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O. Lopakov,
V. Kosmachevskiy,
Y. Babych, PhD, Assoc. Prof.,
V. Tigarev, PhD, Assoc. Prof.,
M. Babych, PhD, Assoc. Prof.
Odessa Polytechnic National University, 1 Shevchenko Ave., Odessa, Ukraine, 65044; e-mail: kedrodessa9@gmail.com

MATHEMATICAL MODELING OF THE MPPT-CONTROLLER FOR RENEWABLE ENERGY SOURCES ON MOSFET TRANSISTORS

О. Лопаков, В. Космачевский, Ю. Бабич, В. Тігарєв. М. Бабич. **Математичне моделювання MPPT-контролера для відновлюваних джерел енергії на Mosfet-транзисторах.** У цій статті розглянуто натурні випробування та практичну реалізацію низьковольтної світлодіодної системи освітлення з відновлюваними джерелами енергії в автономному об'єкті та розробку моделі оптимального управління температурою в автономному об'єкті. А також розробка методу комплексного управління системи електропостачання з використанням Smart контролера енергозабезпечення автономного об'єкта. Для реалізації математичної моделі використовувалося програмне забезпечення Simulink і Sim Power Systems візуального моделювання, що входить у пакет MatLab. Використання програмного забезпечення дозволяє моделювати складні електричні системи. Перевагою використання цієї програми є поєднання методів структурного та імітаційного моделювання, і такий підхід забезпечує гнучкість системи під модель, що розробляється, значно спрощує модель, отже, підвищує швидкість обчислень. При розробці систем керування температурою в приміщенні виникає ряд проблем, таких як визначення часу, необхідного для підвищення температури для забезпечення заданих значень до потрібного моменту, вибір алгоритму регулювання температури та визначення параметрів обраного алгоритму. Завдання вибору закону управління та типу регулятора полягає у виборі такого регулятора, який за мінімальної вартості та максимальної надійності забезпечував би задану якість регулювання. У цій статті вибір був зроблений на PID-регулятор так як при стрибкоподібному зміні регульованої величини PID-регулятор в початковий момент часу надає нескінченно миттєво великий вплив на об'єкт регулювання, потім величина впливу різко падає до значення, що визначається пропорційною складовою, після чого постійно починає надавати вплив інтегральної складової регулятора. Перехідний процес в PID-регуляторах має мінімальні відхилення за амплітудою і часом порівняно з P- і PI-регуляторами (тобто найбільш висока швидкодія).
Ключові слова: MPPT-контролер, PID-регулятор, solar panel, DC-DC converter, рівняння теплового балансу, linear transformer, Mosfet

O. Lopakov, V. Kosmachevskiy, Y. Babych, V. Tigarev, M. Babych. **Mathematical modeling of the MPPT-controller for renewable energy sources on Mosfet transistors.** This article discusses field tests and practical implementation of a low-voltage LED lighting system with renewable energy sources in an autonomous facility and the development of a model for optimal temperature control in an autonomous facility. The method of complex management of the power supply system using the Smart controller of the energy supply of the autonomous object is also considered. To implement the mathematical model, the Simulink and SimPowerSystems software for visual modeling included in the MatLab package was used. The use of this software allows you to simulate complex electrical systems. The advantage of using this program is the combination of methods of structural and simulation modeling, and this approach provides the flexibility of the system for the model being developed, greatly simplifies the model, and therefore increases the speed of calculations. When developing indoor temperature control systems, a number of problems arise, such as determining the time required the temperature to rise to provide the set values to the required moment, choosing the temperature control algorithm and determining the parameters of the selected algorithm. The task of choosing the control law and the type of controller is to choose such a controller, which at minimum cost and maximum reliability would provide the specified quality of regulation. In this article, the choice was made on the PID regulator, since with a jump-like change of the regulated value, the PID regulator at the initial moment of time has an infinitely large influence on the object of regulation. Then the magnitude of the influence drops sharply to the value determined by the proportional component, after which the integral component of the regulator begins to exert its influence constantly. The transient process in PID controllers has minimal deviations in amplitude and time compared to P and PI controllers (i.e., the highest speed).
Keywords: MPPT-controller, PID-regulator, solar panel, DC-DC converter, heat balance equation, linear transformer, Mosfet

1. Introduction

The total installed capacity of small wind power worldwide has reached 443.3 MW, and the total installed capacity of large wind power in the world has reached 240 GW. Small wind energy accounts for 0.18 % of large wind energy in various countries of the world. To date, Germany ranks first in

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terms of installed wind power capacity, followed by Denmark, Spain, the United States of America, and India. Development is also growing rapidly in France and China. In Denmark, 28.1 % of the country's needs are provided with electricity due to wind turbines, in China 1…2 %, in the USA it is 3…4 %.

SMART technologies are widely used in the field of telecommunications, in control and monitoring systems. The abbreviation of the word SMART means specific, measurable, achievable, relevant, timed. Smart technologies are a complex combination of control and management technology that provides an autonomous object with the necessary quantity and quality of energy. At present, the active use of renewable energy sources in many developed countries of the world is accepted as a vital, strategically necessary resource that ensures the promising development of the economies of these countries. According to forecasts, the share of renewable energy (solar, wind, tidal, solar energy, etc.) in global energy consumption will increase annually and will reach 30 % by 2030, and 50 % by 2050. However, despite promising results, alternative energy sources have not yet found the level of optimal compliance with the expectations of the mass consumer.

There are different types of WU blades (wind turbines) that are designed for optimal electricity generation and for them it is enough that the wind speed is 3 m/s [1]. One of the most important problems in the use of renewable energy sources in the power supply system is the significantly non-constant value of the power generated by the solar battery, the wind turbine. The use of renewable energy sources [2, 3, 4] in the power supply system has been widely developed today in Europe, the USA, Japan, South Korea, China, Norway, Canada and other countries [3, 4, 5].

Currently, all developed countries are switching to the use of renewable energy sources such as solar [5] and wind [6], and the use of biomass is only becoming widespread. The largest manufacturers of solar panels are Yingli Green Energy (China), FirstSolar (USA), Trina Solar (China), Suntech Power Co. (China), Canadian Solar (Canada), Sharp (Japan), JASolar (China), Jinko Solar (China), Sun Power (USA), Hareon Solar (China), Hanwha Solar One (China), Kyocera Solar (Japan), Rena Sola (China), Rec (Norway), Tianwei New Energy (China) [3, 4].

2. Analysis of publications and statement of the problem

Modern solar installations are equipped with advanced technologies, the article [8] suggests sun-tracking installations on which solar panels are attached, which ideally should convert the sun's radiation as much as possible, but in reality there are problems with software security and an incomplete control system of the solar battery itself and its controller. There are also problems of lack of power to power a particular building with a solar battery and suboptimal SP illumination. Solar batteries generate a direct current with a voltage of 24V. In order to use this current, a voltage converter is required. In a lighting system using LEDs [9 – 13], it is possible to use low-voltage voltage [14] without using a voltage converter.

Mostly all LED fixtures are powered by 24VDC at the input, but in all countries it is powered by 110V, 220V and 230V. An inverter is installed in the LED device itself, which converts the received voltage to 24V.

Solar battery controllers provide optimal battery charging, but due to the lack of control and monitoring of the controller operation, the batteries are not fully charged only for heating and hot water supply [15 – 18].

In many works, wind turbines are combined with a diesel generator or a battery, and in these works, the installation itself is mainly calculated without automating the process of generating and consuming energy, methods for calculating a wind generator when operating at low wind speed are given.

In scientific papers [19, 20, 21], it is proposed to use the MPPT (Maximum Power Point Tracker) controller to control the wind turbine at low wind speeds. The obtained simulation results show that, regardless of the inclination and power of the turbine, this method provides a greater opportunity to control the wind turbine regardless of wind speed. The active and reactive power of the turbine stator is regulated. The results obtained can be used. The disadvantage at the nominal wind speed of the proposed scheme limits the speed of rotation of the blades.

The analysis of the data [22] revealed that regardless of the technical and operational characteristics of various models of solar panels with an area of 0.2 m^2, the power of the module will be about 10W. The voltage at maximum load is approximately 24…25 V, the short circuit current is about 500 μA, the weight of this module is 2 kg, where the efficiency is 60 % and the service life of the plate is

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25 years. Regardless of the comparatively low efficiency of the solar panel, it is an efficient source among other renewable energy sources and autonomous power sources [23]. The power of solar radiation at the entrance to the earth's atmosphere is 1366 per m^2.

In the article [24], the author presented a new concept for the formation of a control system in distributed energy based on Smart technologies. The concept of distributed energy is based on a variety of energy sources and distribution networks, which implies the presence of many consumers producing heat and electricity for their own needs, as well as directing surpluses to the general network. The author has developed an algorithm for the operation of the control process based on SMART information.

In scientific works [25, 26, 27], it is proposed to use SMART technologies in buildings to ensure a comfortable microclimate and energy supply of the facility without loss of generated energy. When implementing SMART technologies, automation of the processes of the energy supply system was not considered.

In the article [28], SMART technologies are applied to street lighting using solar panels. The authors propose intelligent control in the urban lighting system. In this work, the controller is of functional importance, which ensures the optimization of the control of the energy street lighting system. This lighting control system is designed for 230V voltage.

The articles [29, 30, 31] reflect the issues of traditional energy. The authors propose to use RES (Renewable Energy Source) with elements of a SMART system, and the authors propose a method for detecting inefficient energy use in smart buildings. The data mining system was developed using the synthesis of information received from sensors.

In the study [32], the authors describe the energy integration management system of smart meters for electricity consumers in Smart Meters (SM). The SMs are connected to a SCADA (Supervisory Control and Data Acquisition) system that controls a network of programmable logic controllers (PLCs). The SCADA system and PLC network integrates various types of information coming from several elements of SMART technologies present in modern buildings. For implementation, programmable controllers are used, a communication channel has also been developed that provides data exchange between the SCADA system and the Matlab software. The study [32] describes only the control of the controller.

3. Unresolved problem area

In the articles discussed above, the authors approach solving the problems of introducing intelligent systems into the power supply system of an autonomous object, using different software, and solving individual tasks and subtasks. The lighting system uses double energy conversion, which leads to significant energy losses.

According to the literature review of existing sources, it has been established that, at present, the management and control of the electrical circuit of the power supply system of autonomous objects are not fully considered. The article considers the energy supply system, due to the use of alternative energy sources, the algorithm for managing the energy supply system has not been finalized.

The work proposes a matrix conversion of the current of solar batteries. The article presents the structure of solar power plant based on a matrix current converter of a solar battery, a method for calculating the energy balance in an autonomous power supply system is given. The source of energy supply is the sun and the battery, which cannot provide the full power supply of an autonomous object, and only transistor switches of the solar battery with a special circuit are controlled.

4. The purpose of the work

1. Development of an optimal SMART technology for monitoring and managing the power supply systems of an autonomous object. At the same time, the object of study is the power supply system of an autonomous object;

2. Modeling of automation systems for power supply of an autonomous object;

3. Development of a model for optimal control of the desired temperature in an autonomous object.

5. The method of integrated management of the power supply system using SMART control management

As a result of the analysis made, a standard block diagram of renewable energy management was applied, the power supply system in Fig. 1.

The scheme in Fig. 1 implements the control of the operation of a renewable energy source and the power supply system of an autonomous facility. Depending on the required amount of electrical energy at a certain point in time, the control system controls the energy generation of installations operating on RES. To control the system, it is necessary to know the required amount of electrical energy, which is calculated depending on energy consumers. Energy consumers include household appliances, lighting system, heating system, climate control system, fire safety system, office equipment, audio and video equipment, and others. Together they add up to a load.

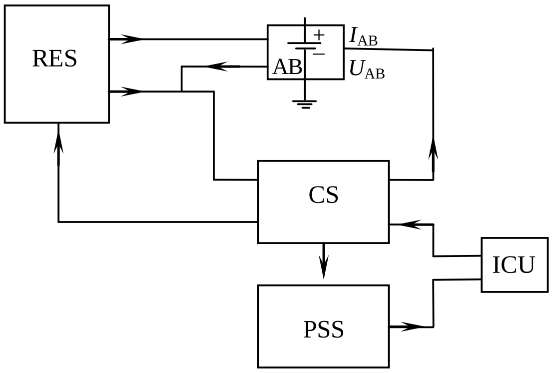

Fig. 1. Structural diagram of renewable source management control and power supply system: RES – renewable energy source, AB – battery, CS – control system, PSS – power supply system, ICU – information collection unit

In this paper, it is proposed to use a low-voltage lighting system for research and modeling. As a result of the studies, it was found that the voltage generated by the solar panel is equal to the voltage of the LED lamp and is 24V.

For the study, a structure was assembled, consisting of a solar panel, a converter, a battery, an LED device, a voltmeter, an ammeter and a wattmeter. An electrical circuit with measuring instruments was assembled, which is shown in Fig. 2. The number of operating batteries depends on the amount of power required by the autonomous object and on the time of day. We choose solar panels of the following characteristics (one solar panel):

– maximum power 400 W;
– short circuit current 2.98 A;
– open circuit voltage 22.3 V;
– voltage at maximum power 18.3 V;
– current at maximum power 2.73 A;
– dimensions 500×80000.

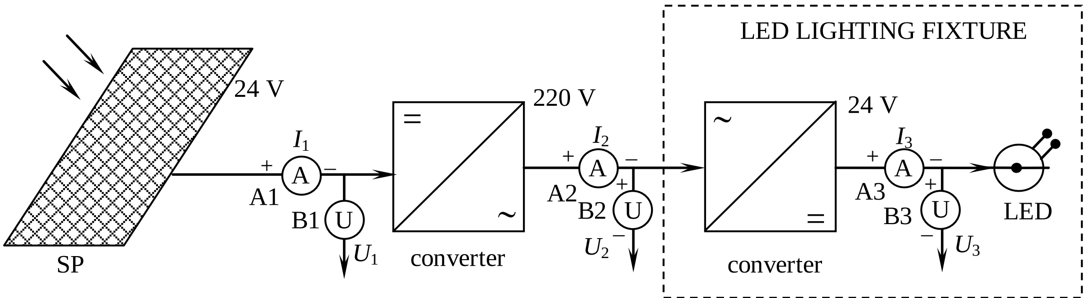

Fig. 2. General scheme of system measurement

The energy source is the solar panel of the joint venture, the voltage and current were measured before and after the converter and converter. Fig. 2 is an AC to DC voltage converter. To implement the mathematical model, the software Simulink and SimPowerSystems for visual modeling included in the MatLab package were used load, battery, solar and wind turbine (Windturbine) current sensors, battery voltage sensor, information acquisition unit (ICU) and power supply. The block diagram of the SMART technology for controlling the power supply system of an autonomous object is shown in Fig. 3.

The control system controls the power switches using a driver located in the SPKCP (solar panel key control panel) and WT (wind turbine) and SLKCD (switching load key control device). The switching of keys is carried out in such a way that one pair of batteries or two pairs at once can be connected to the solar battery, depending on the charge of the batteries. In emergency situations, the power supply system of an autonomous object is carried out from batteries or a wind turbine. In case of emergencies at night, when the battery charge decreases, an alarm signal is generated, which is sent to the SMART center. In turn, the SMART center switches the facility's power supply to another type of renewable energy source.

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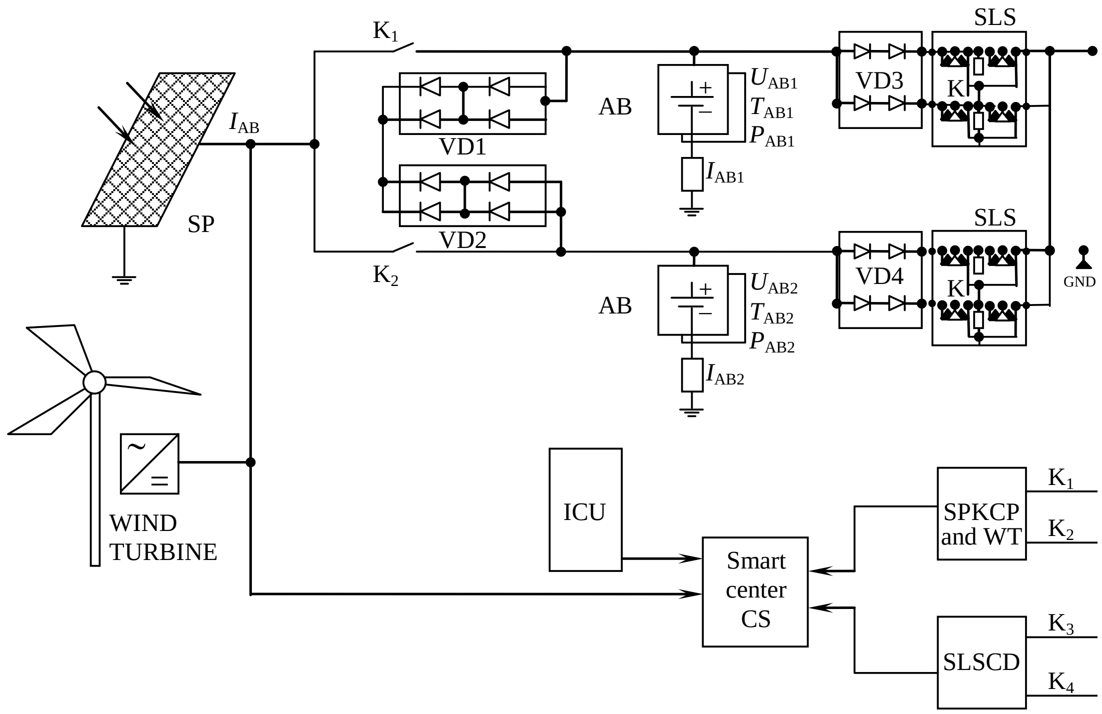

Fig. 3. Block diagram of SMART system management technology power supply of an autonomous facility

The battery charge level is organized according to the principle of subordinate voltage regulation AB, the block diagram of which is shown in Fig. 4. In normal operation, the principle of operation of the PSS power supply system is based on maintaining a sufficient power level on the battery buses by switching sections of the SP. Key management is organized according to the principle of subordinate voltage regulation AB, the block diagram of which is shown in Fig. 4.

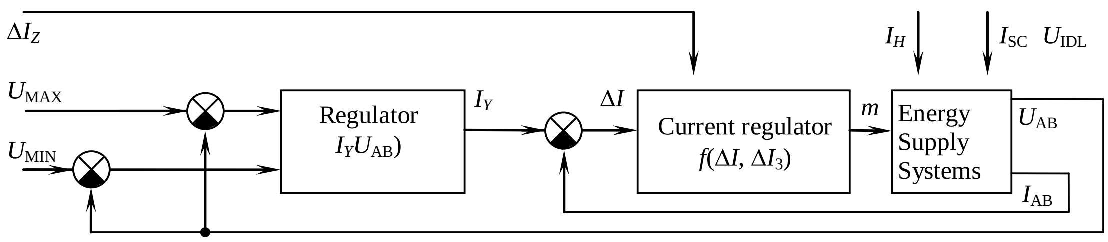

Fig. 4. Structural diagram of the subordinate regulation of the battery voltage

The main voltage regulation circuit on AB is shown in Fig. 4. Based on the voltage level AB, the regulator I_Y (U_{AB}) generates a signal I_Y, which is a current setting for subordinate control loop. The I_Y regulator (U_{AB}) seeks to maintain the AB voltage within the range of specified values $U_{MIN}<U_{AB}<U_{MAX}$. When U_{AB} reaches the maximum value U_{MAX}, the IU signal is set to zero and this mode is called AB charge maintenance. When U_{AB} decreases to the U_{MIN} value, the I_Y signal is set to a value quantitatively equal to the maximum allowable charging current AB and it is called charge AB.

During the operation of the power supply system of an autonomous object, in Fig. 4, a disturbance in the form of a load I_H or parameters of the volt-ampere characteristics of the solar panel (ISC, UIDLE) lead to a change in the battery current by an amount ΔI relative to the installation current I_Y. The current regulator seeks to suppress this deviation so that it does not exceed the maximum allowable value ΔIZ and generates the corresponding signal m for switching keys K_1 and K_2. A block diagram of a solar panel was built on Fig. 5. The power supply system of an autonomous object consists of a solar panel and a wind turbine.

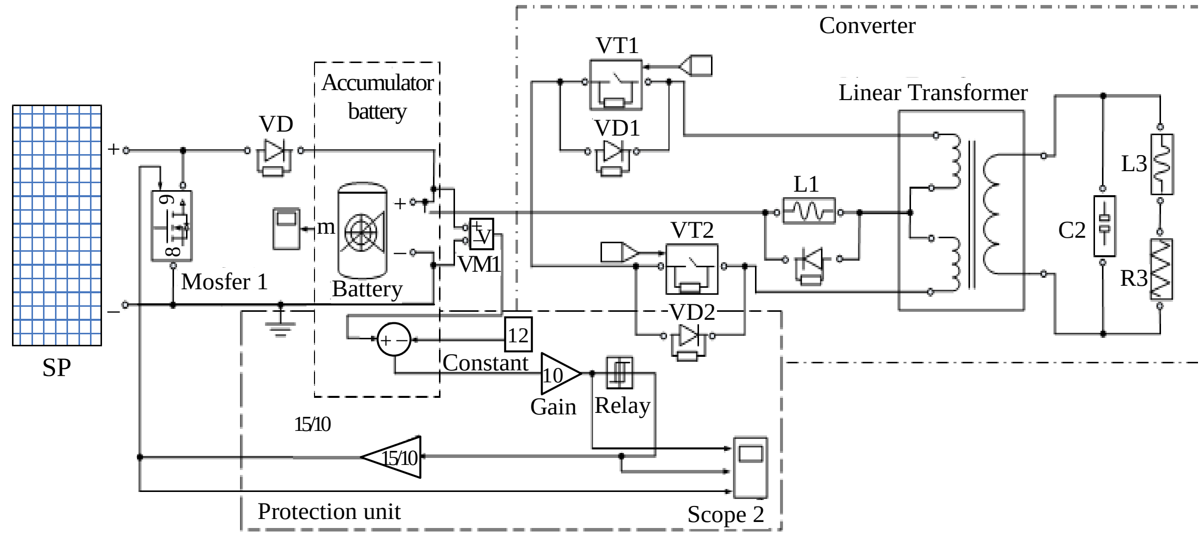

Fig. 5. Structural diagram of the solar panel in Simulink, which is part of the MATLAB package

The protection of the battery (Accumulator Battery) from overvoltage, when converting (Converter) voltage from 24 V to 220 V, is provided by the protection unit (ProtectionUnit) of the battery shown in Fig. 5.

The simulation shows that with a positive energy balance, the voltages on AB1 and AB2 are in the specified mode of 24/220 V, and at the same time the full functioning of the load is ensured. With a negative energy balance, the load operation stops when the permissible voltage value on AB1 and AB2 is reached, while the PSS (power supply system) switches to emergency operation and charges the batteries.

6. Development of a model for optimal temperature control in an autonomous object

Regulators with a linear regulation law according to the mathematical dependencies between input and output values are divided into the following types:

– proportional (P-regulators);
– proportional-integral (PI-regulators);
– proportional-integral-differential (PID-regulators).

The room temperature control loop in Fig. 6.

The air temperature is maintained by heating equipment, but is powered by solar panel energy. The sensor T measures the room temperature, and then this value is fed to the comparison device CY of the measured temperature value T_M and the setpoint T_S. Depending on the difference between the set and measured temperature values, the controller P generates a signal that acts on the actuator M. The actuator opens or closes the valve until the error approaches zero:

$$\varepsilon = T_{set} - T_{measured} \, . \tag{1}$$

A generalized structural diagram of the ACS is shown in Fig. 7.

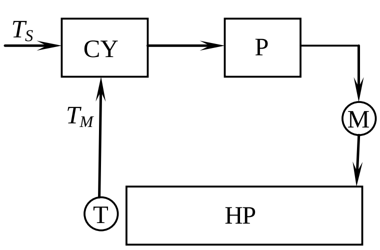

Fig. 6. Indoor temperature control: CY – comparing device; T_s is the set temperature; T_M is the measured temperature value; P – regulator; HP – heating unit; T – temperature sensor; M – actuator

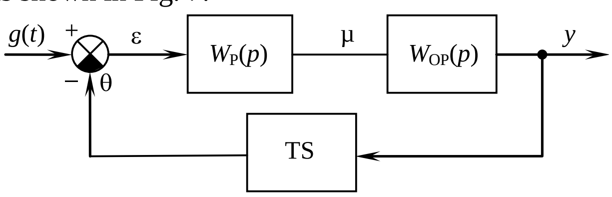

Fig. 7. Block diagram of the automatic control system (ACS): $W_P(p)$ – controller transfer function; $W_{OP}(p)$ – transfer function of the control object (regulation); TS – temperature sensor; g(t) is the set temperature value; ε – regulation error; y is the controlled value; θ – temperature value measured by the sensor

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The transfer coefficient from mismatch ε to output y is given by:

$$W(jw) = W_{\text{P}}(p)W_{\text{OP}}(p)\,, \tag{2}$$

where $W_P(p)$ is the controller transfer coefficient;

$W_{OP}(p)$ is the transfer coefficient of the regulated object.

For modeling, analysis and synthesis of objects and automation, the problem of synthesizing the ACS system for the air temperature in the room of an autonomous object is considered, the temperature inside the room should not exceed 27 °C. The structural diagram of the ACS is shown in Fig. 7.

To synthesize an ACS with a typical control law, it is necessary to describe mathematically the components of its links. Let's theoretically obtain a mathematical model of the room as a control object. The value of the air temperature in the room θ depends on the power of the heating equipment P and the outdoor temperature θ_H. To obtain a mathematical description of the control object, information from the field of heat engineering was used.

In the process of heating the room, one part of the heat output (heater) is spent on raising the temperature in the room, and the second part is dissipated to the outside by heat transfer through the walls. Mathematical formulas, and represent the general heat balance equations and have the following form:

$$P_1 = c\frac{\partial\theta}{\partial t}\,, \tag{3}$$

$$P_2 = \frac{Sk}{l}(\theta - \theta_{\text{H}})\,, \tag{4}$$

where P_1 is the thermal power of the heater, kW;

P_2 – thermal power, dissipated to the outside, kW;

c – heat capacity of the air in the room, kJ/(kg×°C);

S –wall area, m^2;

k –the coefficient of thermal conductivity of the walls (enclosing surface), kW/(m×°C);

l – wall thickness, m.

Considering that the sum of these powers is equal to the power of the heated installation, we obtain:

$$P = c\frac{\partial\theta}{\partial t} + \frac{Sk}{l}(\theta - \theta_{\text{H}})\,. \tag{5}$$

Transforming this formula, we obtain a mathematical description of the control object under consideration:

$$\frac{l}{S_k}P + \theta_{\text{H}} = \frac{cl}{S_k}\frac{\partial\theta}{\partial t} + \theta\,, \tag{6}$$

where $cl/S_k=T$, time constant, s;

$l/S_k=K$ – conversion coefficient, (°C/W), substituting we get these transformations:

$$K_{\text{P}} + \theta_{\text{H}} = T\frac{\partial\theta}{\partial t} + \theta\,. \tag{7}$$

This equation is a linear differential equation of the 1-st order. In automatic control systems, there is a need for a controller that would generate an additional control action proportional to the rate of deviation of the controlled variable from the set value. Therefore, our studies were carried out using PID control. The differential component has the form according to the formula (8):

$$\mu_D = T_D\frac{\partial\varepsilon}{\partial t}\,. \tag{8}$$

PID controllers act on the control object in proportion to the deviation of the controlled variable, the integral of this deviation and the rate of change of the controlled variable:

$$\mu = K_P\varepsilon + \frac{1}{T_U}\int_0^t \varepsilon\,\partial t + T_D\frac{\partial\varepsilon}{\partial t}\,, \tag{9}$$

where T_D is the differentiated time constant;

T_U is the integrated time constant.

In terms of capabilities, PID controllers are universal. Using them, you can get any law of regulation. Using formula (9), we will draw up a general structural diagram and the regulation law of an ide-ideal PID controller. The scheme is shown in Fig. 8.

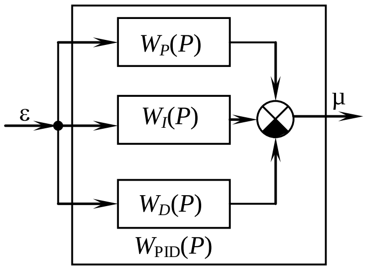

Fig. 8. Structural diagram of the regulation of an ideal PID controller

With a sudden change in the controlled value, the PID controller at the initial moment of time has an instantaneous infinitely large effect on the object of regulation, then the magnitude of the effect drops sharply to a value determined by the proportional component, after which the integral component of the controller constantly begins to influence. The transient process in PID controllers has minimal amplitude and time deviations compared to P- and PI-controllers (i.e., the highest speed). The PID controller tuning parameters are the controller proportionality factor K_P, the integration time constant T_U and the derivative time constant T_D. With increasing delay in the system, negative phase shifts sharply increase, which reduces the effect of the differential component of the controller. In addition, the presence of noise in the measurement channel in a system with a PID controller leads to significant random fluctuations in the control signal of the controller, which increases the dispersion of the control error and wear of the actuator. PID-controllers make it possible to provide good control quality for temperature control systems: control mismatch is less than 1 % of the set point, a short time to enter the mode and low sensitivity to external disturbances. When digitally implemented, the PID law has the form:

$$\mu = \left[K_P \varepsilon_i + \frac{1}{T_U} \sum_{i=0}^{n} \varepsilon_i \Delta t_{\text{measured}} + T_D \frac{\Delta \varepsilon_i}{\Delta t_{\text{measured}}} \right] \cdot 100\,\% . \tag{10}$$

Table 1

Values of the controller settings

Regulator type	Proportional band	Transfer ratio	Integration time constant	Differentiation time constant
P-regulator	$2P_{MS}$	$0.5K_{PS}$	not available	not available
PI controller	$2.2P_{MS}$	$0.45K_{PS}$	$0.83T$	not available
PID controller	$1.67P_{MS}$	$0.6K_{PS}$	$0.5T$	$0.125T$

K_{PS} – proportional gain regulator; P_{MS} – proportional component of the relative control range;
T – is the operating time of the regulator

Based on the developed mathematical models, a solar panel battery charging circuit was assembled in the Simulink and SimPowerSystems visual modeling software included in the MatLab package. This circuit is shown in Fig. 9.

The voltage of the solar panel and storage battery is selected between 12 and 220 V and was converted to 220 V AC at a frequency of 50 Hz.

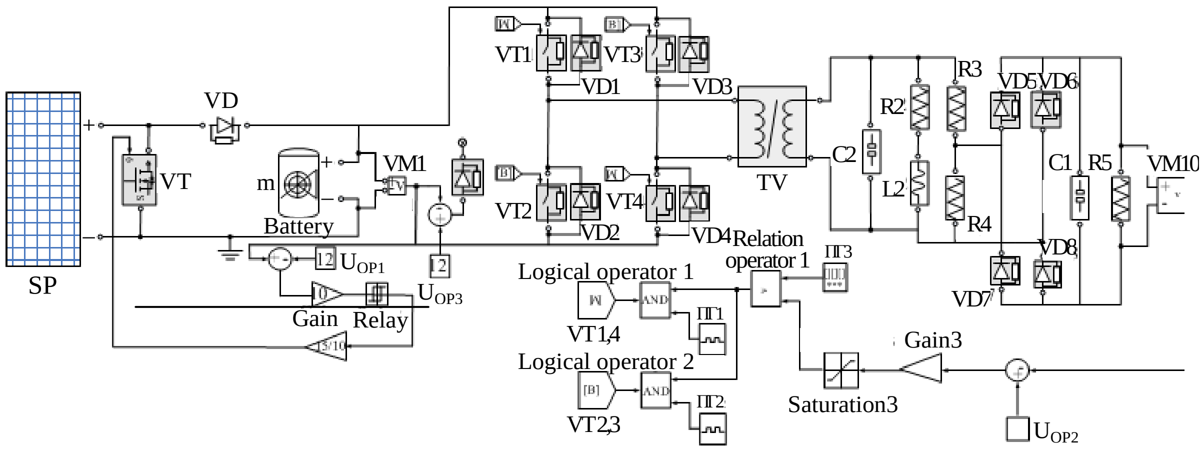

Fig. 9. Scheme of modeling a solar panel in the Matlab program

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7. Analysis of simulation results

As a result of modeling in the Simulink environment with different nominal voltages and a converter, it was possible to choose the voltage of the battery and solar panel. According to the above calculation method, in the second chapter of the solar panel, a model was compiled in the MatLab package, which consists of a current source PV1 connected to the battery through a separating diode VD. A VM1 controller, GainRelay, is connected to the battery circuit to prevent overcharging of the battery. When the battery is charged from the solar panel to the set maximum voltage, the overcharge prevention circuit connects the load transistor VT in parallel with the solar panel to absorb the excess power of the solar panel. The battery is protected from overcharging by a relay regulator, which consists of a Constant reference voltage setter, a Battery to Constant voltage comparison device - sumblock, an error amplifier, a Gain regulator, a Relay relay block that controls VT. When the charge voltage on the battery reaches 14 V, the VT key switches the solar panel.

In a low-voltage circuit with a voltage of U_{AB} 10…24 V, a power transformer TV is used to increase the voltage to 220 V Un, the transformation ratio will be 22…16. When modeling, a rectangular converter was used with 50 Hz output voltage regulation according to the principle of pulse-width regulation. A parallel resonant LC circuit connected to the converter through a TV transformer provides the sinusoidal voltage on the load. The inductance LP smooths the consumed current of the inverter, the inductance LH of an active-inductive load with an angle of 0.8 and a parallel-connected transformer with capacitor C_2 forms a parallel resonant circuit. The load is connected to the capacitor C_2 and has a sinusoidal voltage $K_H \leq 10$ %, when the battery voltage is 220 V, the step-up transformer TV is turned off.

The amplitude of the unfolding voltage of a symmetrical triangular shape U_P=2 V with a reference voltage U_{OP}=3.5 V.

The following Fig. 10 shows the relationship between U_L and U_{AB} with and without regulation.

Fig. 10 shows the characteristics of the converter with regulation by a solid line and without a regulator by a dotted line. The following Fig. 11 shows the regulation characteristic of voltage 220 V and harmonic coefficient K_H depending on the battery voltage from 10 to 14 V.

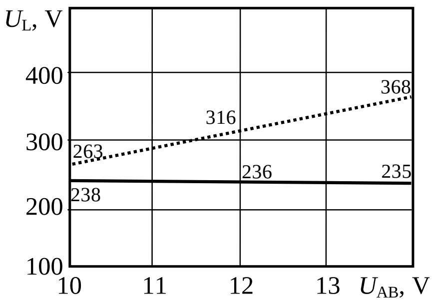

Fig. 10. Characteristics of the converter

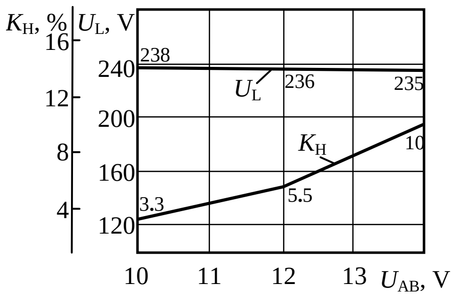

Fig. 11. Regulation characteristics

Fig. 12 shows the load characteristic of the converter at a constant battery voltage of 10 V, which was taken when the load changed from nominal to idle.

The following Fig. 13 shows the external characteristic converter, which is removed without regulation at a voltage of 14 V.

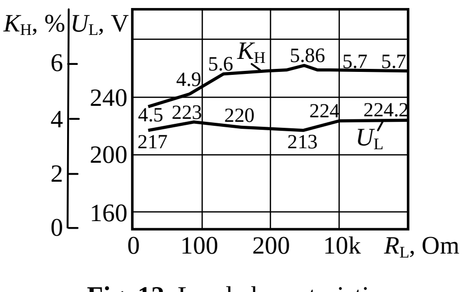

Fig. 12. Load characteristic of the converter

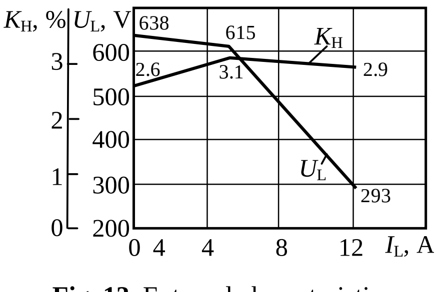

Fig. 13. External characteristic of the converter without regulation

To ensure stability in the classical amplitude regulation mode, we determine the value of the reference voltage and the amplitude of the sweeping voltage are shown in Table 2 and Fig. 14.

Table 2

Parameter results between reference and master oscillator voltage

U_{AB}, V	14			
$U_{OP} + U_P$	5			
U_{OP}, mV	1.5	2.5	3.5	4.5
U_P, V	4	3	2	1
U_L, V	200	217	235	266
K_H, %	14.7	12.8	10	7.4

According to the harmonic criterion, K_H=10 % is acceptable, so we choose the ratios U_L=235 V, U_{OP}=3.5 mV and U_P=2 V.

The results of modeling the control of the solar panel using the classical amplitude regulation of the output voltage at the input voltage of the battery 14 V.

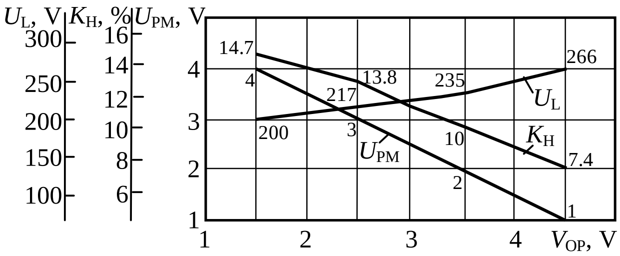

Fig. 14. Inverter parameters

Conclusions

1. A mathematical model has been developed that allows you to control and optimize the operation of a solar battery depending on climatic conditions and on the degree of illumination;

2. The calculation of the low-voltage power supply system was carried out; a technique was proposed that allows the efficient use of the energy generated by the solar panel without conversion losses. When creating an automated control of energy supply and energy consumption of an autonomous object, a mathematical model of optimal temperature control was developed;

3. As a result of the simulation, it was found that with a positive energy balance, the voltages on AB1 and AB2 are in the specified mode 24/220 V, and at the same time, the full functioning of the load is ensured. With a negative energy balance, the load operation stops at the moment the permissible voltage value on AB1 and AB2 is reached, while the EPS goes into emergency operation and charges the batteries;

4. In the program Simulink and Sim Power Systems, which is part of the MATLAB package, a simulation model for controlling the power supply controller of an autonomous object with elements of SMART technology has been developed. This model allows you to really display the logic of the solar panel and wind turbine;

5. A model for optimal control of the perceived temperature in an autonomous object has been developed.

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Лопаков Олексій Сергійович; Oleksii Lopakov, ORCID: https://orcid.org/0000-0001-6307-8946
Космачевський Володимир Володимирович; Volodymir Kosmachevskiy, ORCID: https://orcid.org/0000-0002-3234-2297
Бабич Юлія Ігорівна; Yuliia Babych, ORCID: https://orcid.org/0000-0001-9966-2810
Тігарєв Володимир Михайлович; Volodimyr Tigarev, ORCID: https://orcid.org/0000-0001-8492-6633
Бабич Микола Іванович; Mykola Babych, ORCID: https://orcid.org/0000-0002-3946-9880

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