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# **Mathematical modeling of parameters of solar panels for solar photoelectric power with a capacity of 130 kW in the climatic conditions of the Republic of Uzbekistan**

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**ABSTRACT:** Today, the problem of increasing the efficiency of solar photoelectric plants is one of the most urgent spheres. Computer simulation methods were used to optimally improve and maximize the output parameters of solar panels. As you know from the scientific literature and articles, currently scientific research has achieved great success in mathematical modeling of the parameters of solar panels of different types in various climatic conditions. This article presents the results of mathematical modeling of a solar panel of the HSL 250 type manufactured by the Republic of Korea HANHWA in the Matlab software environment surrounded by a photoelectric installation with a working capacity of 130 kW in the climatic conditions of Uzbekistan. Based on the results of the simulation obtained, it was found that it is possible to study the technical characteristics of the output parameters of solar cells in a state with a change in external temperature and light intensity. The article also provides mathematical modeling of the output power, voltage and current of the solar panel based on changes in the temperature of the solar panel. The resulting mathematical modeling methods confirmed the effectiveness of the experimental results.

## **I. INTRODUCTION**

Currently, the use of renewable energy in the world is increasing day by day. This is due to the fact that, as the increase in prices for hydrocarbon energy resources from year to year, the profit from it in the production of electricity by traditional methods is decreasing as well. In particular, the work of obtaining electricity using solar energy is developing in a wide range. Despite the fact that the useful work coefficient of solar panels is 17-18% percent, scientists around the world are conducting a huge amount of scientific research in order to make the most of their output parameters. Good results are being achieved using mathematical modulating devices for the output parameters of solar panels. At the same time, in many developing countries, large government benefits of these states are being created in relation to the widespread use of renewable energy sources.

Among these, one of the strategic tasks facing the government of the Republic of Uzbekistan today is to increase the share of electricity generated from renewable energy sources (RES). The main purpose of these tasks is to ensure the energy independence of the country.

There are a number of advantages in expanding solar photoelectric plants in the country, that is, due to the abundance of sunny days, laws and decisions issued by the state, the benefits provided, are widely developing. However, there are two significant disadvantages of solar photoelectric plants, namely that their technical characteristics in the process of exploration are variability and that the production of electrical energy is a dependence of climate change [1, 2].

Due to the expansion of the field of application of solar panels under different conditions, in some cases the need arises to determine the variability of their output parameters. It is advisable to use a computer modeling method to analyze the technical characteristics of solar panels at variable values of light intensity and external temperature of different sizes.

On these days, most world scientists are engaged in modeling the volt-ampere characteristic (VAC) and output parameters of solar panels. In the following scientific articles [3-4], the results of mathematical and computer modeling of an equivalent scheme of one diode of the solar element are analyzed.

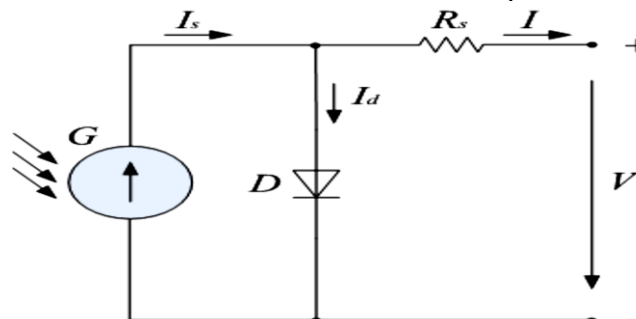
This article presents the procedure for developing a modeling model of solar panels in a Matlab/Simulink environment. The imitation model is based on a three-parameter analytic model of the volt-ampere characteristics of the solar element. In the developed mathematical model, at the expense of changing the intensity of radiation, changes in output power, voltage and current, as well as volt-ampere characteristics are studied. The difference between the results of this mathematical modeling and the data obtained in the experimental method compared did not exceed 4%.

## II. SCHEME AND FORMULAS

The mathematical model of solar panel photoelements consists of many solar photoelements connected separately in series and parallel to provide the desired values of solar panels (PV) output current  $I$  (A) and voltage  $U$  (V). As we know [5], a solar photoelement is based on a photoeffect cell that converts solar radiation energy into electrical energy. The electrical generation of the photoelement is based on the internal photoeffect cell [6, 7].

Based on the process of generating electric current in solar elements, the process of separating electron-hole pairs formed by light quanta lies in the transition compound p-n. The intensity of solar radiation has been found to affect  $J$  ( $W/m^2$ ), solar panel output current value  $I$  (A), temperature  $T$  ( $^{\circ}C$ ), and output voltage  $U$  (V) [8]. Thus, as the light intensity increased the value of  $J$  ( $W/m^2$ ), the temperature of the solar panel gradually increased, in which the value of the short circuit current  $I_{sc}$  (A) began to rise slightly, while the value of the load-free voltage  $U_{oc}$  (V) was observed to decrease slightly.

The classical equivalent scheme of the mathematical module of the photoelement is shown in Figure 1.



**Figure 1. Scheme of equivalent of solar photo element.**

The equivalent scheme of this solar photo element contains a photo element (phototock generator), a diode, a sequentially connected resistor, a shunt ( $R_s$ ).

The source of the phototocurrent  $I_{ph}$ , which is a phototoc dependent on the intensity of solar radiation, describes the current  $I_d$  passing through the imperfect (with ideal factor  $n$ ) p-n transition coupling of the diode  $D$  solar panel. The sequentially connected (shunt)  $R_s$  resistance in the equivalent scheme of the solar photoelement contains parasitic parameters. The sequentially connected  $R_s$  resistance depends on the production technology of the solar panel and greatly affects its performance, while the power of the solar panel  $P_{max}$  decreases when the  $R_s$  decreases [9].

Sufficient accuracy of the mathematical model can be obtained if the values of the internal resistance of its photoelements are known. As a rule, in modeling, systematic deviations are observed in experimentally obtained (VAC) results with results obtained in the theoretical volt-ampere characteristic (VAC), which is the result of variable values of the current strength and voltage gradients [10].

In the equivalent solar photoelement scheme, the current  $I$  (A) and the voltage  $U$  (V) can be found by equating the values of the photoelectricity  $I_{ph}$  (A) and the diode current  $I_d$  (A) to the working current  $I$  (A) by the formula:

$$I = I_{ph} - I_d \quad (1)$$

$$I = I_{ph} - I_{sat} \left[ e^{\frac{q(U+IR_s)}{nkT}} - 1 \right] \quad (2)$$

Here,

$I_{ph}$  – photoelectricity [A];  
 $I_{sat}$  – diode inverse saturation current [A];  
 $R_s$  – sequentially connected resistance [Ω];  
 $U$  – working voltage [V];  
 $I$  – working power [A];  
 $q = 1,602 \cdot 10^{-19}$  Kl;  
 $n$  – diod, idealization factor  
 $k = 1,38 \cdot 10^{-38}$  J/K Bolsman constant  
 $T$  – temperature [°K].

The power that solar panels are generating is calculated using the formula P(W) , (1), by the formula below.

$$P = I \cdot U = U \cdot \left( I_{ph} - I_{sat} e^{\frac{q(U+IR_s)}{nkT}} - 1 \right) \quad (3)$$

The output current of the solar panel is  $I_{ph}(A)$  directly proportional to the intensity of solar radiation  $J$  ( $W/m^2$ ). We calculate the solar panel output current  $I(A)$  through the formula below.

$$I_{ph} = (G, T) = I_{stc} \cdot \frac{G_r}{G_{stc}} + \beta_{scT} \cdot (T_r - T_{stc}) \quad (4)$$

Here,

$I_{stc}$  – short circuit current under standard normal conditions, [A];  
 $G_r$  – intensity of solar radiation in real conditions, [ $W/m^2$ ];  
 $G_{stc}$  – solar radiation intensity under standard normal conditions, [ $1000 W/m^2$ ];  
 $\beta_{scT}$  – temperature coefficient of short circuit current, [%/°C];  
 $T_r$  – solar panel temperature in real conditions, [°C];  
 $T_{stc}$  – solar panel temperature under standard normal conditions (25 °C), [°C].

$$P_{pv} = P_0 \cdot (1 + \beta \Delta t) \quad (5)$$

$P_{pv}$  - solar panel output power, [W];  
 $P_0$ . the output power of the solar panel at 25°C, [W];  
 $\beta$ -temperature coefficient of solar panel power, [%/°C];  
 $\Delta T$  is a change in the temperature of the solar panel, [°C].

In this case, the temperature coefficient is  $\beta$ (%/°C), taking into account the temperature difference of the solar panel, which is several milliamperes per degree °C (Celsius).

Temperature coefficient  $\beta$  (%/°C), affects the output current  $I_{ph}(A)$  and voltage of the solar panel. If the solar panel temperature exceeds  $T$  (°C) under real conditions, the output voltage  $U$  (V) and output power  $P_{pv}(W)$  will decrease, while the output current  $I(A)$  will increase [11].

The value of the output voltage  $U_{oc}$  (V) in the short circuit chain of the solar panel is calculated using the formula below.

$$U_{oc}(G, T) = U_{ocs} + \beta_{ocT}(T - T_s) + kT/q \cdot \ln(I_{mpp}/I_{scs}) \quad (6)$$

Here,

$U_{ocs}$  - is the output voltage in a short circuit loop under normal standard conditions [V];

$\beta_{ocT}$  -temperature coefficient of output voltage in short circuit chain [%/0C];

$I_{mpp}$  – solar panel saturation current [A];

$I_{scs}$  - output current in a short circuit loop under normal standard conditions [A].

Using the above formulas, variations in output parameter power P(W), voltage U(V), electricity I(A), as well as volt-ampere characteristics are given in the Matlab/Simulink environment as a result of increasing solar panel temperature.

**III. MODELING IN THE MATLAB/SIMULINK ENVIRONMENT OF THE SOLAR PANEL**

The necessary data for the mathematical modeling of the parameters of solar panels of a solar photoelectric plant with a capacity of 130 kW in the Pap district: their location angles relative to the horizon, connection scheme, number and power. The solar photoelectric plant installed polycrystalline solar panels of 4 Companies of the Republic of Korea.

In solar photoelectricity, in rows 1,2,3,4,5 and 6, solar panels are arranged so that they do not change at an angle of 300 relative to the horizon, rows 7 and 8 can be changed at an angle of 150 and 450 respectively. Rows 1.2 and 3 House 198 solar panels of HANHWA’s HSL250 type, with a total capacity of 49.5 kW connected in series and parallel. Rows 4.5 and 6 rows 198 solar panels of JSPV’s type JSMM2501, with a total capacity of 49.5 kW connected in series and parallel. 7 and 8 rows rows 72 solar panels of type SM250PC8 from S-ENERGY, with a total capacity of 18.0 kW connected in series and parallel, and 8 rows 24 solar panels of type TS-S400 from TOPSUN, with a total capacity of 9.6 kW connected in series and parallel. We will use HSL250 type solar panel from HANHWA to modulate. Table 1 lists the technical characteristics of the solar panel [12].

**Table 1**

Names of parameters of solar panels	Solar panel parameter values
Model	HSL 250
Rated Power	250 W
Voltage at $P_{max}$	30.4V
Current at $P_{max}$	8.23A
Short-circuit current	8.79A
Open-circuit voltage	37.7V
Operation Temperature	-38 <sup>0</sup> C~+87 <sup>0</sup> C
Module efficiency	15.5%
Temperature Coefficients $I_{sc}$	+0.63 %/ <sup>0</sup> C
Temperature Coefficients $P_M$	0.41 %/ <sup>0</sup> C
Temperature Coefficients $V_{oc}$	-0.31 %/ <sup>0</sup> C
Series resistance	0.333 $\Omega$
Parallel resistance	345.52 $\Omega$
Silicon type	poli-cristal

Using the information provided above, equation 2 is implemented in the Matlab/Simulink environment as follows.

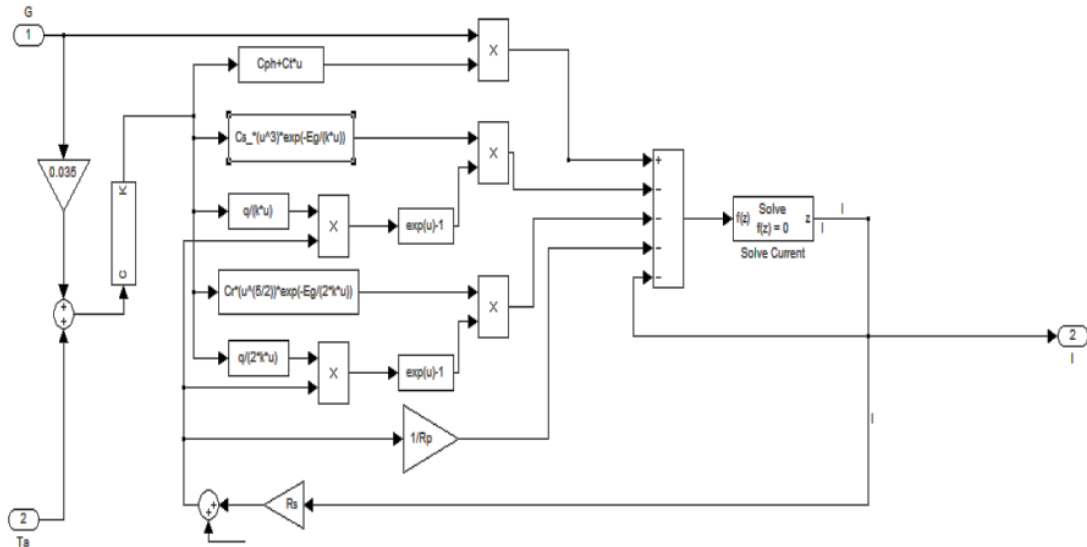
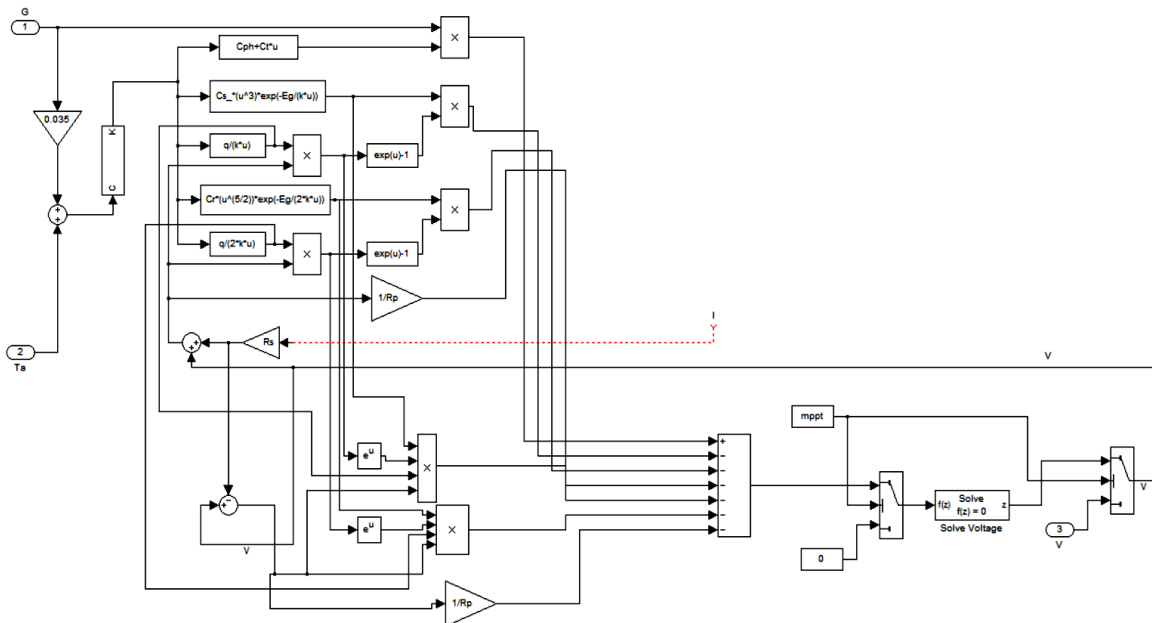


Figure 2. Calculation contour of output current I (A) in a Matlab/Simulink environment.

Using Equation 4, the value of the output voltage  $U_{oc}$  (V) in the short circuit circuit of the solar panel, we cite the output voltage contour in the Matlab/Simulink environment.

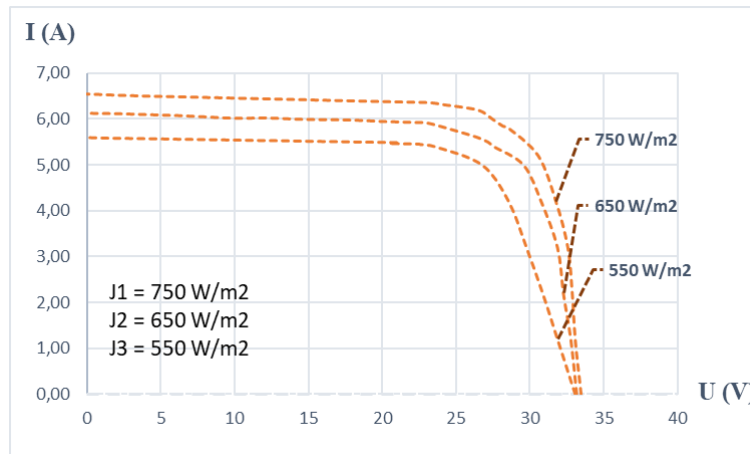


Picture 3. Output voltage U (V) contour in Matlab/Simulink environment

Changes in the intensity of radiation falling on the solar panel at  $550 \text{ W/m}^2$ ,  $650 \text{ W/m}^2$  and  $750 \text{ W/m}^2$  were obtained, as well as changes in the volt-ampere characteristic under conditions of exceeding the temperature of the solar panel.

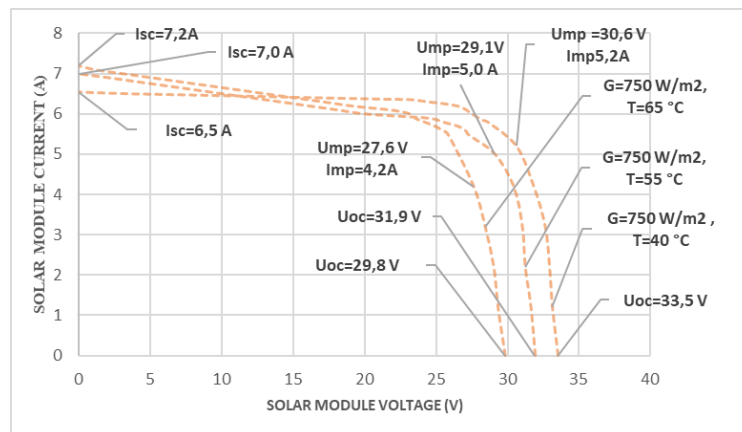
**IV. RESULTS OF MODELING**

As a result of increasing the intensity of radiation falling on the solar panel by  $J(W/m^2)$ , output current  $I(A)$  has also been found to increase. Figure 4 describes the change in output current  $I(A)$  in a Matlab/Simulink environment.



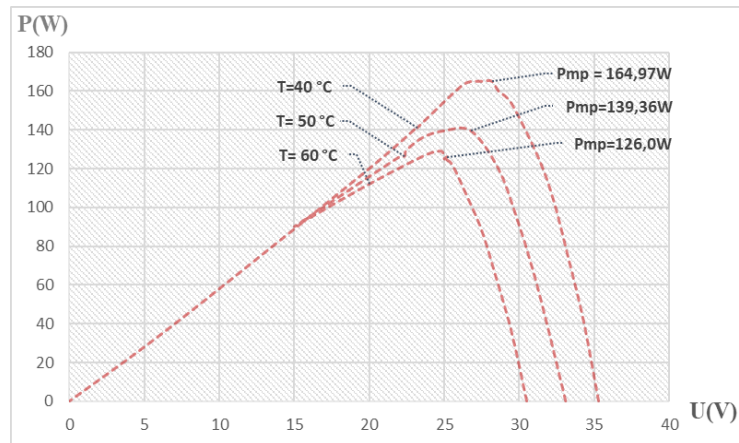
**Figure 4. Dynamics of change in output current  $I(A)$  in a Matlab/Simulink environment.**

It has been found that the output voltage  $U(V)$  decreases as the temperature of the solar panel increases  $T(^{\circ}C)$  without changing the intensity of radiation falling on the solar panel to  $J(W/m^2) = \text{const}$ . Figure 5 describes changing the output voltage  $U(V)$  in a Matlab/Simulink environment.



**Figure 5. Change the output voltage  $U(V)$  in the Matlab / Simulink environment**  
It has been found that as the temperature of the solar panel increases  $T(C)$ , the output power  $P(W)$  gradually decreases.

Figure 6 shows a change in output power  $P(W)$  in a Matlab/Simulink environment.



**Figure 6. Change output power P (W) in Matlab/Simulink environment.**

## V. CONCLUSION

Based on the results of the obtained modeling, it was found that it is possible to study the technical characteristics of the output parameters of the solar panels in a state with a change in external temperature and light intensity. There has also been mathematical modeling of the output power, voltage and current of the solar panel based on changes in the temperature of the solar panel. The resulting mathematical modeling methods confirmed the effectiveness of the results of the experiment.

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