Modeling Solar Battery Efficiency

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Annotation: The article discusses topical issues related to modeling the physical processes in the operation of solar photovoltaic batteries. In the course of the research, the simulation of photovoltaic batteries was carried out in the MATLAB / Simulink / Simscape simulation environment. The output current of the solar cell is chosen as the main electrical parameter. The model is tested using the characteristics of the ABi-Solar P60270-D polycrystalline photo module. During the analysis, changes in the characteristics of the solar panel are considered for such cases: change in the intensity of solar radiation at a constant operating temperature of 25 ° C; changing the operating temperature for the given values of the intensity of solar radiation; the effect of load changes on the electrical characteristics of the solar panel. The simulation results made it possible to investigate the connection between the electrical parameters of photocells with various factors, external phenomena and processes. So, the dependence of current and voltage on illumination and temperature changes is established. When the temperature decreases by 20 ° C from the nominal, the current practically does not change, and the voltage and power increase by 11%. The current increases by no more than 2%, the voltage increases by 20%, and the power by 22% in the zone of negative temperatures (at -20 ° C), In addition, proposals are formulated to improve the method for monitoring the defects of photovoltaic solar cells. The developed model can be used to construct various variations of photovoltaic panels and determine the initial parameters, which allow analyzing the effectiveness of using specific types of solar cells. The practical value of the results obtained is due to the fact that the proposed model takes into account the main factors that affect the functioning of the solar photovoltaic panel and, in general, adequately reflects the outgoing characteristics of the solar module.
Keywords: photovoltaic batteries, MATLAB / Simulink, voltage, solar energy, capacity, defects, control.

At present, the capacity of solar power plants in the world is constantly increasing [1]. A promising direction for increasing the energy efficiency of power supply systems and increasing their independence is the use of photovoltaic energy both in autonomous systems and when operating under system loads [2]. Experts assume that by 2030 the volume of energy production using photovoltaics will increase to 70 MW/h and its share will amount to 10% of the total electricity produced in the world [3].

Traditionally, manufacturers and distributors of solar power plants provide general characteristics of the equipment in the technical documentation, without taking into account its more precise adjustment to the specific needs of the consumer. Most often, a photovoltaic battery is represented by a simplified mathematical model with a certain constant efficiency [4, 5]. In fact, the output power of a solar installation depends on many factors, in particular, on the ambient temperature, the photo panel temperature, the battery load current.

Taking into account the above, today an important scientific and practical task is to solve the issues of selecting equipment for photovoltaic batteries, increase in the technical and economic indicators of the solar power plant functioning, ensure the maximum power of the solar photovoltaic system, which in turn implies the need to select not only its optimal structure, as well as optimal control algorithms.

The world scientific schools of photovoltaics are represented, first of all, by divisions of the US National Renewable Energy Laboratory (NREL) and the Fraunhofer Institute, Germany (Fraunhofer ISE - Fraunhofer Institute of Solar Energy). The characteristics of solar cells and methods for controlling their defects are studied by such foreign scientists as: Nyholm, Emil [6], Mundada, Aishwarya S.; Shah, Kunal K.; Pearce, J.M. [7, 8], Liu, Z. Y.; Sun, J. Q.; Ma, Z. C. [9], Ganiyu, Soliu O. [10], Gottfried H. Bauer [11]. Among national authors, the study of the behavior of solar photovoltaic systems in various operating modes is included in the range of scientific interests of M.V. Cheremukhin, A.V. Shipovskiy. [12], V.S. Kalinovsky. [13], Sokolov P.M. [14], Arefiev N.V., Safronov N.S., Mozhayev E.E. [15].

At the same time, despite the existing significant developments, the issues of modeling the main physical processes in the solar PV system and its control system are still open.

So, taking into account the above, the purpose of the paper is to simulate physical processes in a solar PV system in the Matlab / Simulink environment to study the relationship between the electrical parameters of photocells with various factors, external phenomena and processes.

A simulation model is developed in the Matlab / Simulink software environment to simulate the processes in the solar PV-system figure 1.

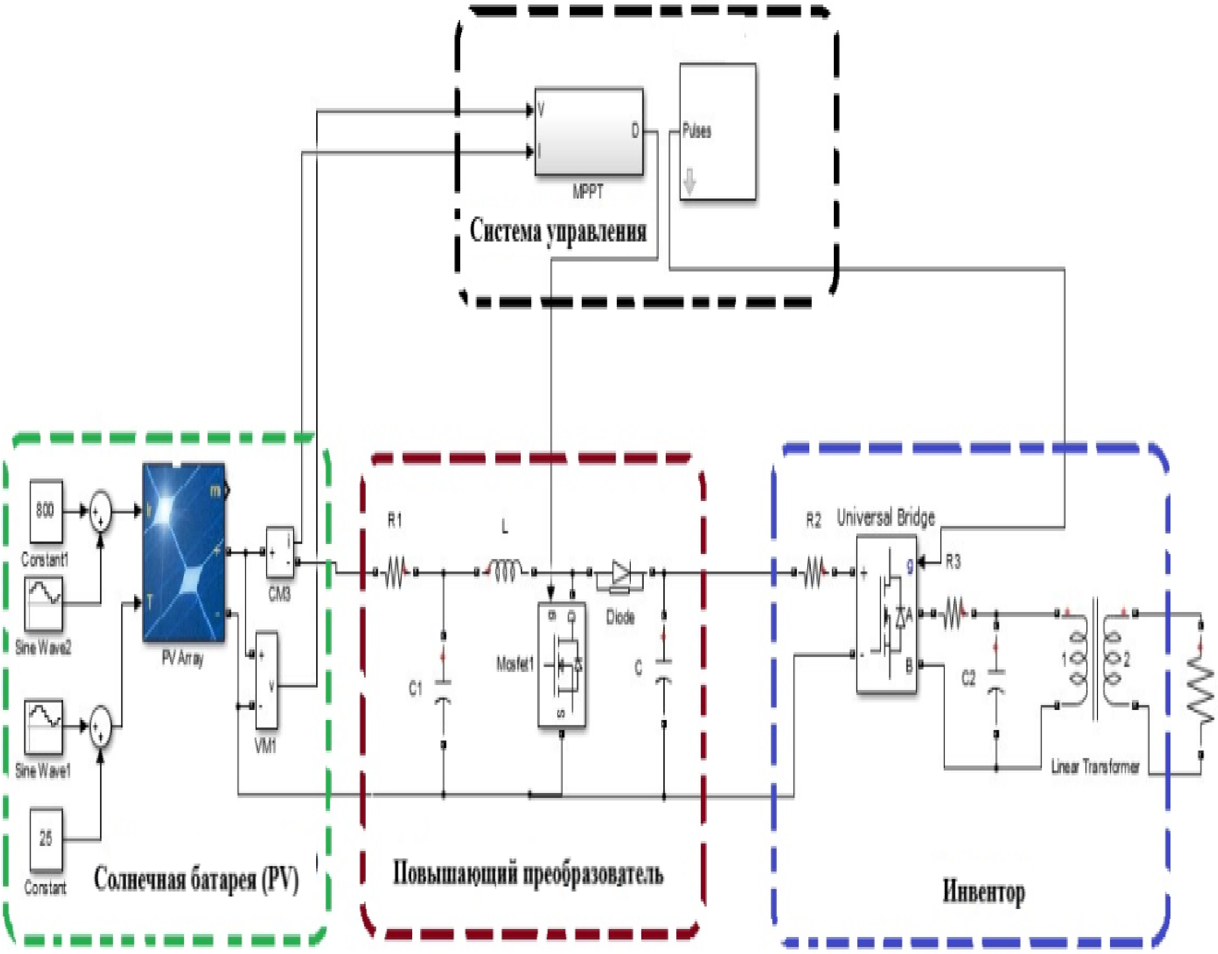


Fig. 1. - Matlab model of solar PV system

The main electrical parameter of such a system is the output current of the solar cell. The output current of the solar cell is determined by the formula:

$$I = I_{ph} - I_s\left(e^{\frac{U+IRs}{NVt}} - 1\right) - I_s\left(e^{\frac{U+IRs}{NVt}} - 1\right) - \frac{U+IRs}{R_p} \qquad (1)$$

where, I_{ph} is photocurrent that depends on the radiation density, A;

I_s is saturation current, A;

Rs is series resistance, Ohm

Vt is temperature coefficient,% / K;

U is operating voltage, V;

Rp is shunt resistance, Ohm; p R

N is the number of diodes.

Checking the model is carried out according to the known characteristics of the polycrystalline photo module ABi-Solar P60270-D, which are given in table 1.

Table № 1

Characteristics of the ABi-Solar P60270-D PV module

Cell type	Polycrystal 156×156 mm	Cell type	Polycrystal 156×156 mm
Short-circuit current (Isc)	9,15 A	no-load voltage (V_{oc})	38,3 V
Dimensions (L × H × W)	1640×991×35 mm	Current MPPT (I_{mpp})	8,66 A
Capacity MPPT (P_{max})	270 Watt	Voltage MPPT (V_{mpp})	31,2 V
Number of cells	60 (6×10)		

Further, the study of changes in the characteristics of the solar panel is made for such cases: change in the intensity of solar radiation at a constant operating temperature of 25 ° C; changing the operating temperature for the given values of the solar radiation intensity; the effect of load changes on the electrical characteristics of the solar panel.

The results of checking the model for reliability at nominal parameters are presented in table 2.

Table № 2

The results of checking the model for reliability at nominal parameters

Parametres	Simulation Result	Nominal Value	Deviation,%
I, A	8,73	8,7	0,34
U, V	31,2	31,08	0,39
P, W	272,3	270	0,88

As Table 2 shows, the maximum deviation of the main electrical characteristics is within the standard limits and does not exceed 1%.

Determination of the solar battery characteristics in the temperature range from -20 ° C to 60 ° C, allows to establish a number of dependencies. The significance of some experimental measurements is shown in table 3.

Table № 3

Solar module characteristics with temperature changes

at 5°C temperature						
γ, W/m^2	1000	800	600	400	200	100
I, A	8,6	6,5	4,9	3,2	1,4	0,5
U, V	34,8	35	34,8	34,7	34,1	33,2
$P_{мах}$, W	299,3	267,8	170,5	111,04	47,74	16,6
at -20°C temperature						
γ, W/m^2	1000	800	600	400	200	100
I, A	8,7	6,8	5	3	1,4	0,5
U, V	37,5	37,5	37,4	37,6	37,1	37
$P_{мах}$, W	326,3	255	187	112,2	51,94	18,5
at 25°C temperature						
γ, W/m^2	1000	800	600	400	200	100
I, A	8,5	6,7	4,9	3,2	1,3	0,5
U, V	31,7	31,3	31,2	30,9	30,7	30,5
$P_{мах}$, W	269,4	209	152,88	97,9	39,9	15,3

So, we can state the fact that when the temperature decreases by 20 ° C from the nominal, the current practically does not change, and the voltage and capacity increase by 11%. In the zone of negative temperatures (at -20 ° C), the current increases by no more than 2%, the voltage increases by 20%, and the capacity by 22%.

A graphic interpretation of the current dependence on the illumination at different temperatures is shown in figure 2. This dependence reveals the stability of the current values at various levels of illumination and changes in the ambient temperature. The deviation in the values does not exceed 5%, even with an illumination of about 1000 W / m2.

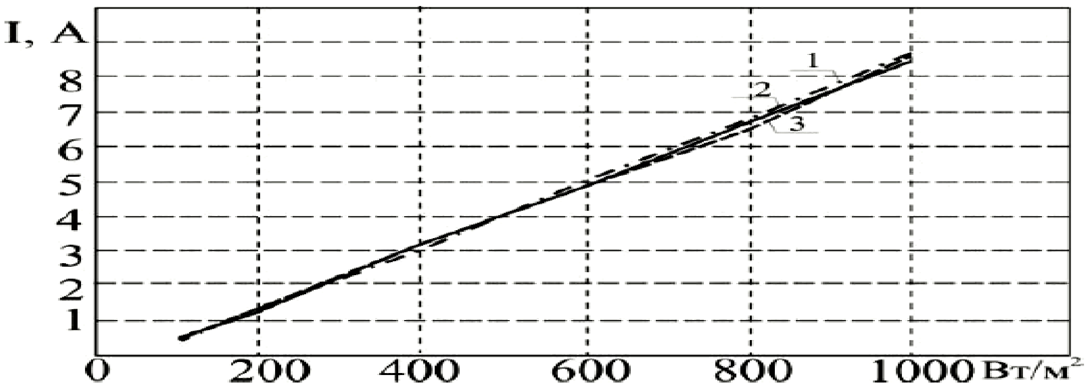


Fig.2. - Dependence of the solar panel current on illumination at the following temperature values: 1) - 5 ° C; 2) - 25 ° C; 3) - 20 ° C

The dependence of voltage on illumination at various temperatures is shown in figure 3.

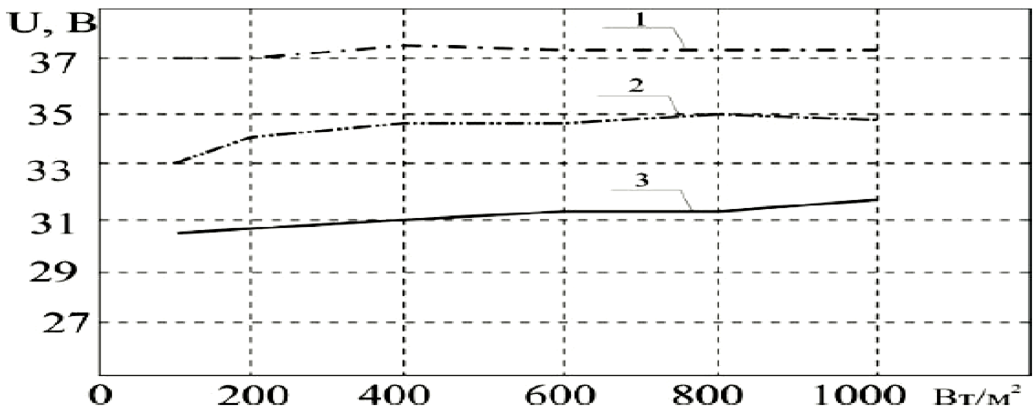


Fig. 3. - The dependence of the solar panel voltage on the illumination at the following temperatures: 1) - 20 ° C; 2) - 5 ° C; 3) - 25 ° C

The analysis of the results obtained showed that when the load changes, namely, when the resistance increases, the current decreases by no more than 10%, while the voltage increases slightly (not more than 5%).

It is planned to consider the solar battery characteristics in the high temperature zone in further studies.

Special attention in the process of modeling the physical processes in solar photovoltaic battery operation is occupied by issues of controlling their defects.

In order to carry out control procedures, it seems appropriate to use the method of infrared thermography (IRT). The IRT method makes it possible to identify defects and measure their capacity from the obtained thermogram (heat pattern). The control of defects in solar photovoltaic batteries under operating conditions by the IRT method is poorly studied, especially with regard to defects arising from heating batteries with a dark current.

For the purpose of practical application of this method, it is proposed to use the following mathematical model of the linear current sweep, which forms the basis of a new dynamic method for measuring VAC **(**volt-ampere characteristic).

$$P_{деф} = \sum_{i \in M} [\sigma S \varepsilon (T_{di}^4 - T_l^4) + h_c S (T_{di} - T_l)] \qquad (2)$$

where Tdi is the temperature of the i-th pixel, which belongs to the set of M points in the defect zone;

T1 - air temperature;

S - pixel area;

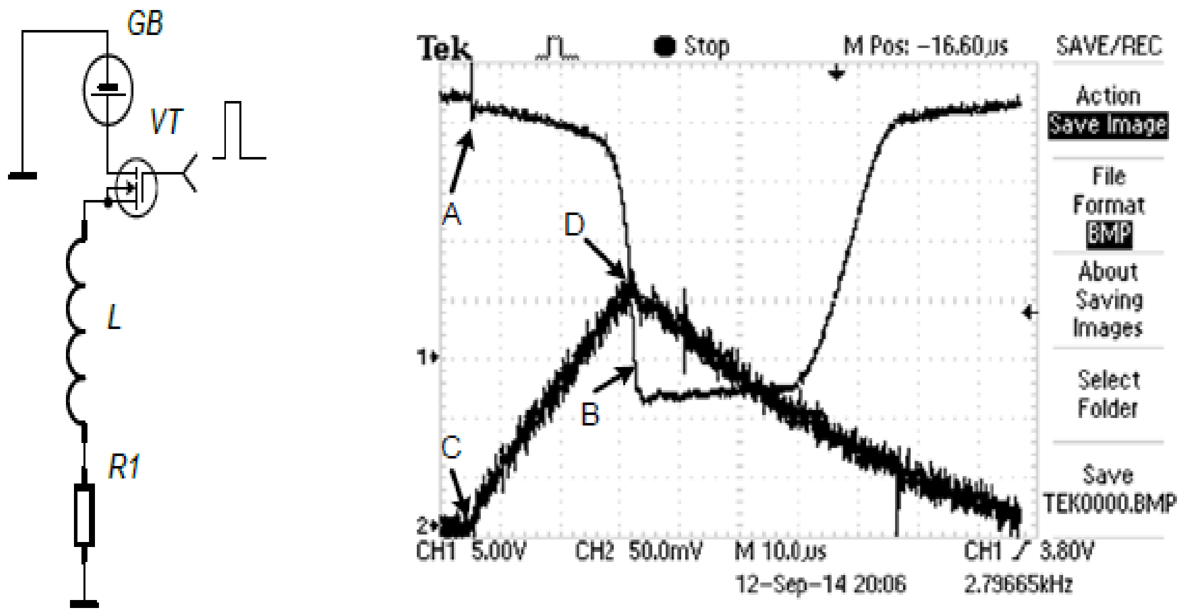
σ - Stefan-Boltzmann constant;

ε - glass emissivity;

hc - convection coefficient.

The presented mathematical model for monitoring solar photovoltaic battery defects by the IRT method is built on the basis of determining the thermal capacity of a defect, equal to the total capacity of all points in the defect area.

The feature of the IRT method is the measurement in only one impulse signal with a duration of 10 - 20 μs, which makes it possible to call this method a single-impulse one. The essence of the method consists in commutation by a power transistor in a series circuit of solar photovoltaic batteries and an inductor figure 4, the current in which changes linearly with time.



а) б)

Fig. 4. - Diagram of the sweep circle: a) GB - solar photovoltaic battery; L - inductor; R1 - resistor for current measurement; b) - oscillograms: CH1 - voltage channel on the collector of the transistor VT; CH2 - current channel; A and B - the beginning and end of the VAC; C and D - the beginning and end of the current sweep.

It seems expedient to add a measuring resistor for independent measurement of the current and experimental verification of the sweeping process linearity to the measuring circuit in series with the inductor. When carrying out oscillographic control, it is possible to obtain the volt-ampere characteristic in current-voltage coordinates with an error of 1%. The use of a digital oscilloscope allows to record the volt-ampere characteristic in its memory in Excel MS Office format and then carry out mathematical processing.

Let's consider the features of the application of this method in practice.

Let the solar cells be heated by two methods - direct figure 5 and reverse dark current. In the first case, a defective solar cell will act as a shunt for all its neighbors; the type of defects controlled in this case is Schottky parasitic diodes. The required voltage in the first method is approximately 0.7V for one and 22V for a solar cell section consisting of 36 solar cells connected in series. Overheating cells with a direct dark current have the form of periodic stripes and are also concentrated near the feed buses and output contacts of the solar battery figure 5.

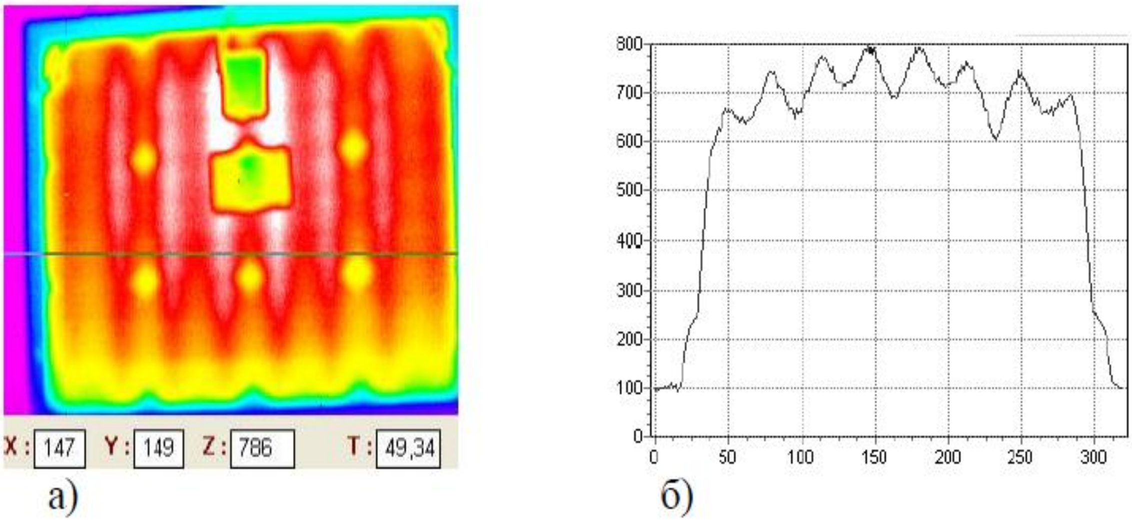


Fig. 5: a) - thermogram of the back panel in the solar battery with a capacity of 30 W with direct dark current: voltage 22V, current 5A; b) - pixel-by-pixel temperature distribution along the Ox axis

The heating process with a predominantly direct dark current (99%) is provided by supplying an alternating voltage of 48-52 V. Defects, such as an additional shunt resistance, are controlled by using the second method, based on the reverse dark current flow figure 6.

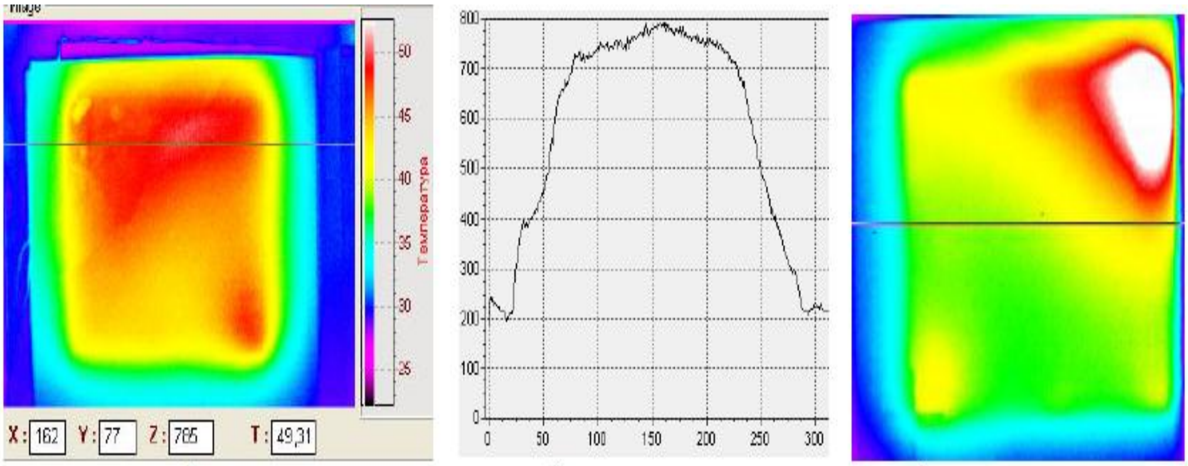


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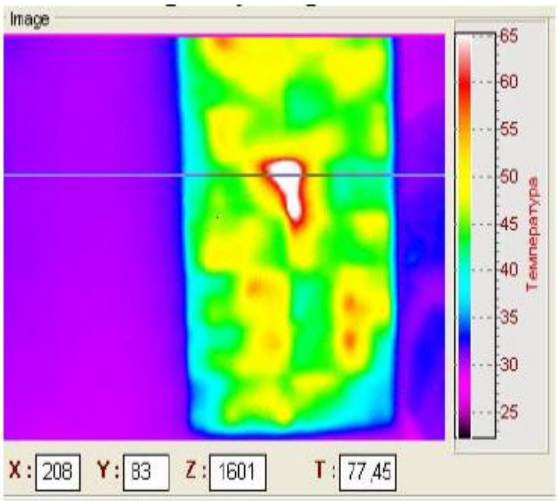
Fig: 6: a) - thermogram of the solar cell without defects; b) - pixel-by-pixel temperature distribution of the solar cell without defects along the Ox axis; c) - thermogram of the solar cell with temperature 72 ºC in the defect zone.

In the process of applied research, it is found that a separate solar cell, when heated with a reverse dark current, requires capacity of 5-6 W and voltage of 10-30 V, depending on the internal shunt resistance. At the same time, a power source with a capacity of up to 400 W with a constant voltage of up to 1000 V is required to heat the solar battery.

It is experimentally proven that the heat flux in glass structures, typical for solar cells, propagates mainly in the direction perpendicular to their plane due to the radiation and convection components. It is possible to calculate the capacitance rate of the defect by the radiation and convection components based on the thermograms using the developed method figure 7.



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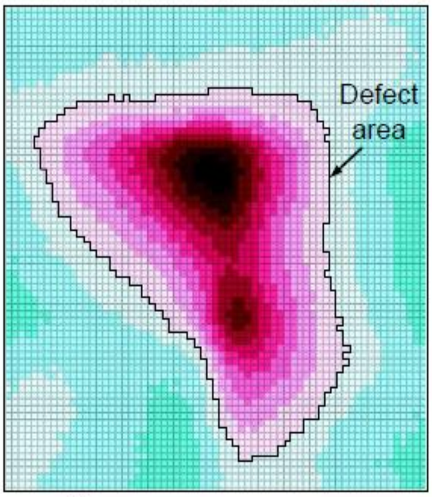

б)

Fig. 7: a) - solar battery thermogram made of polycrystalline silicon with a capacity of 60 W b) - image of the defect area on the pixel grid

As evidenced by the experimental data, the use of the IRT method in the process of monitoring the defects of photovoltaic solar cells makes it possible to ensure a decrease in the relative error of up to 5% at stationary heat exchange.

Modern developments and advances in nanotechnology are essential for the development of solar photovoltaic batteries. According to The Global Technology Revolution 2020, low-cost solar energy has been included in the list of 20 most promising technologies by international experts. Table 4 lists some of the world's most famous nanotechnological developments for photovoltaics, aimed at solving the problems of creating and improving new highly efficient devices and materials, the use of which will make it possible to reduce the solar cell cost and increase the efficiency.

Table № 4

Worldwide nanotechnology developments for photovoltaics

Technologies / Products	Basic nanomaterials	Expected effect
Organic Solar Cells	Fullerene polymeric nanostructure	Improving the charge carriers transport, which is implemented using a network of organic molecules and nanocrystals
Multi-stage photovoltaic converters	Nanoheterostructures	Increase in efficiency up to 35% at 1000-fold concentration of ground-based solar radiation (2 times cheaper than existing analogues) for concentrator-type solar power plant
Solar panels	Organic and inorganic materials with nanostructure or cluster-fractal structure	Improving the efficiency of energy storage and transfer
Flexible organic solar cells	C60 / p-Si heterostructures and fullerenes (C60)	Increase in absorptivity in the shortwave solar spectrum
Solar panels	Quantum dots	Efficiency increase up to 45% (theoretically - up to 87%) due to the generation of three electrons per incident photon

More promising areas for the use of nanotechnology and nanomaterials are highly efficient leading systems (transformers, wires and other devices), as well as supercapacitors and rechargeable batteries in the segment of transmission, storage, distribution and accumulation of energy.

Thus, the model proposed in the article, which describes the operation processes of solar photovoltaic batteries in the MATLAB / Simulink environment, makes it possible to relate the electrical parameters of photocells with the level of illumination and temperature of the environment.

The implementation of the research results simplifies the calculation of the parameters at the input and output of photovoltaic modules for building solar stations and evaluating the effectiveness of the proposed solutions.

In addition, in the course of the study, proposals are formulated regarding the improvement of the method for calculating the thermal conductivity of a solar battery design based on IRT, using which the average temperature of the front and back surfaces of the solar battery heated by the reverse dark current is preliminarily measured. The method is characterized by a systematic error of no more than 5%.

Further development of the solar battery model lies in creating a database of different types of solar batteries, as well as including a description of the amount of incident solar radiation on a particular territory depending on the season and time of day. It should also be noted that the use of new nanotechnological developments for photovoltaics, will most effectively solve the problems of creating and improving new highly efficient materials and new devices that have a significant potential to reduce the cost of solar cells and increase their usefulness.

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