is used. But also at the same time due to the fact that with constant tracking of the sun, all the energy is output, and in this case there is a small sequence of the energy coefficients themselves, tending to half of it, due to which in 1 quarter one sixth of the total angle is taken. Therefore, to calculate the sum of such a sequence (6), it is enough to use (7).

$$E_n = E' \cos n, n \in (0.30) \quad (5)$$

$$S(E_n) = E' \cos 1 + E' \cos 2 + \cdots + E' \cos n = \sum_{i=1}^{29} E' \cos i = E' \sum_{i=1}^{29} \cos i \quad (6)$$

$$E_1 = \int_1^{29} E' \cos x \, dx = E' \int_1^{29} \cos x \, dx = E' (\sin x)|_1^{29} \approx \frac{E'}{2} \quad (7)$$

The specified approximate calculations are compensated due to previously unspecified weather conditions, movement of other bodies, etc. Based on this, they can also be considered as introduced in the calculation. Thus, the gain in a standing position and taking into account half of the entire revolution will be 75%. That is, the lost energy is equal to a quarter of the total energy received.

If, when turning the solar panel towards the sun, the solar battery will lag behind by some value, then in the first case this slowdown was and the sum of the slowdown coefficients - cosines. In the absence of tracking, losses to significant energy would be observed. in the selected case, this constant is single and is the cosine of 5 degrees, multiplied by the total revolution, that is, this conclusion will lead to expression (8).

$$E_2 = 180 * E' \cos 5 = 180 * E'k \quad (8)$$

$$k = \cos 5 = 0.996194698 => k = 99.6194698\,\% \quad (9)$$

That is, the total loss in this case will be 0.38%.

In the calculations, we can consider the third assumption, that is, the derivation of the general pattern of the location of the angle, the tilt relative to the horizon, depending on the available latitude. If we indicate that the centers of the Earth and the Sun are on the same straight axis, and both objects do not change the axes of their rotation, then the pattern is extremely elementary, simple and is defined as the equality of the latitude and the angle of the solar panel itself, due to the fact that the lines derived from the center of the planet in this case will be directed in different directions, and if we use the same angles relative to the horizon, that is, the surface of the earth, then these derived lines will be directed directly towards the sun itself.

Consequently, the angle of rotation depends on the latitude as follows (10).

$$\varphi = (180 \pm) 2\alpha, \alpha \in [0,90] \quad (10)$$

Although this pattern is elementary, it is valid. But this is for two cases, to reveal this pattern, it is enough to apply (11).

$$\varphi = \begin{cases} 180 - 2\alpha \\ 2\alpha \end{cases}, \alpha \in [0,90] \quad (11)$$

In case of being in the northern hemisphere, the first expression is used in the direction of the luminary, and in case of being in the southern hemisphere, the second equality is used.

Also, in case of any deviation, it is enough to calculate the doubled cosine of the incorrect deviation, that is, the error will be (12).

$$E_3 = E' \cos \Delta(\varphi, \alpha) = E' \cos|\varphi - \alpha| \quad (12)$$

That is, for 5 degrees the loss will also be 0.38%.

At the same time, it is important to point out that the latitude indicator, no matter how strange it may seem, for this situation tends to change from 20 to 60 degrees, depending on the time of year according to the pattern (13).

$$\alpha = \alpha_{1.2} \mp \frac{\alpha_1 - \alpha_2}{181} * d = \begin{cases} \alpha_2 - \dfrac{\alpha_1 - \alpha_2}{181} * d \\ \alpha_1 + \dfrac{\alpha_1 - \alpha_2}{181} * d \end{cases},$$
$$where, \alpha_1 = 20, \alpha_2 = 60 \quad (13)$$

3 RESULTS AND DISCUSSION

The conclusions of the conducted research, as results, can be given in 3 graphs. These results are obtained by numerical description of this entire mathematical system processed in electronic tables. The illustrated model is developed based on the above analog mathematical expressions. As a result of the model, the first diagram can be given, where the energy conversion indicators are considered in the middle of winter (January 15), spring (April 15), summer (July 15) and autumn (October 15) at 12 o'clock in the afternoon (according to the time of solar radiation by the season).

Figure 1: Change in solar battery output energy in the middle of each season.

When changing the angle of the beam to the solar panel horizontally, the following dependence is obtained as a result of the mathematical model of the system:

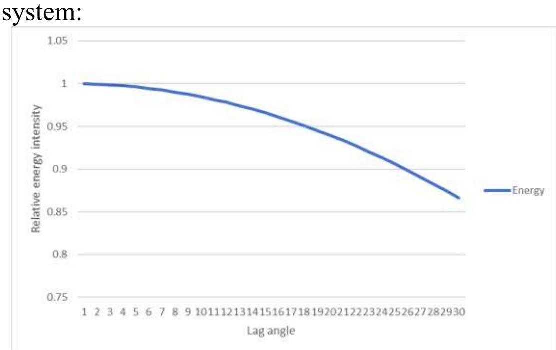

Figure 2: Change in relative energy generated when the solar panel lags behind the sun along the horizontal axis.

And finally, the diagram for the case when the error in choosing the angle of inclination of the solar battery vertically, from that determined in (3), changes as follows:

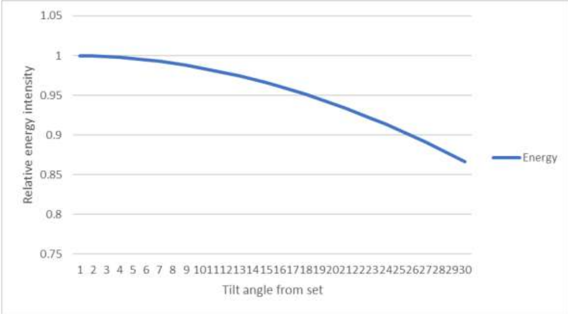

Figure 3: Change in relative energy generated when the solar panel lags behind the sun along the horizontal axis.

4 CONCLUSIONS

Thus, it can be concluded, as indicated by the developed mathematical models, that when installing solar panels, energy losses in the case of vertical and horizontal alignment are the same. These statements are supported by numerous experimental data.

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