UDC 621.311.243+681.518.3
DOI: 10.15587/1729-4061.2023.277835

DESIGN OF AN INTELLIGENT SYSTEM TO CONTROL EDUCATIONAL LABORATORY EQUIPMENT BASED ON A HYBRID MINI-POWER PLANT

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The object of research is the processes of energy conversion based on the use of alternative energy sources with an intelligent control system of actuators. This technological advancement is part of the equipment at the laboratory of dispatch control over power supply of Ternopil Ivan Puluj National Technical University. The research and the designed system could increase the level of training of future specialists for production activities during the educational process. Another task addressed was to provide technological production with practically trained specialists who could successfully work under conditions of its high automation and informatization. As a result of the research, an operating model of a hybrid solar mini-power plant and a controller with a Wi-Fi module were constructed. On the basis of the designed controller, an intelligent control system of actuators was built, which is powered by this power plant. Owing to the flexible configuration system, the controller is easily adjusted for various production tasks while the controller software provides the possibility of updating and expanding its functionality in the future. The controller has a web interface that allows monitoring and debugging from browsers without using specialized applications. A feature of the designed intelligent control system is that it can operate continuously owing to power from a hybrid solar power plant. The power plant built operates both from solar energy and from a centralized network and rechargeable batteries under an automatic mode. The results of research and technological advancements could be useful in forming practical skills of would-be specialists in the design and implementation of energy-efficient technologies, as well as intelligent control systems in the electric power industry

Keywords: hybrid power plant, intelligent system, solar panel, controller, educational process

Received date 08.02.2023
Accepted date 18.04.2023
Published date 28.04.2023

***How to Cite:** Orobchuk, B., Buniak, O., Sysak, I., Babiuk, S. (2023). Design of an intelligent system to control educational laboratory equipment based on a hybrid mini-power plant. Eastern-European Journal of Enterprise Technologies, 2 (9 (122)), 59–72. doi: https://doi.org/10.15587/1729-4061.2023.277835*

1. Introduction

Under the conditions of active development of information technology, educational institutions must solve an important task – to prepare specialists who will be able to actively integrate into the technological process of social development. This is due to the demand from informatized and automated production for specialists who will be able to qualitatively perform their tasks. Also worth noting is the insufficient level of training of would-be specialists for production conditions during the educational process [1].

Experts in the electricity generation industry face the issue of reducing electricity consumption, that is, the introduction of energy efficiency, which requires improving the process of distribution and use of electricity. This is the basis for building an intelligent power supply system, the basic criteria of which are intelligent generation by renewable sources, flexible distribution, consumer-side control, intelligent objects, etc. [2]. Power supply systems of the future, or intelligent networks, are quite actively researched and implemented by the leading technological countries of the world (USA, China, Japan, South Korea).

The process of developing intelligent energy systems involves modernizing the existing system of generation and delivery of electric energy on the basis of improved management, protection, optimization of technological objects of the electric power system in their interconnection.

The development of information technologies and Internet capabilities have become a prerequisite for the development of an intelligent type of energy. This includes the emergence of the latest achievements in the field of information and network technologies, information and control systems using power and microprocessor electronics. The emergence of market relations in the energy business has led to a qualitatively new movement towards energy efficiency [3, 4].

The frequent change in the amplitude and nature of power in local power grids due to the connection of alternative and renewable energy sources predetermines special attention to the following issues:

– analysis of the parameters of the quality of electricity, which is received, in particular, from solar power plants;

– revision of energy systems sustainability standards;

– in-depth study of this issue.

2. Literature review and problem statement

Hybrid solar power plants are one of the reliable options for solar stations for use both under domestic conditions and to ensure the visibility of the educational process of electric power specialties. Such power plants make it possible to generate a significant amount of electricity that can be accumulated and used if necessary; they do not depend on the operating modes of the central power grid and do not affect the environment during operation. Hybrid solar power plants are ideal for autonomous lighting and power supply of low-power electrical equipment when it is possible not to use a common power grid, as well as for lighting communal and private property. It is worth noting that autonomous lighting does not depend on the connection point in the general power grid, its malfunctions and power outages, has high energy efficiency [5]. But it also has a number of drawbacks: it needs sufficient daylight to fully charge the rechargeable battery, the need to replace it, and properly dispose of it. Insufficient battery charge reduces the intensity of light and, respectively, reduces the efficiency of lighting installations. It is also impossible to charge the rechargeable battery from another source and at sub-zero temperatures their operation may malfunction.

Elements in the hybrid power supply system are connected in parallel, in series, or in parallel-in series [6]. In the case of a serial connection, the rechargeable battery can be charged from solar panels or a wind turbine, and then through the inverter the energy from the rechargeable battery produces alternating current. This hybrid system operates under two modes: manual or automatic (if there are necessary sensors), and has been widely used in small hybrid systems since it has a simple design [7]. The disadvantages [7] include frequent recharge cycles of the rechargeable battery, which negatively affects the service life, increasing its capacity to reduce the depth of discharge. Another bottleneck is the inverter, the failure of which leads to a complete disconnection of the system from the network.

Hybrid systems can be divided into the following groups: autonomous; connected to a common power system; with and without rechargeable batteries; using renewable energy sources or using traditional energy sources [8]. But with a complete rejection of rechargeable batteries in energy storage systems, the controllability of an autonomous power system may decrease. Therefore, for a backup means of accumulation, lithium-ion rechargeable batteries can be offered, which have a high ability to instantly respond to changes in shortage or excess energy.

Network power supply systems usually include powerful power plants that operate as part of both regional and integrated power systems; small power supply systems can be partially or completely autonomous. Each option has disadvantages and advantages. The configuration of the hybrid power supply system is determined based on the needs of the user and the possibilities of controlling generation modes.

The construction of an intelligent control system is to form a new information and energy structure, which is based on power and information technologies, a system of efficient electricity markets, as well as system and information services [9]. The use of intelligent energy technologies provides better adaptation to the grid of the pulsating dynamic nature of distributed generation and unconventional and renewable energy sources.

There is an active process of modernization of residential and domestic premises in accordance with the requirements and needs of technological progress. They are equipped with a large number of automated systems, actuators, and sensors to create the most comfortable conditions and are aimed at energy-saving and environmental interaction with the environment. Much of this equipment is a high-tech system programmed to autonomously assess and analyze harmful environmental factors, as well as diagnose smaller changes to temporarily detect the problem [10]. It is worth noting here that these devices process information individually, without a single control center, and often conflict with each other, thereby reducing the beneficial effect of their work and increasing power consumption. Usually, the user focuses primarily on energy saving, environmental friendliness, and efficiency. This problem can be solved with intelligent control systems that will reduce operating costs and improve power reliability. It should be continuous due to automated control of power flows, coordination of centralized and distributed generation, digital monitoring of the electric power system [11]. Although such systems are mainly built of simple sensors, surveillance cameras, sensors, their price is quite high, and it takes a long time to payback. Also, in the event of a system breakdown, experienced specialists are needed to eliminate it, who are difficult to find. In addition, the breakdown of one part may cause failure of other components of the system.

Navigation and control of such a system can be carried out using indoor meters and sensors, controllers and specialized actuators that operate under an automatic mode. When using intelligent control systems for a domestic or industrial environment, you can use the following ways to control their functions: push-button remotes and panels, touch panels, smartphone/tablet, personal computer, voice control, remote control [12]. But a sufficiently large number of "smart equipment" devices and their manufacturers do not make it possible to develop common requirements for the design, production, and use of such devices, as well as methods of information processing and its exchange with other devices. Users of such systems need to additionally analyze the selected type of equipment and its manufacturer in order to coordinate with the connection requirements by specialists providing individual services, for example, distribution network managers.

After analyzing studies [13], it can be argued that the impact of low-quality electrical energy on electrical installations is quite noticeable. Therefore, investigating the problem of the impact of renewable generation sources on the characteristics of electricity quality forms approaches to reducing electricity losses. This could increase the life of electrical equipment, reduce the aging rate of insulation of electrical lines, and reduce the heating of transformers due to asymmetry. The connection of solar power plants to the grid and the introduction of intelligent systems will improve the voltage levels in its nodes. This approach could also solve the issue of power reserve in the system to reduce its deficit in the case of unforeseen circumstances automatically.

3. The aim and objectives of the study

The aim of this study is to implement a circuitry solution for the construction of a hybrid mini-power plant enabling uninterrupted operation of actuators based on an intelligent control system. This will make it possible to meet the need from automated production for practically trained engineering specialists who will be able to work successfully under the conditions of saturated informatization. In addition, it makes it possible to increase the level of training of would-be specialists for production activities during the educational process. It also makes it possible for students to master the practical aspect of reducing power consumption, in particular, to learn how to improve the processes of generation, distribution, and use of electricity, which underlie the construction of an intelligent power supply system.

To accomplish the aim, the following tasks have been set:

– to calculate and select the constituent elements of an autonomous solar installation;

– to design and manufacture an experimental sample of a controller with a Wi-Fi module;

– to build a scheme and make a real model of an intelligent control system for actuators based on a Wi-Fi module;

– to synchronize the operation of the intelligent control system with the training SCADA system “Energy” and the telemechanics system “Strila”.

4. The study materials and methods

The object of research is a hybrid solar mini-power plant and an intelligent control system for actuators.

Based on the systematization and generalization of information about the advantages and disadvantages of using available methods of technological and technical support, a block diagram of an autonomous hybrid solar power plant was developed, which is planned to be used in the educational process to power the laboratory of dispatch control of electricity supply (Fig. 1).

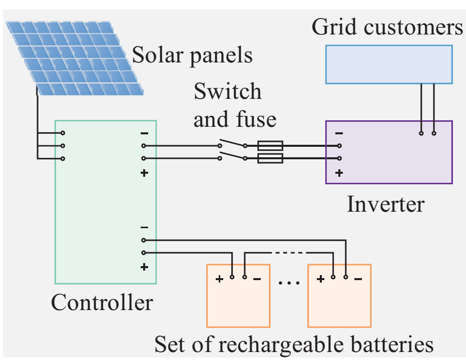


Fig. 1. Block diagram of an autonomous solar system with rechargeable battery reserve

The autonomous power supply system based on a hybrid solar power plant is a set of solar panels that are connected to the consumer. The controller provides distribution of received electrical energy and automates the operation of the entire system. The excess energy produced accumulates in the rechargeable batteries, and the conversion of direct current to alternating current for the needs of consumers is carried out using an inverter. The advantages of such an autonomous system include mutual compensation for the deficit of electricity generation, which has a rather high productivity of solar panels in summer and relatively low in winter.

The research and testing of the devised project were conducted at the Department of Electrical Engineering of Ternopil National Technical University named after Ivan Puluj (Ternopil oblast, Ukraine). The research and results are aimed at increasing the level of training of would-be specialists under conditions of high automation and informatization even during the educational process.

Research methods of this work are theoretical and practical in accordance with the requirements that are given in relevant information sources [3, 7, 10]. To solve the task of controlling a hybrid solar mini-power plant and actuators, the designed control system was used with the control algorithm implemented in the C/C++ programming language.

The software package MATLAB was used to analyze the characteristics of rechargeable batteries and methods of their charge-discharge; we proved the need to execute charge impulse with asymmetric currents [14]. This current exceeds analogs in terms of quality indicators and, accordingly, makes it possible to increase rechargeable battery life almost by 3 times. And this, in turn, could significantly reduce the impact on the environment and reduce the cost of purchasing new rechargeable batteries.

An alternative to diesel and gasoline generators, which are characterized by high maintenance costs and short service life of equipment, is the introduction of solar power plants as an autonomous energy source. When, due to certain reasons, connection to a standard power grid is not possible, a solar power plant can to some extent completely or partially solve this problem. The design of an autonomous solar power plant, in which solar panels are connected to rechargeable batteries with the help of a controller, and the accumulated electrical energy is used by the consumer, is quite simple. In order for the consumer to have an AC voltage from this energy, it is necessary to include an inverter in the installation [5]. The main disadvantage of such an autonomous solar installation is the need for rechargeable batteries, which are the most expensive equipment of this system with the shortest service life compared to other equipment [14].

An alternative to an autonomous solar power plant can be a network solar power plant, the essence of which is the parallel operation of solar panels and the general power grid and saving electricity consumed from this power supply network. In this case, the service life of the equipment will significantly exceed the payback period with much smaller initial investment. To ensure the most efficient operation of such a solar installation, it is necessary that electricity generation is consistent with consumption.

Along with advantages, a grid solar installation has disadvantages:

– solar systems connected to the network require voltage in the network for their operation, otherwise the grid inverter will not work;

– when solar panels generate more energy than is consumed, excess energy is sent to the grid, which creates a conflict situation since the bulk of electricity meters are unidirectional. In this case, you need to install special grid solar inverters to reduce power with an excess of solar energy, or a special controller for excess solar energy [15].

One can also use hybrid solar installations, which have the functions of network and autonomous installations. The difference between the scheme of a hybrid installation and an autonomous one is that here, instead of a conventional rechargeable battery inverter, a hybrid converter with a network input is used and can add solar electricity to the grid. From a consumer point of view, this is a profitable point for the consumer since it is possible to provide an energy reserve at the expense of rechargeable batteries and save money by generating energy by solar panels.

When calculating a power plant based on renewable energy sources, methodological support based on information and estimation parameters was used. For solar installations, information parameters are data on the amount of solar radiation that can be obtained from specialized available sources or databases. They provide data on the amount of solar radiation based on long-term observations of climatic and solar energy characteristics in many world geographical locations [16].

The estimation parameters are the calculation of the characteristics of an autonomous solar installation and the corresponding choice of component equipment: solar panels, charge-discharge controller, grid inverter, rechargeable batteries, etc.

5. Results of investigating the hybrid mini-power plant and intelligent control system

5. 1. Calculation and selection of components of an autonomous solar installation

An indispensable component of a solar electrical installation is an inverter since solar panels generate only DC voltage while the main load is usually powered by AC voltage [17].

In this case, the output power and input voltage are the main parameters when choosing an inverter. Since the peak power of the load, as a rule, is compensated by the ability of the inverter to give power for a short time that is greater than the specification value, it is not necessary to separately calculate the inverter for this parameter. The specification value should be selected with a small margin (up to 10 %) since the excess power of the inverter under an idle mode causes an increase in energy losses when powering load devices.

The inverter is an integral part of the solar power plant of the station and is powered by solar panels or rechargeable batteries. Therefore, to determine the parameters of these devices, it is necessary to know the amount of power consumed by the inverter. This value may exceed the required output power by the value of its own internal losses, which are 10 % of the specification output power of the equipment for power inverters.

That is, the input power of the inverter can be determined by the formula:

$$P_{inv}=P_{rat}\times k, \quad (1)$$

where P_{rat} is the value of the rated load power, about 30 % of the power for all switched on devices, W;

k – value of the reserve factor for power and natural losses in the inverter; k=1.2.

When choosing an input voltage, it was taken into account that with an increase in the power of the inverter, the input currents and, accordingly, losses at the connections of switching wires would also increase. To reduce these losses, a choice was made from the standard series of 12, 24, 36, 48 V higher input voltage.

To ensure the required reserve time, the required total capacity of rechargeable batteries was determined according to the following formula:

$$q_B=\frac{P_{inv}\cdot N_B\cdot \alpha}{U_{inv}\cdot \gamma}, \quad (2)$$

where q_B is the total capacity of rechargeable batteries, A·h;

α – temperature coefficient of rechargeable battery capacity;

γ – discharge coefficient;

N_B – number of rechargeable batteries.

Coefficients α and γ are used when choosing the type of rechargeable battery; they also serve to determine the calculated capacity of the rechargeable battery and the rate of decrease of this indicator during operation (number of charge-discharge cycles) and the total service life of rechargeable batteries [18]. Rechargeable battery life is very often used for sealed rechargeable batteries, which are part of an autonomous power supply system.

The results of the simulation in the MATLAB package and the constructed plots (Fig. 2) show that in order to ensure the required rechargeable battery life (at the level of 1500 cycles), the discharge depth should not exceed 80 %. But it is also worth noting that reducing the depth of discharge causes a decrease in the energy available for consumption. Accordingly, this, at a set amount of power consumption, will require more rechargeable batteries as part of a solar installation.

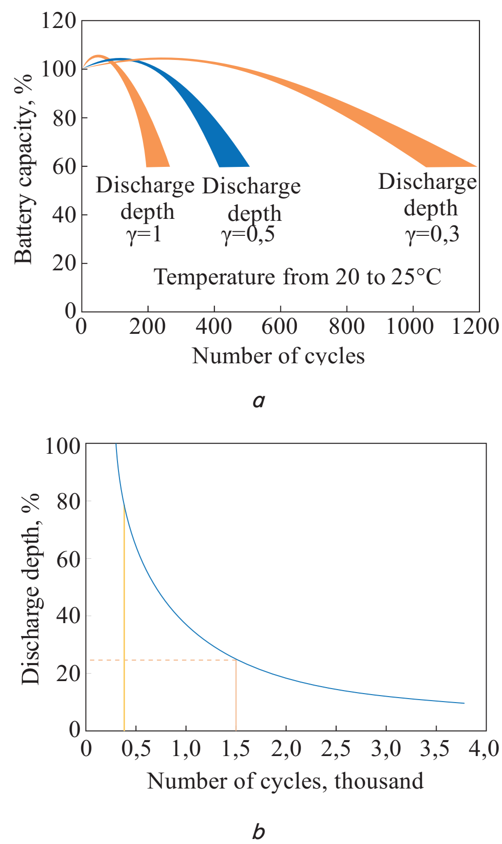
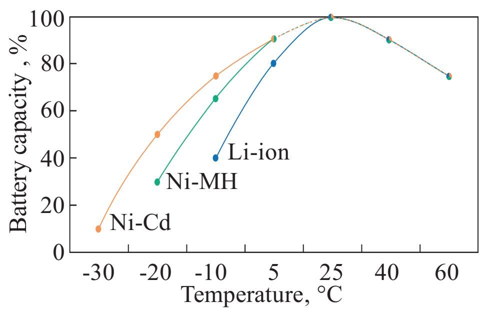


Fig. 2. Dependence of the depth of discharge on: *a* – the rate of drop of the residual capacity of the rechargeable battery; *b* – rechargeable battery operattion time

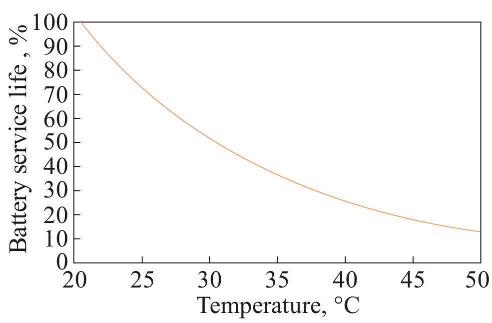
To ensure the required durability of rechargeable batteries and their optimal number as part of a solar installation under real conditions, it is necessary to look for a compromise solution that can be provided with various technologies from manufacturers of rechargeable batteries for solar installations. For example, when using lead-acid rechargeable batteries, a coefficient of γ=0.2–0.5 is recommended, and when using lithium-ion and nickel-cadmium rechargeable batteries, which are more resistant to deep discharge, in the calculations they take larger values of the discharge coefficient.

Therefore, these types of rechargeable batteries are in most cases used in autonomous power supply systems, although they cannot operate normally at sub-zero temperatures.

The constructed simulation plots in the MATLAB package showed that this causes incorrect load conditions and a reduction in the operating time of the solar installation under a sunless mode (Fig. 3, *a*). Due to work at elevated temperatures, negative consequences can also occur. If the capacity of rechargeable batteries is restored at optimal parameters, then their operation at high temperatures can cause a critical decrease in their service life (Fig. 3, *b*).



a



b

Fig. 3. Dependence of the ambient temperature on:
a – rechargeable battery capacity;
b – rechargeable battery life

In [19, 20], the value of the temperature coefficient of capacity α is introduced, which is a multiplier for increasing the required total capacity of the rechargeable battery in order to take into account its drop relative to the nominal value when the ambient temperature changes. In autonomous solar installations, in most cases, rechargeable batteries of the same type and capacity are used [9]. To achieve the required voltage and total rechargeable battery capacity, they are combined into a series-parallel circuit, the number of individual rechargeable batteries in which is equal to:

$$N_B=N_{par}\times N_{ser}, \qquad (3)$$

where N_{par}, N_{ser} is the number of rechargeable batteries that are connected in parallel and in series.

Given the fact that the total rechargeable battery capacity q_B is equal to the sum of the capacities of individual rechargeable batteries, and the voltage on each parallel group is equal to the input voltage of the inverter, formula (3) can be represented as follows:

$$N_B = N_{par} \cdot N_{ser} = \frac{q_B}{q_{nom}} \cdot \frac{U_{inv}}{U_{nom}}, \qquad (4)$$

where q_{nom} – capacity of one rechargeable battery, A·h;

U_{nom} – rechargeable battery voltage, V.

The dimensions of the most used solar panels approximately have an area ranging from 1.5 to 2.0 m^2, and their power is in the range from 200 to 280 W. Further, solar panels can be connected in parallel, but in one assembly only panels of the same type should be used [21].

The market for solar panels is saturated with a large number of different types, the choice of which takes into account such determining parameters as their area, output rated voltage, as well as the type of photovoltaic cells. The electricity generated by photovoltaic converters per year can be determined by the formula:

$$W_{ph} = F_{ph} \cdot \eta_{ph} \cdot t \cdot \sum_{i=1}^{k} N_{i\,SR}, \qquad (5)$$

where F_{ph} is the area of photovoltaic panels, m^2;

η_{ph} – efficiency of the panel;

$N_{i\,SR}$ – intensity of solar radiation in the i-th period, W/m^2;

t_i – duration of the i-th period, hours;

k – number of periods.

The simplest option for obtaining information on the intensity of solar radiation for the territory of the solar installation are climate databases [22]. When calculating solar panels, the initial load data is the nominal power of the consumer and the energy consumed from the installation by all devices per day [19].

To cover the required load, the following condition must be met:

$$W_{phd}=W_{ph} \cdot k_{-} \cdot 365, \qquad (6)$$

where k_{c-d} is the coefficient of losses for charging-discharging rechargeable batteries, for autonomous power supply systems k_{c-d}=1.2.

Using (5), (6), it is possible to obtain an expression for determining the total area of solar cells for a solar installation:

$$F_{ph} = \frac{W_{ph} \cdot k_{c-d} \cdot 365}{\eta_{ph} \cdot \sum_{i=1}^{k} N_{i\,SR}}, \qquad (7)$$

in which only the efficiency of the panel is unknown, which can be determined by the material of the working photovoltaic layer of the solar panel.

After selecting the panel type, you need to determine the number of solar cells according to the formula:

$$N_{ph} = \frac{F_{ph}}{S_{ph}}, \qquad (8)$$

where S_{ph} is the area of one panel, m^2.

The general view of solar panels in the working position, which are installed on the roof of the educational building of Ternopil National Technical University named after Ivan Puluj, is shown in Fig. 4.

Solar panels are connected to a power switchboard, which is installed in the room above which they are located.

Fig. 4. Solar panels Photovoltaic JKM280PP-60-V, installed on the roof of the educational building

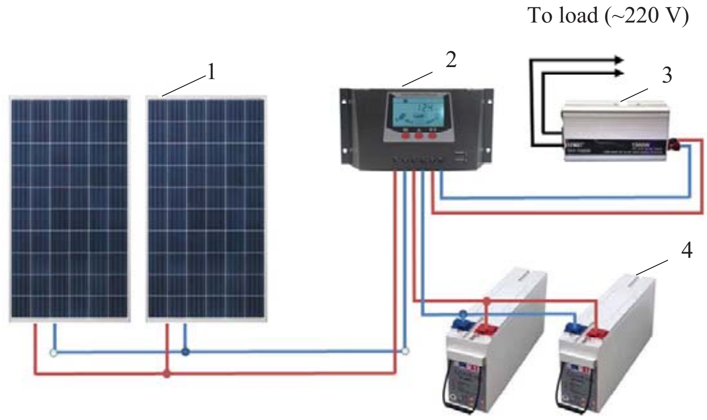


Fig. 5. Scheme of solar installation for training laboratory: 1 – solar panel JKM280PP-60-V (36 V, 280 W, 2 pcs.); 2 – charge controller WP8048 PWM (80A, 12V/24V/48V); 3 – inverter UKC SAA-1500W (DC 12V to AC 230V); 4 – gel rechargeable batteries MONBAT 12MRV100 (12V, 100 A•h, 2 pcs)

When charging/discharging the rechargeable battery, it is necessary to maintain the set values of current and voltage in order to prevent their premature exit from working condition. This task is assigned to the charge controller, which must also maintain the optimal level of rechargeable battery charge under different operating modes of solar panels:

– compensates for self-discharge at maximum rechargeable battery capacity;

– disables the load when discharging to a critical value.

In autonomous power supply systems, MPPT controllers are the most common and practical to use. They can track the maximum power point, which make it possible to use all available power under different charging modes to maintain maximum charging voltage. As a result, it is possible to increase the efficiency of using solar energy, which is converted into electrical energy with the help of solar panels, up to 30 % compared to installations equipped with controllers of other types [23, 24]. The choice of the controller is carried out according to parameters such as input voltage and power.

In order to improve the reliability of the controller, it is given a certain power reserve compared to the total power generated by solar cells and which is determined by the following formula:

$$P_{\Sigma}=I_c \times U_{sc}, \qquad (9)$$

where I_c is the value of the output current of the controller, A;

U_{sc} – value of the output voltage of the solar cell, V.

After carrying out the necessary calculations and selecting the basic equipment, a variant of the solar installation scheme for power supply to the laboratory of dispatch control of power supply was built (Fig. 5).

Next, the permissible cross-sectional area of the power wires was calculated and their brand and switching equipment were selected. The system is connected to the network in the training laboratory through the device of automatic activation of the reserve: when the power supply from the 220 V network disappears, the automatic activation of the reserve is triggered, and the power supply is supplied from the designed mini-power plant. The control system of a hybrid solar mini-power plant is placed in a small metal cabinet in the laboratory (Fig. 6).

Fig. 7 shows a part of the premises of the laboratory of dispatch control of power supply, in which the lighting system and roller blinds are powered by the designed solar mini-power plant.

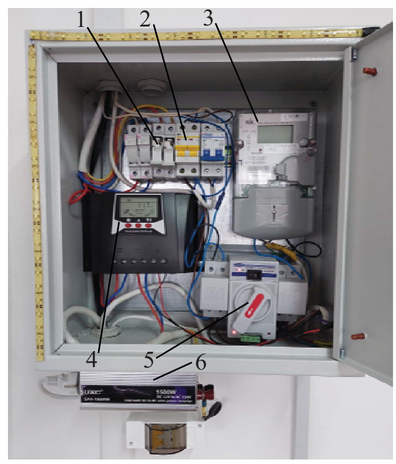


Fig. 6. Control system cabinet: 1 – fuse switch of solar panels (25 A); 2 – circuit breaker-automate of centralized lighting system 220 V (15 A); 3 – electricity meter NIK 2104 (single phase, RS-485); 4 – charge-discharge controller WP8048 PWM (80A, 12V/24V/48V); 5 – device for automatic activation of reserve TOMZN (single phase); 6 – inverter UKC SAA-1500W (DC 12V-AC 230V)

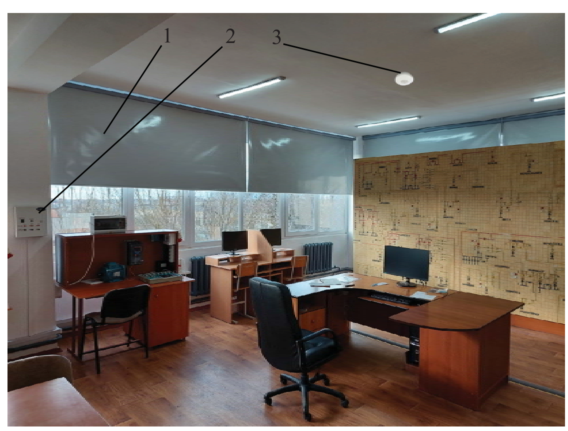


Fig. 7. Operation of the lighting system and roller blinds from the designed hybrid solar mini-power plant: 1 – roller blinds; 2 – control board; 3 – wireless light sensor

The system operates around the clock, powered by the designed hybrid solar mini-power plant. Control is carried out using an intelligent control system.

5. 2. Design of an experimental sample of a controller with a Wi-Fi module

To implement an intelligent control system of actuators, an experimental sample of a Wi-Fi controller was designed and manufactured (Fig. 8).

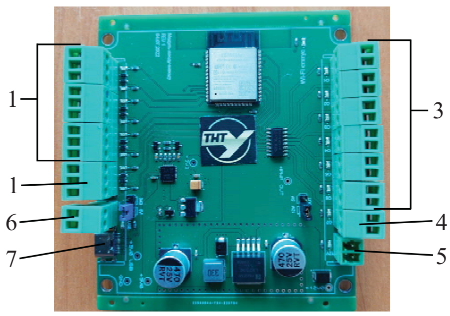


Fig. 8. Wi-Fi controller of the control system: 1 – to buttons "Open", "Close"; 2 – to the "Stop" button; 3 – output to the control relay; 4 – access to the lighting sensor; 5 – power supply 12V; 6 – RS-485 serial port; 7 – USB-port

The controller is built on one software platform, which makes it possible to control it from one application. It has easy and intuitive setup, modern element base, as well as diagnostic software. The designed controller provides the possibility of updating software, software configuration change, selecting and configuring input filters, controlling from user programs using standardized protocols. The controller has a wireless network connection, can be integrated into a single system, has the function of automated data acquisition, remote control via VPN tools. The controller provides the ability to use backup power and configure the software according to user requirements.

The designed controller can be used to manage various devices in production and at home. The controller supports Wi-Fi, which makes it possible to control it from your computer, tablet, or smartphone. For this purpose, a specialized application "Diagnostics" (Windows, Android) was developed, the general view of which is shown in Fig. 9. The "Diagnostics" software is written in the programming language C/C++ using the environment of Visual Studio Community and WPF technology (Windows Presentation Foundation). It is part of the .NET platform and is its subsystem of building graphical interfaces [25].

Fig. 10 shows the smartphone control interface window.

For debugging and testing, the "Diagnostics" application is used, which allows for initial debugging and diagnostics of the controller. Owing to the flexible setup system, the controller can be configured for various production tasks. The controller software provides the possibility of updating, which makes it possible to expand its functionality in the future. Also, the controller has a web interface that makes it possible to monitor and debug from browsers (without using specialized applications).

The designed Wi-Fi controller can be used as a function of "smart curtain" when connecting a light sensor (Fig. 11) [26], which is located in the optimal place of the auditorium and can be connected to output 4 (Fig. 8).

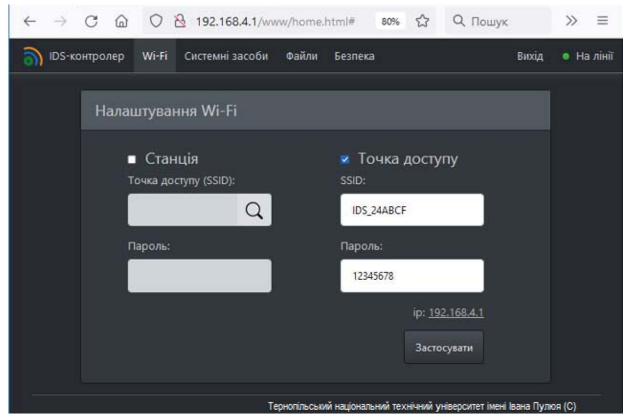


Fig. 9. "Diagnostics" application interface

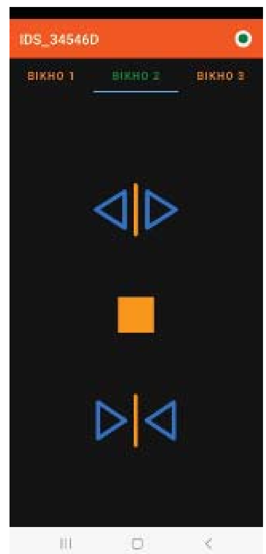


Fig. 10. Smartphone control interface

Fig. 11. Light sensor Xiaomi Light Detection Wi-Fi

The sensor records daily changes in illumination, which can be viewed in the "Diagnostics" application. When the sensor's battery is low, the information is transmitted to the phone. The sensor is based on high-precision laser elements, it has high sensitivity, a wide range of settings, and supports the smart control function. The sensor can accurately detect changes in ambient light intensity and automatically change the measurement interval for different lighting conditions. The sensor is integrated into the operation of the designed controller. If the light level is too high, then the sensor is triggered and the curtains are automatically folded, creating a given level of illumination without outside human intervention. When the light level is too low, the curtains open. The only drawback of this control method is that in the case of variable cloudiness, the Sun either comes out from behind the clouds, then sets, respectively, the sensor is constantly triggered and moves the curtains either up or down.

5. 3. Building a model of an intelligent control system for actuators based on a Wi-Fi module

For visual and practical use of the designed hybrid mini-power plant in the educational process, a part of laboratory equipment was connected to it, in particular the laboratory lighting system, roller blinders control system, and motorized multimedia screen. As a laboratory installation, a scheme was developed and an experimental sample of an intelligent roller blind control system was manufactured, which is assembled from affordable and cheap components, which is a worthy analog of similar branded systems. The proposed approach to the design of such control systems makes it possible to organize the practical assimilation by students of theoretical material in specialized ssubjects when performing real final qualification works [1, 2, 27, 28]. Management can be carried out as follows:

– using the remote control (manual control);

– control using the designed Wi-Fi controller (via smartphone, laptop, Wi-Fi network [26, 27]);

– automatic control using the designed Wi-Fi controller and light sensor;

– control by means of software and hardware environment of the remote-control system "Strila", which is an integral part of the equipment at the laboratory of dispatch control of power supply [23].

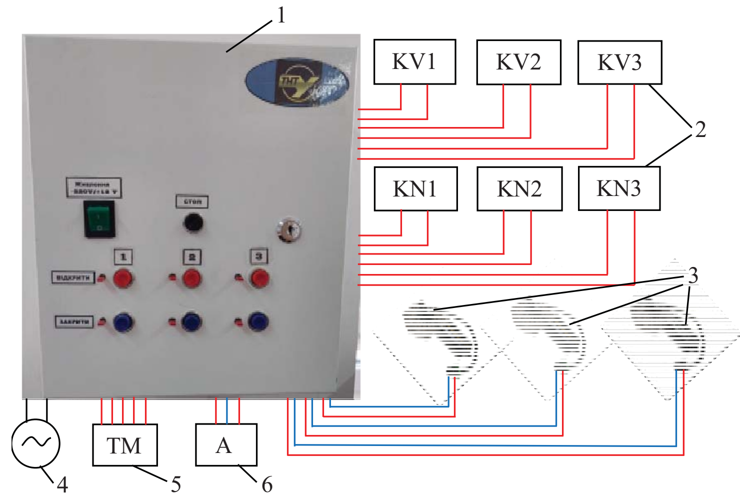


Fig. 12. Block diagram of power part of the intelligent control system: 1 – control panel; 2 – terminals (reed switches); 3 – 12V DC motors; 4 – 220 V power supply; 5 – to the equipment of the Strila remote control system; 6 – to the light sensor

Fig. 12 shows a block diagram of the power part of the intelligent roller blind control system for three windows measuring 5.0×2.0 m each (Fig. 7).

Fig. 13 shows the installation of the designed roller blind control system in the control panel. The operation of the circuit involves the principle of self-picking up the relay. When you press the "Open 1" button, the self-pickup relay 1 is activated, the electric motor begins to raise the roller blind until the end trips, which is made on the basis of a normally closed reed switch. At the lower end of the blinds there is a fixed neodymium magnet, which drives the reed switch. The "Close" button works similarly.

Endpoints (reed switches) are fixed at the upper and lower endpoints of the window. When the lower end of the curtain passes by the reed switch, the power to the relay is interrupted and the motor stops. If necessary, you can forcibly stop the engine from moving with the "Stop" button. When you press the "Stop" button, the power to all relays is interrupted, that is, this button is universal for all three circuits. The 12 V system power off button is connected sequentially to the "Stop" button when the control panel is opened. If you open the shield while the curtains are moving, the power supply in the 12 V circuit will disappear, which is associated with compliance with safety precautions during laboratory classes. As an electric drive for raising and lowering roller blinds, DC motors 12 V from the car wiper drive were used. The electrical schematic diagram of the control panel (Fig. 14) was constructed and simulated in the software package Proteus [29].

If you press two buttons of the same circuit "Close" and "Open" at the same time, the protection will work, and the system will stop. To restore the system, you must click the "Stop" button, the contacts will fall into place and the system will resume work.

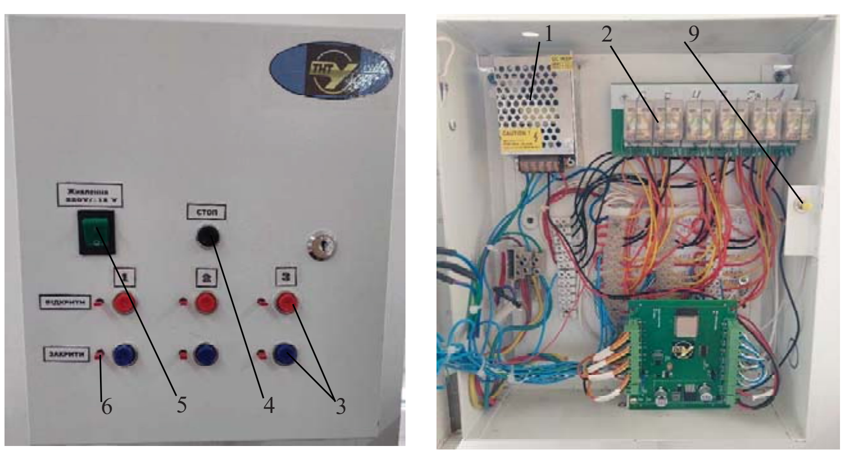


Fig. 13. Control panel: 1 – DC power supply unit 220/12V (5A); 2 – control relay of actuators; 3 – buttons "Open", "Close"; 4 – "Stop" button; 5 – power switch 220V; 6 – fuse (220V); 7 – Wi-Fi controller; 8 – LED indicators; 9 – 12V power off button when opening the control cabinet

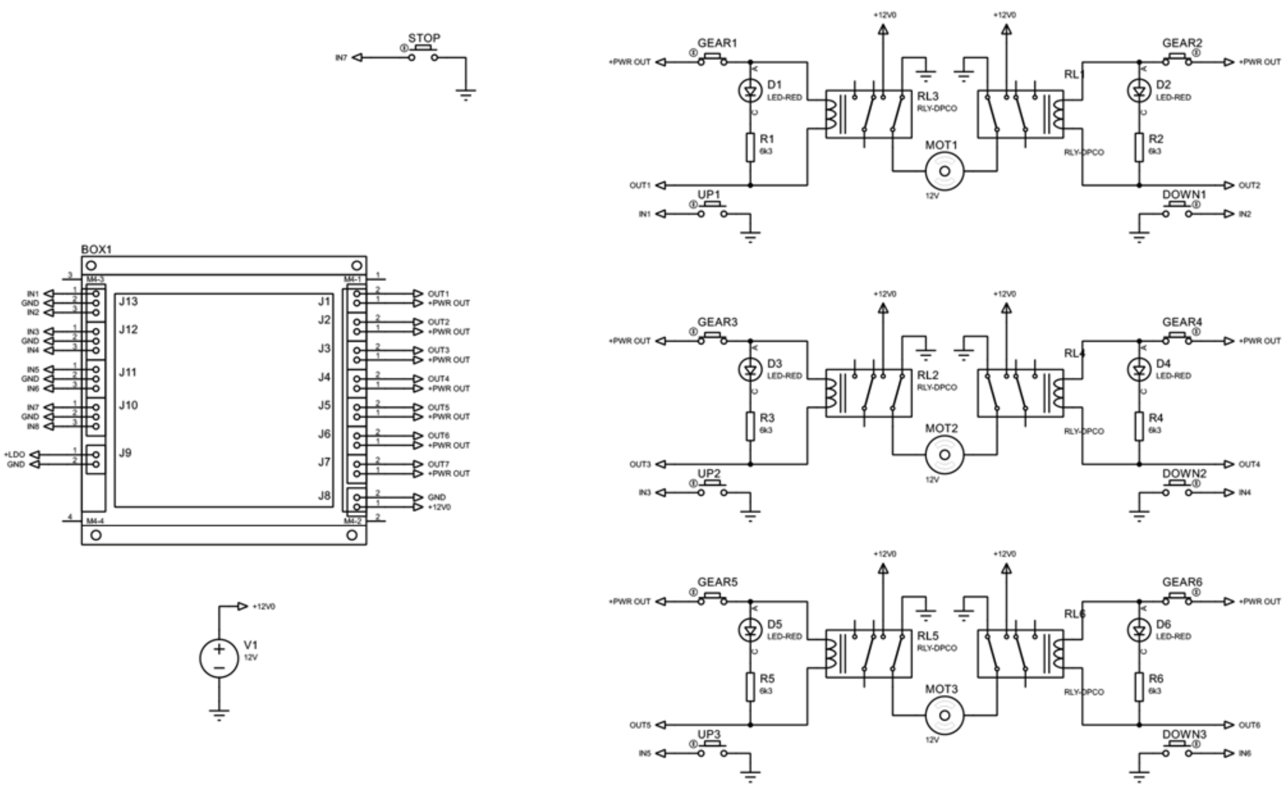


Fig. 14. Schematic diagram of the control system

5. 4. Synchronization of the intelligent control system with the training SCADA-system "Energy" and the telemechanics system "Strila"

Remote control is based on connecting the Wi-Fi controller to this system either via RS-485 serial port or USB port. In this case, the designed system is controlled using a personal computer or laptop on which the training SCADA system "Energy" is installed. This system is a simulator of an automated control room system for research and control of modes of electric power systems [1, 2]. The simulator is a hardware and software system and is used in the educational process for conducting classes on emergency training exercises with a reflection of the operational situation of the electric power system. The simulator makes it possible to simulate during practical classes the modes of operation of the electrical network, as well as connect various actuators and equipment and control them remotely.

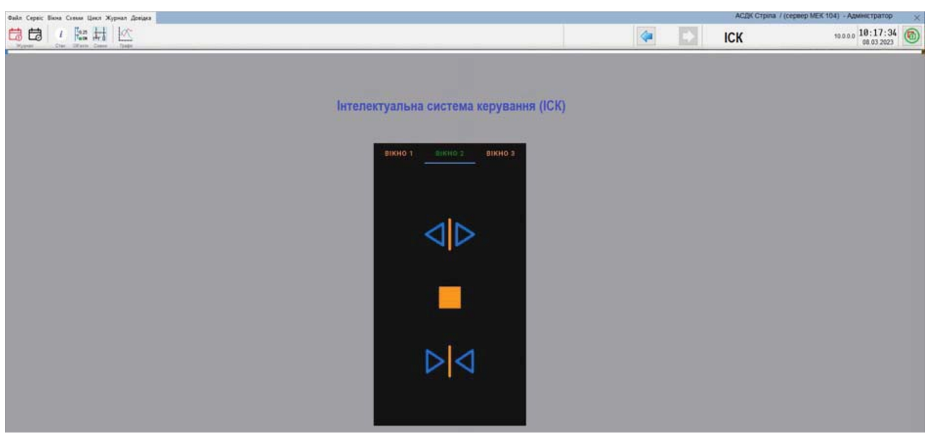


Fig. 15. The window of the intelligent system control program in the environment of the "Strila" remote control system

When starting the program, a special interface for control appears on the computer monitor, on which the placement of the buttons is duplicated in virtual form (Fig. 15). If you click on one of them with the mouse cursor, then a short-term impulse is applied to the relay and its self-picking up will work. Next, the scheme works according to the same algorithm as with control using the remote control.

The advantage of this control option is that the system can be managed from anywhere in the presence of the Internet [28]. In addition, when using the remote-control system, you can program the operation of the curtain system for any mode (for a day, for a month, for a year), as well as forcibly turn off the lighting sensor. With the help of the remote-control system, it is possible to manage the designed hybrid solar mini-power plant. This requires that a charge-discharge controller 4 (Fig. 6) is connected to this system via Ethernet-cable.

6. Discussion of results of investigating an intelligent control system based on a hybrid mini-power plant

Our paper considers the construction of an intelligent control system for actuators based on a hybrid solar mini-power plant. It is shown that the designed intelligent control system makes it possible for actuators to work over a long time under an automatic mode according to the predefined algorithm for an unlimited time. This is achieved due to the presence of several power sources – solar energy, rechargeable batteries, and a centralized network, which are connected automatically depending on the situation. Connecting a hybrid solar mini-power plant to the training system of telemechanics and SCADA system makes it possible to successfully select the current generation and load at any time (1) to (4). At the same time, the system ensures constant stability, quickly responding to generation and load surges. The peculiarity of the method of controlling a hybrid solar mini-power plant is the maximum use of solar energy. To meet this requirement, rechargeable batteries were used, which can accumulate excess electricity at significant levels of illumination (Fig. 2, 3).

Based on our research, a conceptual solution for building the structure of a solar mini-power plant based on its hybrid design as an educational complex for laboratory and practical classes is proposed (Fig. 5–7). This system also integrates an intelligent control system based on the designed controller, which is synchronized with the training SCADA system "Energy" and the telemechanics system "Strila" (Fig. 15). The designed controller is universal and can be used to manage various equipment for industrial and domestic purposes (Fig. 8). Since the controller supports Wi-Fi wireless communication, it can be controlled using a computer, tablet, or smartphone (Fig. 10). To implement the control task, a specialized application "Diagnostics" was developed in the C/C++ programming language using theVisual Studio Community environment and Windows Presentation Foundation technology for building graphical interfaces (Fig. 9). We provide technical characteristics of the designed educational system; its main components are indicated, and a list of equipment is given. Due to the fact that solar panels are the main element of the system that converts the energy of solar radiation into electrical energy, the basic dependences for calculating their parameters (5) to (9) are given.

The proposed solution for the use of the designed hybrid solar mini-power plant in an educational building can be an example of energy savings in various formats of this type. The maximum capacity of the solar designed mini-power plant is achieved in the absence of objects of shading of its solar panels – therefore, the roof of the building of the educational building is the optimal place for their placement (Fig. 4).

In order to implement the designed control scheme (Fig. 14), a real model of the intelligent control system of actuators was made (Fig. 12, 13).

The studies have shown that the integration of a solar power plant into an existing power supply system, together with the extensive use of power electronics equipment, changes the nature of energy and transient processes. This causes a change in the balance of electrical energy, the appearance of a change in power and pulsations, as well as a change in the magnitude of the voltage and a deterioration in the quality of electricity. It is also necessary to take into account that the power inverter is part of the solar power plant, sensitive to voltage levels (Fig. 6). Therefore, if connected incorrectly to the grid, depending on its configuration, properties, structure, and condition of the equipment used, this can cause a violation of the stability of the parallel operation of the existing power supply system and the solar power plant.

The study of hybrid solar installations has some limitations, in particular:

– cost, which can be quite high compared to conventional solar systems in the presence of additional components (energy storage, additional energy generators);

– design complexity, as they must be properly configured to ensure optimal interaction between different components;

– complexity of operation, especially if they contain additional components for energy storage and additional energy generators;

– environmental impact. Hybrid solar systems can be more sensitive to environmental influences, especially if they contain complex components such as energy storage or additional energy generators;

– unavailability of data. Some parameters, such as weather conditions or electrical loads, can be difficult to predict, which can complicate the design and operation of hybrid solar systems;

– the need for energy infrastructure to store energy obtained from a hybrid solar power plant.

The construction and research of intelligent control systems in the energy sector may have the following limitations:

– lack of sufficient data. To design an intelligent control system, you need to have enough data from the power system. If this data is missing or insufficiently complete, it can complicate the development of the system;

– complexity of algorithms development. Developing efficient algorithms for an intelligent control system can be complex, especially a complex control system that takes into account many factors;

– security issues. An intelligent control system can be vulnerable to cyberattacks, which can lead to serious consequences, especially in the energy sector. Therefore, the application of cybersecurity measures is extremely important;

– regulatory issues. There are many different regulatory authorities in the energy sector, which may result in certain intelligent control systems not meeting their requirements;

– lack of standardization. In many cases, there are no standardized protocols for collecting, processing, and transmitting data in the energy sector. This can make it more difficult to design an intelligent control system and may reduce its efficiency;

– cost. Development and implementation of an intelligent control system can be quite high in cost.

While hybrid solar installations have many advantages, they also have some disadvantages. Some of them and ways to fix them are listed below:

– high installation costs. Building a hybrid solar installation can be costly. One of the ways to eliminate this drawback is to reduce the cost of technologies used in the installation;

– dependence on weather conditions. Hybrid solar installations can depend on weather conditions, especially when there is no sunlight. To eliminate this disadvantage, you can use additional energy sources, such as wind energy or biofuels;

– require additional equipment. Hybrid solar installations require additional equipment to integrate with the energy system. This disadvantage can be eliminated through the use of specialized control systems that make it possible to efficiently integrate various energy sources;

– limited power. Hybrid solar installations may have limited power, especially when compared to other energy sources. This disadvantage can be eliminated by using more powerful solar panels and increasing the size of the installation;

– storage systems. Hybrid solar installations may require storage systems that can be additionally costly. This disadvantage can be eliminated by designing efficient storage systems, such as lithium-ion rechargeable batteries or hydrogen storage.

Intelligent control systems in the energy sector have many advantages, but also have some disadvantages. Some of them and ways to fix them are listed below:

– high installation costs. Building an intelligent control system can be costly. One of the ways to eliminate this drawback is to reduce the cost of technologies used in the system;

– system errors. Errors may occur in intelligent control systems, which can cause malfunctions in the power system. This disadvantage can be eliminated by using reliable algorithms and testing the system before putting it into operation;

– dependence on data. Intelligent control systems may be dependent on data that may be incomplete or inaccurate. This disadvantage can be eliminated by accumulating more accurate data and using machine learning algorithms that make it possible to correct unreliable data;

– irreversibility of processes. Intelligent control systems can lead to irreversible processes that can damage power system equipment. This disadvantage can be eliminated by developing algorithms that allow them to be stopped in case of emergencies and automatic recovery of processes;

– require additional equipment. Intelligent control systems may require additional equipment to integrate with the power system. This disadvantage can be eliminated by using specialized control systems.

Hybrid solar installations, like any other technology, have problems that complicate their development and use. Some of them are:

– high cost. The cost of hybrid solar installations is quite high compared to traditional energy sources, which can reduce their availability for most consumers;

– unstable operation. The efficiency of hybrid solar installations can depend on various factors, such as weather conditions, which can be unpredictable. This can lead to unstable operation of the system and inefficient use of solar energy;

– reliability and durability. Most hybrid solar installations use lithium-ion rechargeable batteries, which have a limited lifespan and need to be replaced in a few years. In addition, the possibility of damage to solar panels can also affect the reliability and durability of the system;

– problems with energy storage. Although solar panels can generate energy during the day, the use of electricity can be needed at any time of the day. This can create problems with energy storage, especially in the dark;

– network connectivity issues. Hybrid solar installations can have grid connectivity problems, especially in cases where the system generates excessive amounts of electricity.

Intelligent control systems in the energy sector are becoming increasingly popular but they also face development challenges. Here are a few of them:

– insufficient amount of data. Intelligent control systems require a lot of data for training and decision-making. In underdeveloped countries, there may be a limited amount of available data, which can be an obstacle to the development of intelligent control systems;

– problems with standardization and compatibility. Intelligent control systems in the energy sector can be built on the basis of different technologies and protocols, which can create problems with compatibility and standardization between different systems;

– security issues. Intelligent control systems can be targeted by hackers and intruders, which can lead to data loss, system disruption, and other problems;

– high costs. The development and implementation of intelligent control systems can be very costly. For underdeveloped countries, this can be an obstacle to the development of such systems.

Eliminating these problems requires international standards and cooperation between technology manufacturers, governments, and scientific institutions. It is also necessary to ensure the security of data and systems using security technologies and network protocols.

7. Conclusions

1. For the proposed training solar mini-power plant, the components were calculated, in particular: an inverter, the number of rechargeable batteries and solar panels, a charge-discharge controller. This made it possible to design and practically implement the structure of a solar power plant, which can operate both from solar energy and from a centralized network and rechargeable batteries under an automatic mode.

2. To implement an intelligent control system, a microprocessor-based controller was designed using a Wi-Fi module that makes it possible to change the control program for the required tasks without changing the hardware. This is ensured by wireless network connectivity, the ability to integrate into a single system, the function of automated data acquisition and remote management via VPN tools.

3. On the basis of the designed controller, a working layout of the intelligent control system of actuators was implemented. The advantage of this system is flexible configuration of the controller to handle various devices at work and at home, wireless support, which makes it possible to control it from a computer, tablet, or smartphone.

4. To ensure the visibility of the educational process, the designed intelligent control system was synchronized with the educational SCADA-system "Energy" and the telemechanics system "Strila". This provided an additional opportunity to control the system from anywhere in the presence of the Internet and manage the designed hybrid solar mini-power plant.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

Funding

The study was conducted without financial support.

Data availability

All data are available in the main text of the manuscript.

Acknowledgments

The authors express their gratitude to the students of the Faculty of Applied Information Technologies and Electrical Engineering, who helped in various aspects of the study and practical implementation of this project. Special thanks to the Ternopil Design Bureau of Radio Engineering "Strila" for an important contribution to the development of the simulation model of dispatch control, in particular to Director O. Rafalyuk, Chief Engineer S. Piskun, and programmer S. Dudin.

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