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SIMULATION OF THE WORK OF PHOTOELECTRIC PLANTS

The article draws attention to the fact that nowadays the demand for energy is not decreasing, but its cost is increasing. The need to research the parameters of photovoltaic modules and the capabilities of microprocessor technology for this is substantiated. It is noted that the scheme of electric distribution networks has become more difficult to operate, and the algorithms and methods of reliable and optimal management of modes are changing due to the modernization of the infrastructure of electricity supply and electricity consumption of the district. Nowadays, renewable energy sources are installed in the electrical distribution system at various levels of power supply and power transmission between the substation and consumers. Due to damage to the electrical equipment, there may be interruptions in the power supply, which unintentionally cause "islanding". During operation, situations sometimes arise when the power supply system of the "islands" is promptly de-energized starting from the points of connection of the "islands" to the unified electric power system. This happens based on the results of measuring the parameters of the mode of local electric power systems or based on the results of mathematical modeling of processes in local electric systems when, for example, the current levels of nodal voltages will not allow the use of an "island" electric network. For the purpose of researching processes in local electrical systems with photovoltaic plants, the article proposes their physical model in the form of a research bench, which can be used during the practical training of future employees who will manage the modes of distribution electrical networks with photovoltaic plants and maintain the equipment of such networks, systems and electrical stations Algorithms for optimal management of generated power, consumption and accumulation of electric energy tested using the proposed stand are designed to show the operating personnel ways of high-quality operation of distribution electric networks under the conditions of implementation of the Smart Grids concept.

Key words: *renewable sources, photovoltaic stations, photovoltaic modules, physical modeling, Arduino.*

Аналіз останніх досліджень і публікацій. The control system of planned modes of district electric networks is sometimes operated with smaller reserves, with a smaller reserve. It can be caused by internal damage, faulty power equipment, and power fluctuations, and it can also be related to frequency, voltage, and generation and consumption instabilities [3]. Various methods are available in the literature, which are used to analyze violations of scheduled modes, methods of preventing emergency modes, preventing non-supply of electricity to consumers, etc.

The integration of renewable sources into power supply systems is a multifaceted task, based on the use of the results of mathematical and computer modeling of normal, emergency and post-emergency modes, physical modeling of equipment of distributed sources of electricity, for example, for the purpose of studying the impact of damage to their parts and nodes, for example, on quality indicators electrical energy.

Nowadays, renewable energy sources are installed in the electrical distribution system at different levels of electricity supply and electricity transmission between the substation and consumers. Due to damage to electrical equipment, there may be interruptions in the supply of electricity [4], which unintentionally cause "islanding". An unregulated "island" and its behavior are unpredictable and can lead to fluctuations in frequency, voltage, and abnormal deviation of other power quality parameters [5]. The conditions for safe living are deteriorating [3]. Damage to the equipment of electrical distribution networks and RES leads to a shortage of electricity to consumers and to disruption of technological processes at consumers' enterprises. During operation, situations sometimes arise when the power supply system of the "islands" is promptly de-energized starting from the points of connection of the "islands" to the unified electric power system [5]. This happens based on the results of measuring the parameters of the mode of local electric power systems or based on the results of mathematical modeling of processes in the LES when, for example, the current levels of nodal voltages do not allow the use of an "island" electric network, or do not allow receiving electric energy from thermal electric stations that traditionally use fossil fuels fuel.

Results and discussion. Modern physical models are used for the purpose of researching the processes in LES with RES. It is known that the modeled object is a system entity that, in a simplified form, reflects and represents its original [6]. There are mathematical and physical models of photovoltaic plants (PHS). The FES model in a certain sense represents (reproduces, reflects) some original, for example, the FES.

Thus, a laboratory stand was created to study the parameters of the photovoltaic panel (Fig. 1).

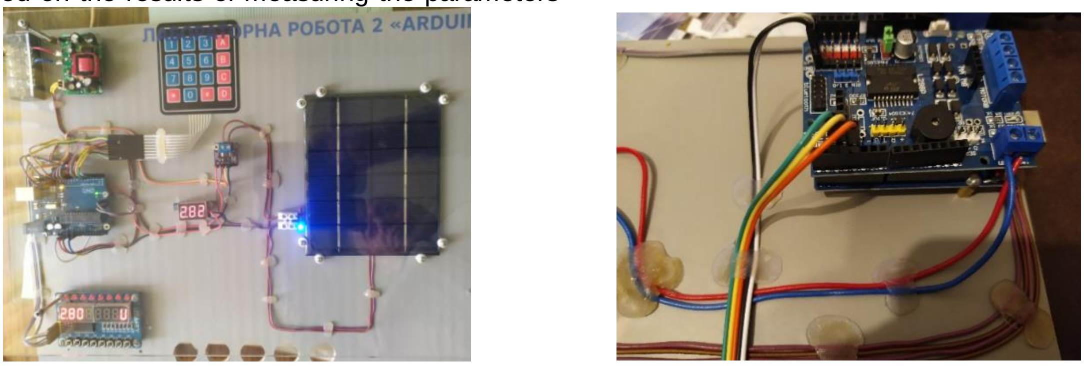

Fig. 1. Appearance of the created stand

This stand uses: a CJMCU-219 digital current and voltage meter on an INA219 microcircuit with an I2C bus [7]. The INA219 microcircuit measures current flow parameters in any direction with automatic switching of measurement polarity. The module can be used in systems that control the charging/discharging process of storage batteries, power sources with control of voltage and current consumed by the load. The ability to change the I2C address of the meter allows you to connect up to 4 such devices on one bus. To increase the accuracy of measurements, a calibration register is provided.

An indication and control module on the TM1638 chip is also used. The indicator keyboard module on the TM1638 chip is designed for input and output of information from the microcontroller. The board displays information on 8 seven-segment indicators, 8 LEDs and allows you to enter information from 8 buttons. A serial interface is used for management. Control of indicators and detection of button presses is carried out by the TM1638 microcircuit of the Chinese company Titan Micro Electronics. The TM1638 receives from the MCU and transmits data over a unique three-signal serial interface, close to the SPI interface. The difference from SPI consists in combining two lines of reception and transmission into one line. The names of the signals are different from those adopted in SPI, but they are well recognized [8].

The Arduino Uno Rev3 (ATmega16U2) controller [9] is used in the laboratory stand. This controller differs from previous versions in its USB-UART chip (ATMega16u2). The feature of the microcircuit is high data transfer speed and no need for additional installation of drivers. They are installed automatically when you install the Arduino IDE development environment. Uno also has additional SDA and SCL contacts (I2C interface), AREF outputs of the reference voltage source for the ADC of the controller and IOREF - output voltage of the input-output ports (for automatic switching of the peripheral voltage when using 5V and 3.3 controllers). In everything else, it is still the same Arduino UNO controller based on the Atmega328 microcontroller with a lot of example programs, including a program for the physical model of the FES. Arduino is an open platform that allows you to assemble a variety of electronic devices. A simplified version of the C++ programming language is used for programming.

Software development can be conducted both using the free Arduino IDE environment and using the C/C++ programming language toolkit.

The stand uses a highly efficient source of ecologically clean and free electrical energy, namely: a photovoltaic panel [10]. The moisture-proof design of the panel allows you to use it outdoors and in the field.

Functional capabilities of the stand have been improved as follows:

The voltage of 12 V from the photovoltaic panel (PEP) is supplied to the storage battery (12 V) for energy storage through the charging device. The voltage of this battery is constantly monitored by a microprocessor voltmeter and a microcontroller. Since the voltage is applied to one of the inputs of the microcontroller, if this voltage is less than the required voltage of 12 V, then the microcontroller automatically disconnects the power supply of this battery by sending a disconnection signal to the power circuit of the electric motors located on the stand. The load connected through the inverter is disconnected by means of a reed switch from the first battery (AB1) and connected to the second AB2 in the engine power circuit. In this way, the equipment of the stand ensures uninterrupted power supply of electric motors. At the same time, to achieve the maximum power from the FEM, a voltage monitoring system is included, which consists of LDR'S (light-dependent sensors, for example, to photoresistors). Photoresistors are connected to the microcontroller. Their resistance reacts to light. These sensors send a signal to the microcontroller, which in turn sends a signal to the motor control circuit. This signal is used in the electric drive control circuit of the actuator (DC motor) to control the rotation of the FEM, to change its position in the direction of the light source location.

In comparison with the technical characteristics of different AB. AB cells used in the Li-Ion stand are able to store electricity. At the same time, the battery voltage will be in the range from 3.6 to 3.85 V. In these batteries, the lithium-ion cell has a greater capacity for storing electricity.

Lithium-ion cells can be used for energy storage in networks that have a high power density. The capacity of the battery depends on the materials from which the battery is made. The lithium-ion battery has advantages in terms of cost and ease of use.

Program code for the Arduino Uno Rev3 (ATmega16U2) controller used in the stand proposed in the article.

```
#include <TM1638lite.h>//indicator library
#include <Wire.h>//I2C library
#include <Adafruit_INA219.h>//INA219 measurement module library
#include <Keypad.h>//keypad library

// I/O pins on the Arduino connected to strobe, clock, data
// (power should go to 3.3v and GND)
TM1638lite tm(10, 9, 8);//initialization of the display module
Adafruit_INA219 ina219;//initialization of the measurement module

const byte ROWS = 4; //determine that the keyboard has 4 rows of keys
const byte COLS = 4; //determine that the keyboard has 4 rows of keys

//determine the assignment of buttons on the keyboard
char hexaKeys[ROWS][COLS] = {
  {'1','2','3','A'},
  {'4','5','6','B'},
  {'7','8','9','C'},
  {'*','0','#','D'}
};
byte rowPins[ROWS] = {2, 3, 4, 5}; //keyboard rows connected to pins 2, 3, 4, 5
byte colPins[COLS] = {6, 7, 11, 12}; //the keyboard columns are connected to pins 6, 7, 11, 12
//initialize the keyboard
Keypad customKeypad = Keypad( makeKeymap(hexaKeys), rowPins, colPins, ROWS, COLS);

//define the variables
  char customKey;
  float energy;
  float energy_mWs; //energy mW*s
  float energy_mWh; //energy mW*h
  float shuntvoltage = 0;
  float busvoltage = 0;
  float current_mA = 0;
  float loadvoltage = 0;
  float power_mW = 0;
int butt,butt2;

const uint8_t digits[11]={ //define the symbol table for the indicator
  0x3F, /* 0 */
  0x06, /* 1 */
  0x5B, /* 2 */
  0x4F, /* 3 */
  0x66, /* 4 */
  0x6D, /* 5 */
  0x7D, /* 6 */
  0x07, /* 7 */
  0x7F, /* 8 */
  0x6F, /* 9 */
  0x80, /* . */};
```

```
void setup()
{
 tm.reset();//resetting the display board
 ina219.begin();//initialization of the measurement board
 ina219.setCalibration_16V_400mA();//setting up the measurement board
 }

void FloatToTm1638(float dataIn){ // the function of correct output of the dot on the indicator
 String dataOut;
 uint8_t data[5];
 dataOut= String(dataIn);
 int dpn=dataOut.indexOf('.');
 if(dpn== -1){ }
 else{
   for (int i =0; i< dataOut.length(); i++){
    if(i < dpn){
      data[i]=digits[dataOut[i]-0x30];
     }
    if(i == 1){
       data[i-1]=data[i-1] + 0x80;// add to digits code dot point
       }
    if(i > dpn){
       data[i-1]=digits[dataOut[i]-0x30];
       }
   }
  }
 for (int i =0;i<3; i++){
 tm.displaySS(i, data[i]);
 }
}

void loop() {
 //read the value from the measurement board
 shuntvoltage = ina219.getShuntVoltage_mV();
 busvoltage = ina219.getBusVoltage_V();
 current_mA = ina219.getCurrent_mA();
 power_mW = ina219.getPower_mW();
 loadvoltage = busvoltage + (shuntvoltage / 1000);
 energy=energy+power_mW;
 energy_mWs=energy/5;
 energy_mWh=energy_mWs/3600;

butt=tm.readButtons();//read the status of the buttons of the display board
customKey = customKeypad.getKey();//read the state of the keyboard buttons

 if (butt != 0){
 butt2=butt;
 }
if (customKey != NO_KEY){
  if(customKey == '1'){
  butt2=0b1; }
  if(customKey == '2'){
  butt2=0b10; }
  if(customKey == '3'){
  butt2=0b100; }
  if(customKey == '4'){
  butt2=0b1000; }
  if(customKey == '5'){
  butt2=0b10000; }
 }

 if(butt2 == 0b1 ){ //if button 1 is pressed
 tm.reset();
 FloatToTm1638(loadvoltage);
 tm.displayASCII(7,'U');
 }

 if(butt2 == 0b10){ //if button 2 is pressed
 tm.reset();
 if(current_mA <0){
   current_mA=0;
  }
 FloatToTm1638(current_mA);
 tm.displayASCII(7,'A');
 }

 if(butt2 == 0b100){ // if button 3 is pressed
 tm.reset();
 FloatToTm1638(power_mW);
 tm.displayASCII(7,'P');
 }

  if(butt2 == 0b1000){ // if button 4 is pressed
 tm.reset();
 FloatToTm1638(energy_mWs);
 tm.displayASCII(6,'P');
 tm.displayASCII(7,'S');
 }
 if(butt2 == 0b10000){ // if button 5 is pressed
 tm.reset();
 FloatToTm1638(energy_mWh);
 tm.displayASCII(6,'P');
 tm.displayASCII(7,'h');
 }
delay(200);
 }
```

Study of simulation results. In order to study the discharge of the first and second storage batteries (AB) of the stand, we monitor the decrease in voltage (at the inverter terminals) over time at the maximum load of the stand. The table below indicates the voltage (at the terminals) of the inverter in the stand's distribution network.

Table 1

The results of observations of voltage changes during discharge of AB

№ measurements	Stand batteries SB1		№ measurements	Stand batteries SB2	
	Time, h:min	High-voltage, B		Time, h:min	High-voltage, B
1	00:00 (disconnection of the load from the 50 Hz)	13,6	8	00:30 (disconnecting the load from SB1 and turning on SB2)	13,4
2	00:05	13,0	9	00:35	12,9
3	00:10	12,7	10	00:30	12,7
4	00:15	10,9	11	00:35	10,5
5	00:20	7,0	12	00:35	8,2
6	00:25	5,1	13	00:35	6,2
7	00:30	4,8	14	00:35	5

In fig. 2, 3, 4 show the discharge graphs of SB1, SB2 and two SBs on one graph.

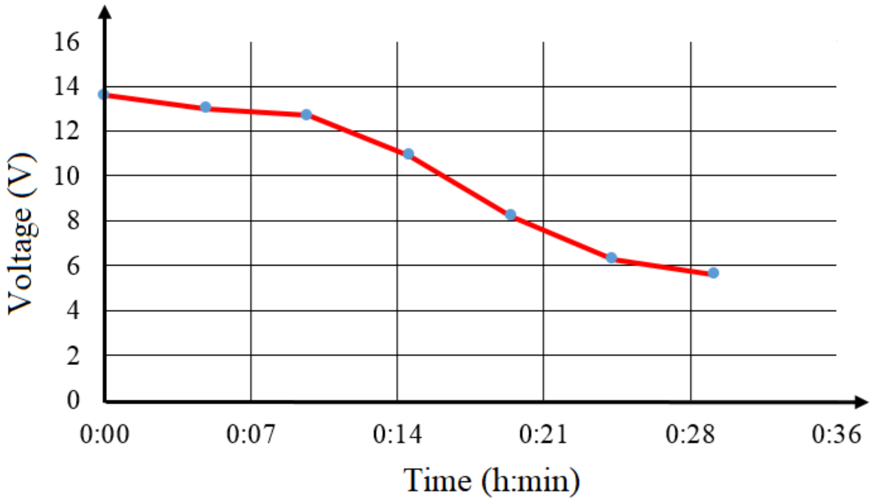

Fig. 2. Graph of voltage reduction AB1 during discharge

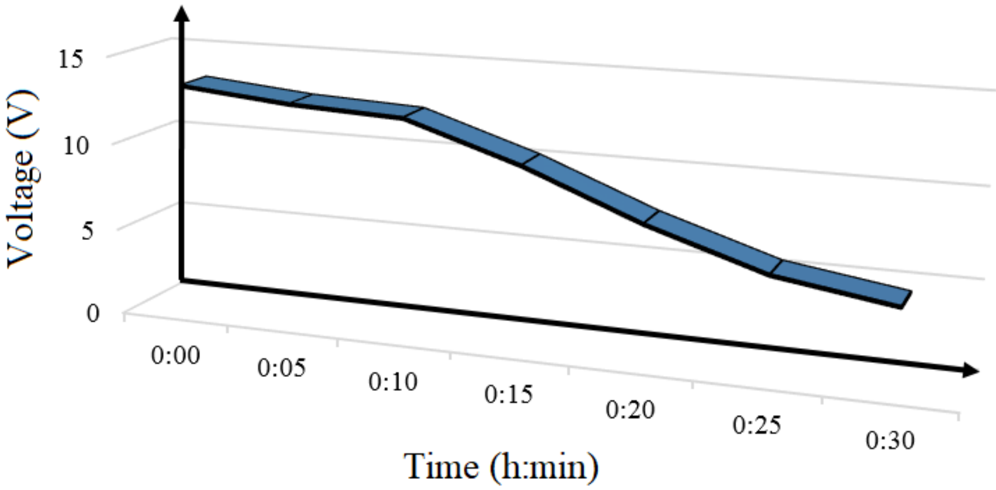

Fig. 3. Graph of reduction of SB2 voltage during discharge

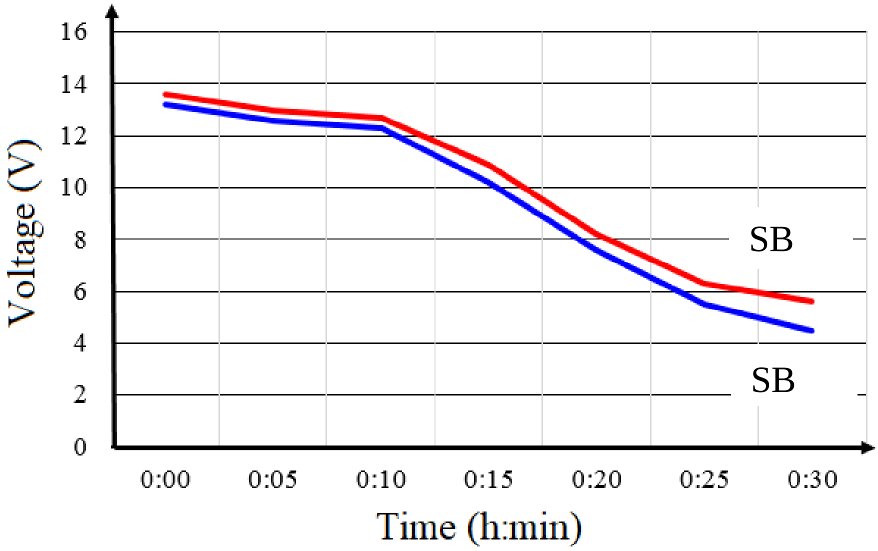

Fig. 4. Combined graphs of SB1 and SB2 voltage reduction during discharge

Conclusions. The developed stand allows you to explore the advantages of Smart Grid technology in distribution electric networks with FES.

The properties of the Smart Grid technology, which are implemented in the developed stand, are as follows:

automatic recharging of the stand's batteries with sufficient insolation; automatic switching of storage batteries from charge mode to discharge mode to the load, if the voltage on the load decreases overtime; automatic shutdown of the stand's electric motors, if subsequently the voltage of the motors decreases overtime apparently with the stand's batteries connected.

Implication functions of optimal control of the hardware components of the stand: relays, motors, photovoltaic module, power source, etc., are implemented in the developed stand through real-time integration.

The automatic control system developed for the stand is best suited for controlling the load's electric motors connected to the stand's power grid and the power supply system of this load from the centralized power network or from a local power supply source (batteries).

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МОДЕЛЮВАННЯ РОБОТИ ФОТОЕЛЕКТРИЧНИХ СТАНЦІЙ

В статті звертається увага на те, що в наш час попит на енергію не зменшується, а її вартість зростає. Обґрунтовано необхідність дослідження параметрів фотоелектричних модулів та можливостей мікропроцесорної техніки для цього. Відзначається те, що схема електричних розподільних мереж стала складнішою в експлуатації, а алгоритми та методи надійного та оптимального керування режимами змінюються через модернізацію інфраструктури електропостачання та електроспоживання району. В наш час відновлювальні джерела енергії встановлюються в розподільній електричній системі на різних рівнях електропостачання та передавання електроенергії між підстанцією та споживачами З причини пошкоджень електрообладнання можуть бути перебої в постачанні електроенергії, які ненавмисно викликають «острівування». Під час експлуатації інколи виникають ситуації, коли система електропостачання «островів» оперативно знеструмлюється починаючи з місць приєднання «островів» до об'єднаної електроенергетичної системи. Це відбувається за результатами вимірювання параметрів режиму локальних електроенергетичних систем або за результатами математичного моделювання процесів в локальних електричних системах коли, наприклад, поточні рівні вузлових напруг не дозволять використовувати «острівну» електричну мережу. З метою досліджень процесів в локальних електричних системах з фотоелектричними станціями в статті пропонується їх фізична модель у вигляді дослідницького стенда, який може використовуватись під час практичної підготовки майбутніх працівників, які керуватимуть режимами розподільних електричних мереж з фотоелектричними станціями та обслуговуватимуть обладнання таких мереж, систем та електричних станцій. Випробувані з використанням запропонованого стенду алгоритми оптимального керування генерованою потужністю, споживанням та акумулюванням електричної енергії покликані підказати експлуатуючому персоналу шляхи якісної експлуатації розподільних електричних мереж в умовах впровадження концепції Smart Grids.

Ключові слова: відновлюване джерело, фотоелектричні станції, фотоелектричні модулі, фізичне моделювання, Arduino.

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