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DEVELOPMENT AND RESEARCH OF A MATHEMATICAL MODEL OF A SOLAR PHOTO CONVERTER WITH AN INVERTER FOR CONVERTING DIRECT CURRENT TO ALTERNATING VOLTAGE

Abstract. This article presents a mathematical model of photovoltaic systems. For the analysis of energy processes in autonomous power transmission systems, it is now advisable to use computer simulation methods. The use of a simulation model makes it possible to provide an energy balance in an autonomous power transmission system with specific energy characteristics of ground and buffer sources of energy and a time scale from the power consumption of the load. This allows you to influence the energy characteristics of transmission systems to ensure the energy balance in the system in terms of temporary changes in the energy characteristics of energy sources, as well as the impact on the energy characteristics of the systems of transmission parameters such as solar energy. lighting, temperature, time of year, etc. This model is described by the current-voltage characteristic (CVC) at a given temperature, and the lighting conditions are the basis for calculating the parameters of the photoelectric energy in a wok. A new inverter was also designed and researched to convert direct current into alternating voltage, which allowed saving from 18.5% to 35.19% of expensive solar photo converters.
Keywords: solar cell; the current-voltage characteristics; mathematical model; MatLab.

1.Introduction

Solar cells in the production of electricity from renewable energy sources, is now developing rapidly and soon will be increased overall use [1]. For example, small solar cells used in watches, calculators, small toys, radios and portable TVs. While large objects are combined into modules and are used to supply the power system [2,3].

A solar cell is an electrical device that converts light energy into electricity using the photoelectric effect. The main material used for the production of solar cells is silicon.

I. The design and manufacture of silicon solar battery Large blocks of molten silicon carefully cooled and solidified is made from cast ingots of polycrystalline silicon square. Polycrystalline silicon is less costly than single crystal and are less effective [4,3,5]. Solar battery consists of the following elements [6,7,8].

- Silicon wafer (mono- or polycrystalline) with a p-n junctions on the surface.
- Front and back contact; front contact must have the correct shape to make the most of the incident radiation.
- Antireflection layer - cover the front surface. There are three major types of solar cells.
- Single crystal formed on a silicon crystal with a homogeneous structure. The basis for the formation of cells that are suitable silicon-sized blocks.
- They are cut into plates whose thickness is about 0.3 mm. Photovoltaic cells achieve the highest levels of performance and life [4,6].
- Polycrystalline are comprised of many small grains of silicon. These solar cells are less efficient than single crystal. The production process is simpler and have lower rates [4,6].

- Amorphous (thin film) - produced by incorporating multiple layers of silicon on the surface of another material, such as glass. In these solar batteries, we can not distinguish individual cells. Amorphous solar cells are generally used in small devices such as calculators and watches[4,6,9,10].As the metal contacts are made, the solar cells are interconnected by flat wires or metal ribbons, and assembled into modules or solar panels [7,11,12]. If the lower flow resistance of the current, the output current is a multiple of the current cell panel and associated with parallel connections of elements and modules. Similarly, the output voltage of the module depends on the amount series-connected cells and modules [3,13]. Photovoltaic solar cell generates electricity only when it is illuminated, electricity is not stored [13].

The current-voltage characteristics of the cell are shown the output current PV generator, depending on the voltage at the set temperature and lighting [2.14]. Short circuit current (ISC) - the output current of the photoelectric. Generative at a given temperature and irradiance, PMPP - point MPP (Maximum Power Point) is [2,6,15]. The output voltage is heavily dependent on the temperature of solar cells: increase results in a lower operating temperature and efficiency of [2,9].

The inverter is an inevitable component of the photovoltaic module.

There are many inverters available on the market. The cost of these inverters is a bit high due to the microcontroller-based SPWM generator [17,18,19]. In the article [20], researchers devoted to the design and construction of an inverter with a power of 100 W, 220 V and 50 Hz. The system is designed without a microcontroller and it has a cost-effective design architecture. The elementary purpose of this device is the conversion of 12 V DC to 220 V AC.

Solar Photovoltaic Modules (SPM) are popular in agriculture. For a lot of small farms, the main source of electrical energy is electric generators driven by Internal Combustion Engines (ICE), since installation of electrical networks is economically unprofitable. In these conditions, SPM are economically and environmentally promising, since it does not require the consumption of fuels and lubricants does not harm the environment. Determination of the main SPM operating parameters in 2 modes is considered in this research. In the cases when the panels oriented towards the sun (tracking mode) and in a stationary state with orientation to the south (without tracking mode). The dependences of current, voltage and power on time and density of solar radiation were measured. Accordingly, the voltage and current of Transportable Photovoltaic Unit (TPU), the charging current and the voltage of the batteries, the voltage at the output of the inverter, the temperature and humidity of the outside air and the electrical energy consumption by the electric receivers were recorded. The study of the TPU operation showed that the mode of orientation to the sun increases the daytime power generation by 25, ..., 33% in comparison with the fixed installation of Solar Panels (SP). The analysis showed the discrepancy between SP passport data and the experimental results. The decrease in electricity generation was 14% compared to the expected estimates [21]. The advent of unique technologies of the developing Solar Energy (SE), actual energy, faces economic and environmental problems. The main obstacle to the widespread use of SE is the low value of the average annual efficiency of known solar installations. In a sharply continental climate, they are exploited only in the warm season, about 6-7 months. Known combined systems, where additional conventional water heaters duplicate the operation of solar units, require additional costs for energy carriers. These disadvantages are not offered by the integrated system of SE use. In the article, the system was studied using the example of a cattle-breeding farm. The new system performs these functions; it recycles heat, organizes their movement and accumulation, and smooths out the uneven SE. The main components of the system are: Solar Power Plant (SPP), milk cooler, climate unit, Heat Pump (HP), the battery heat, automatic control system, and device heating and hot water. The main goal, i.e. lower cost of the energy produced and the elimination of the uneven SE, compared to the known SPP, is achieved through the flow of energy from the sources mentioned above [22].

2.Model Solar Battery

Photovoltaic generators for direct conversion of solar radiation into electrical energy, collected from a large number of series-connected photovoltaic solar cells (solar cells), are called solar cells (SC). Modern Security generate significant light on electrical power and are used both for power spacecraft (SC), and for many terrestrial autonomous devices for different purposes. Solar panels are made up of tens or hundreds of thousands of individual solar cells connected in parallel, in series in order to provide the required voltage and current ratings.

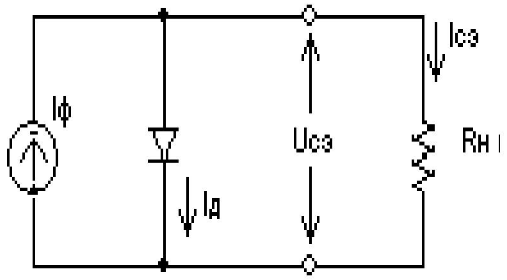


Figure 1 - Equivalent circuit of a solar cell

Figure 1 shows an equivalent circuit of the solar cell of substitution (SE). It is described by the following expression [16]:

$$I_{NY} = I_O(W) - I_0 \cdot \left[exp\frac{qU_{NY}}{kT} - 1\right] \leftrightarrow U_{NY} = \frac{kT}{q} ln\left[\frac{I_O(W) - I_{NY}}{I_0} + 1\right] \quad (1)$$

Where I_{NY} - current through an external load, I_0 - reverse saturation current, q - electron charge, T - the absolute temperature, ° K, k - is Boltzmann's constant, U_{NY}- voltage at the output element, I_O - current of minority carriers generated by the light (photocurrent).

Influence of irradiance on the FE value U_{NY} value expressed by the formula [13].

$$\mathrm{I_O(W) = W \cdot I_O} \quad (2)$$

where W - Illumination SE.

Figure 2 - The full-scale model of the solar panels

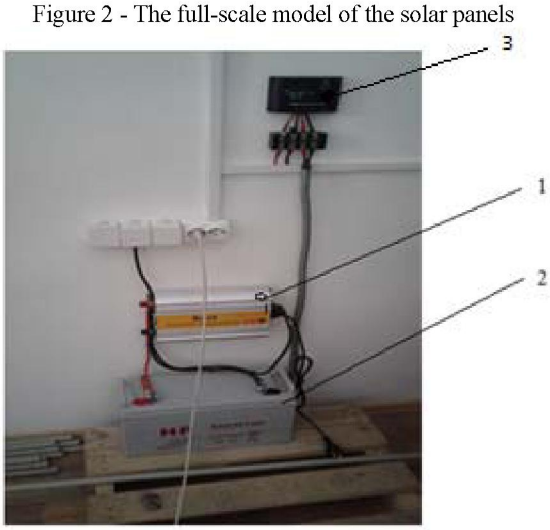


Fig. 3. The solar power systems:
1-inverter; 2- battery;3-controller

3. Inverter to convert DC to AC voltage

The objective of this study is to reduce the load on the power supply with maximum efficiency and increase the term of stability, simplify the design of the device, reduce the cost and expand the scope of their use in industry.

This task is achieved by the fact that when turning on the PWM controller that regulates the width of the pulses 1 to the logic elements 3, 4, the maximum sequence of gates of field-effect transistors is achieved.

As shown in Figure 1, the device has a PWM controller that regulates pulse width 1, voltage regulator 2, with field-effect transistors connected 3.4, to convert from DC to AC, capacitors 5, to filter the input voltage, diode bridge 6, transformer consisting of primary and secondary windings 7, switch 8, housing 9, you can use any material, plastic, iron, aluminum.

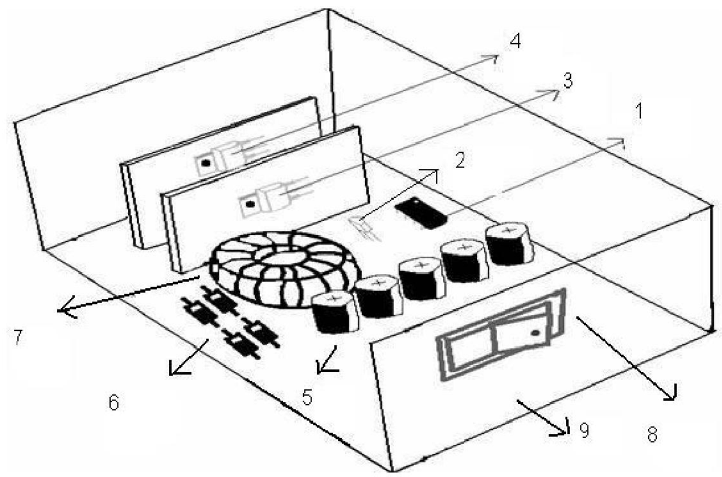


Figure 4 - Inverter to convert DC voltage to AC

Assembly and manufacture of the device is as follows. A PWM controller regulating pulse width 1 is connected via voltage regulator 2, and capacitors 5, for filtering and limiting the input voltage, followed by connecting field-effect transistors 3, 4, screwed to passive cooling, to prevent heating, and with parallel connection of the secondary winding transformer 7, the primary winding is connected directly to the diode bridge 6, with the connection to the input voltage circuit of the switch 8, with the subsequent location in the housing 9.

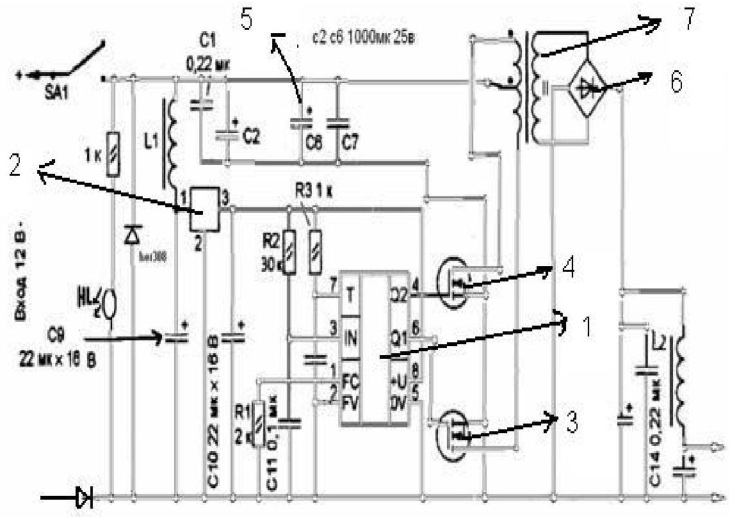
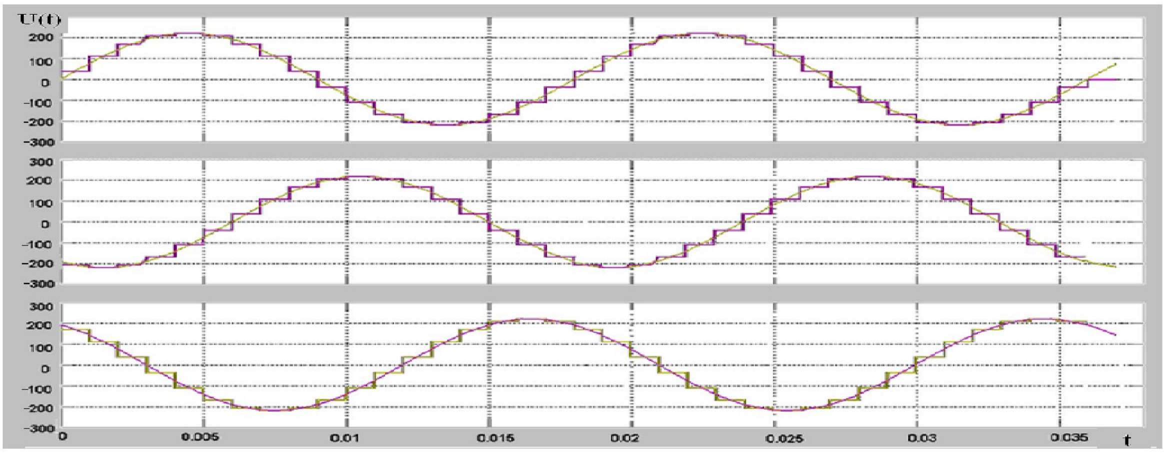


Figure 5 Schematic diagram of the inverter

The operation of the proposed device is as follows. When the input voltage is connected, with the switch 8 connected to the input voltage circuit, the current is fed to the PWM controller that controls the pulse width 1, through the capacitors 5, to filter the current, and the voltage regulator 2, then connect the field-effect transistors 3, 4 screwed to the passive cooling, to prevent heating, and with the parallel connection of the secondary winding of the transformer 7, the primary winding is connected directly to the diode bridge 6, with the connection to the input voltage circuit of the switch 8, followed by p As position in the housing 9.

According to the developed method of rational use of solar photo converters, calculations were carried out for a three-phase conversion system for various inversion schemes. According to calculations, it was found that with a three-phase conversion system, it is possible to save from 18.5% to 35.19% of expensive solar photo converters.



1- Output step voltage curve; 2- perfect sine curve

Figure 6 - The output voltage of a three-phase five-step model

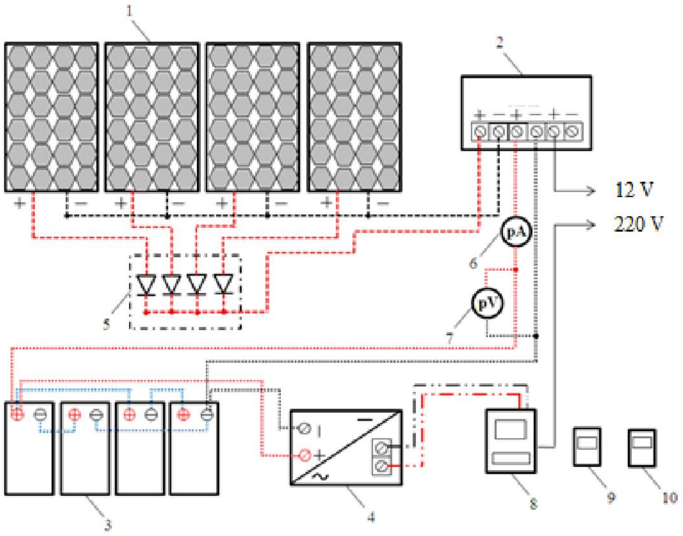
In accordance with the graphical analysis, it can be asserted that with a three-phase load, as the steps grow, a voltage curve can be obtained that is close to a sinusoid.

4. Result

During the research, the following are recorded: the voltage and current of the FCM, the charging current and the voltage on the batteries, the voltage at the output of the inverter, the temperature of the outside air (from +5 to +35 0C) and the humidity of the outside air, and the electric power consumption of the electric receivers of the connected load.

In the experimental studies we used: a solar radiation meter SM-206, an ammeter and a DC voltmeter, a UT206 multimeter, a Saiman electric energy meter, a CENTER-350 infrared thermometer, and an MES-202 meteorometer. The measurement of solar radiation was carried out with a portable SM-206 instrument with an accuracy of ± 5% (measuring range 0.1 ... 399.9 W / m2, temperature - with an infrared thermometer CENTER-350 with an accuracy of ± 2% (measuring range -20 + 5000C) And the air humidity were measured with a psychrometer MV-4M with an error of ± 4% and a meteorometer MES-202, the limit of the permissible value of the absolute error of the pressure measurement is not more than ± 0,3 kPa in the temperature range from 0 to 60 0 C. Overall dimensions were measured with a tape measure of metal PM with an error ± 0.5 mm (measuring range 0 to 10m, the division price is 1mm) and a metal ruler (length 1m) with an error of ± 1mm.

The diagram of the connection of devices and equipment during laboratory-field testing is shown in Figure 1.



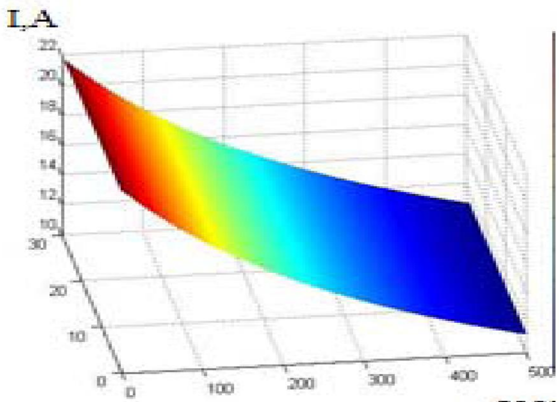
1-PV panel; 2- controller; 3- rechargeable battery; 4- inverter; 5- diodes; 6 - direct current ammeter; 7 - DC voltmeter; 8 - the counter of electric energy; 9 - solar radiation meter; 10 - a weather meter

Figure 7 - Scheme for mounting equipment and connecting devices

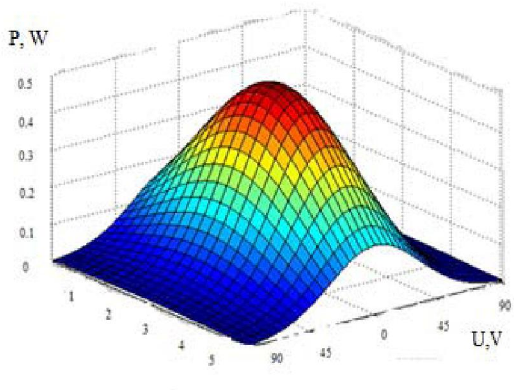
We are implementing the mathematical model of SE. As an example, we choose an SE with the following characteristics:

$$U_{xx} = 0{,}45B,$$
$$I_{kz} = 4{,}5A,$$
$$I_0 = 2{,}045 \cdot 10^{-9}A$$

The circuit that realizes the volt ampere characteristic of the solar cell described by the expression (1) is shown in Fig. 2. It allows one to estimate the influence on the operation of such parameters as the illumination level of the solar cell (nominal value W = 1360 kW / m ^ 2), the ambient temperature (Nominal value K = 298 K), as well as the angle of incidence of the light flux (nominal value α = 90 ° = π / 2 rad).



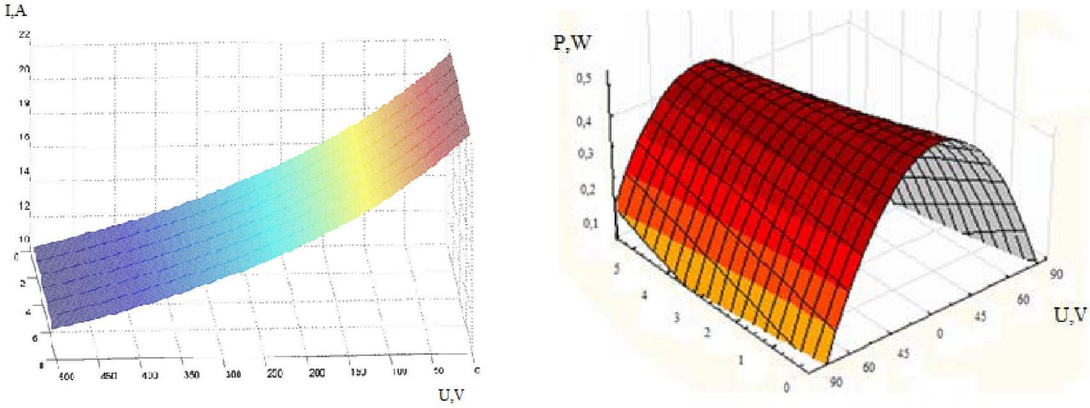
a



b

a - current-voltage characteristic, b – volt watt characteristic
Fig. 8. Characteristics of the SE, described by the equation (2)

We test the solar battery consisting of 3 elements connected in series. In this case, the voltage at the output of the U_NA SB is determined by the formula$U_{NA} = U_{YEA} = U_{NY} \cdot N$, where N is the number of solar cells connected in series$I_{NA} = I_{YEA} = I_{NY}$.



a b

a - current-voltage characteristic, b – volt watt characteristic
Figure 9 - Characteristics of the circuit shown in Figure 4

As can be seen from Fig. 9, the idling voltage of the SB is 3 times greater The open circuit voltage of the solar cell (see Figure 3) => the model is compiled correctly.

V. CONCLUSION

Comparison with experimental data, processed by MATLAB, and with the characteristics of the PV panels, provided by manufacturers, has shown that the model implemented in MATLAB/Simulink can be an accurate tool for the prediction of energy production. A PV system model, using the same equations and parameters as in MATLAB/Simulink to define the PV module and characteristics, has also been developed and implemented in domestic consumers in agriculture to study load flow, steady-state voltage stability and dynamic behavior of a distributed power system. A comparison between both simulation models, implemented in MATLAB/Simulink and domestic consumers in agriculture , has shown a good similarity. That means that this work can be used for further development of tools for DER components in a distributed network. The developed mathematical model of the solar battery makes it possible to evaluate the influence on the characteristics of the SB both internal factors (U_{xx}, I_{kz}), and external (W, T, α). The model is designed for design of SES. The results of testing the model confirm its operability.

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ТҰРАҚТЫ ТОК АЙНЫМАЛЫ КЕРНЕУГЕ ТҮРЛЕНДІРУ ҮШІН ТҮРЛЕНДІРГІШТІКПЕН КҮН ФОТОЭЛЕМЕНТТЕРІНІҢ МАТЕМАТИКАЛЫҚ МОДЕЛІН ӘЗІРЛЕУ ЖӘНЕ ЗЕРТТЕУ

Аннотация. Бұл мақалада фотовольтаикалық жүйелердің математикалық моделі берілген. Дербес энергетикалық жүйелердегі энергетикалық процестерді талдау үшін компьютерлік модельдеу әдістерін қолдану ұсынылады. Модельдеу моделін пайдалану автономды электр энергиясын беру жүйесінде энергетикалық тепе-теңдік қамтамасыз етуге мүмкіндік береді және энергияның буферлік көздері мен жүктің энергияны тұтынуының уақытша шкаласы. Бұл қуат көздерінің энергетикалық сипаттамалары бойынша уақытша өзгерістерге байланысты жүйедегі энергия теңгерімін қамтамасыз ету үшін трансмиссиялық жүйелердің энергетикалық сипаттамаларына, сондай-ақ, трансформатор параметрлері жүйелерінің энергия сипаттамаларына әсері сияқты, күннің энергия. жарықтандыру, температура, жыл уақыты және т.б. Бұл модель берілген температурада ағымдағы кернеу сипаттамасымен (CVC) сипатталады, ал жарықтандыру жағдайлары фотоэлектрлік энергияның параметрлерін есептеу кезінде негіз болады. Сондай-ақ жаңа ток түрлендіргішті айнымалы кернеуге айналдыру үшін әзірленген және зерттелді, бұл 18,5% -дан 35,19% қымбат күн фотоэлементтерін үнемдеуге мүмкіндік берді.

Түйін сөздер: күн батареясы; ток кернеуінің сипаттамалары; математикалық модель; MatLab.

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РАЗРАБОТКА И ИССЛЕДОВАНИЕ МАТЕМАТИЧЕСКОЙ МОДЕЛИ СОЛНЕЧНОГО ФОТОПРЕОБРАЗОВАТЕЛЯ С ИНВЕРТОРОМ ДЛЯ ПРЕОБРАЗОВАНИЯ ПОСТОЯННОГО ТОКА В ПЕРЕМЕННОЕ НАПРЯЖЕНИЕ

Аннотация. В данной статье представлена математическая модель фотоэлектрических систем. Для анализа энергетических процессов в автономных системах электропередачи сейчас целесообразно использовать методы компьютерного моделирования. Использование имитационной модели позволяет обеспечить энергетический баланс в автономной системе передачи энергии с конкретными энергетическими характеристиками наземных и буферных источников энергии и шкалой времени от потребляемой мощности нагрузки. Это позволяет влиять на энергетические характеристики систем передачи, чтобы обеспечить энергетический баланс в системе с точки зрения временных изменений энергетических характеристик источников энергии, а также влияния на энергетические характеристики систем параметров передачи, таких как солнечный энергия. освещение, температура, время года и т. д. Эта модель описывается вольт-амперной характеристикой (CVC) при данной температуре, и условия освещения являются основой для расчета параметров фотоэлектрической энергии в воке. Новый инвертор был также разработан и исследован для преобразования постоянного тока в переменное напряжение, что позволило сэкономить от 18,5% до 35,19% дорогих солнечных фотопреобразователей.

Ключевые слова: солнечный элемент; вольт-амперные характеристики; математическая модель; MatLab

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