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Tashkent state transport university

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# Control and management of active and reactive power balance in a solar power supply system

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Abstract: This article discusses the development of a measurement and control system for monitoring and managing the balance of active and reactive power at power plants based on "Green" energy sources. Monitoring and management of the balance of active and reactive power based on a measurement and control system, calculated expressions are developed to solve the problem of reactive power compensation when transmitting electricity at power plants based on "green" energy sources. Reactive power is calculated based on measured active power, and combined reactive power sources generate the reactive power required by the network based on control signals. Schemes for connecting these reactive power sources to the network have been developed, and this diagram shows the installation of a measurement control device. The schematic block diagram of a measurement control device shows the sequence of the process of measuring and processing electrical data, as well as the generation of control signals. To study the operating principle and elements of a device created to monitor and manage reactive power consumption, a microcontroller, a signal converter and measuring transducers were selected. An algorithm for monitoring and managing the balance of active and reactive power has been developed for the device software. At the same time, equations for separating current, voltage and frequency signals in the phase section were developed.

Keywords: Green energy, active and reactive power, balance, monitoring and control, measurement and control system, microcontroller, signal converter, current, voltage, frequency, traditional power plant, solar and wind power plants, calibration factor, Arduino Uno, integrated circuit, Atmega328

## 1. Introduction

Today, power plants based on renewable energy sources are being built in the republic. Today, practical work is underway in Uzbekistan to build 22 solar and wind power plants with a capacity of 9 GW. In particular, a solar power plant with a total capacity of 900 MW has been built and commissioned in Samarkand, Jizzakh and Surkhandarya regions, while the Chinese company China Gezhouba Group has built and commissioned two solar power plants with a total capacity of 1,000 MW in Bukhara and Kashkadarya regions. At the same time, design and construction of wind power plants worth 650 million US dollars each have begun in the Peshku and Gijduvan districts of Bukhara region. The foreign company ACWA POWER from the Kingdom of Saudi Arabia is working on the creation of wind power plants with a capacity of 300-500 MW in the Peshku and Gijduvan districts. In general, by 2030, it is planned to build solar and wind power plants with a capacity of 27 GW based on "Green" energy sources in our Republic.

Based on the above, we can say that great attention is paid to providing the population with uninterrupted electricity in our republic.

This requires, along with the uninterrupted supply of electricity, ensuring the quality of electricity. In particular, along with active power consumers in the electricity network, there are also reactive consumers. This, in turn, requires paying attention to the issues of compensation for reactive power when transmitting electricity at power plants based on "Green" energy sources. There is still a lot of work to be done in this regard.

In this article, a measurement and control system has been developed to monitor and control the balance of active and reactive power when transmitting electricity to the network at power plants based on "Green" energy sources. Based on the measurement and control system for monitoring and controlling the balance of active and reactive power, a device installation scheme, a measurement and control system, a control and control device, and software were developed to control and control reactive power consumption in power plants based on "Green" energy sources.

## 2. Research methodology

In this work, the visualization of the energy performance of a solar power plant connected to the grid is considered. Usually, the visualization of the energy performance of a solar power plant is obtained using the Huawei online calculation program. When obtaining the visualization results of the energy performance of a solar power plant, climate and weather conditions, the angle of incidence of sunlight, and the pollution of the panels are important issues of the study. Inverters used in the electric power generation system have a significant impact on the quality of electric energy. Quality control when transmitting the generated active power to the grid has certain problems. It is known that in a power supply system, the active power balance is related to the network frequency, while the reactive power balance is a voltage-dependent quantity. The active power balance in a power supply system should be as follows [1-2]:

$$\sum P_{gen} = \sum P_{ist} = \sum P_{yuk} + \sum \Delta P$$

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if,

$\sum P_{gen} < \sum P_{ist}$ or $\sum P_{gen} > \sum P_{ist}$

If the frequency in the power supply system decreases or increases. For stable operation of the power supply system, the nominal permissible deviation of the frequency is set at ±0.2 GHz. [4].

The reactive power balance should look like this [3-5]:

$$\sum Q_{gen} = \sum Q_{ist} = \sum Q_{yuk} + \sum \Delta Q$$

if,

$\sum Q_{gen} < \sum Q_{ist}$ or $\sum Q_{gen} > \sum Q_{ist}$

If, the voltage of the power supply system decreases or increases.

It is known that the amount of reactive power generated by traditional power plants is insufficient for the power supply system, 2/3 of the reactive power required by consumers is covered by consumers, and 1/3 is taken from the power supply network. Therefore, in power supply systems with solar power plants, monitoring and controlling the transfer of active and reactive power to the power supply system network is an important issue.

Information on the amount of active and reactive power supplied to the power supply system by an 80 kW solar power plant during the day on March 15, 2024 is presented in Figure 1. It can be seen that the solar power plant generated 379.96 kW*h of active electricity during this period and transferred it to the power supply system network.

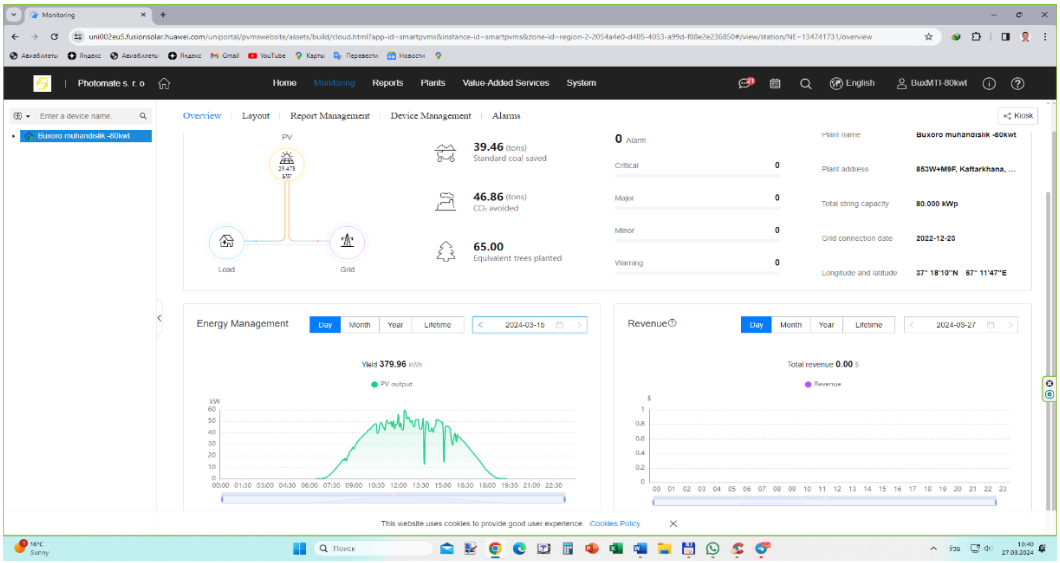



**Fig. 1. Electricity generated by an 80 kW solar power plant**

The solar power plant operates in parallel with the power supply system network in the electricity generation mode. In this process, an inverter is used to ensure the quality of the transmitted electricity. The reactive power balance is not considered in the described power supply system.

Developed schemes and equations. The results of the analysis and research have shown that the algorithm for monitoring and controlling the reactive power balance for a power supply system with a solar power plant, as well as the structural and electrical schemes for reactive power compensation, are important issues.

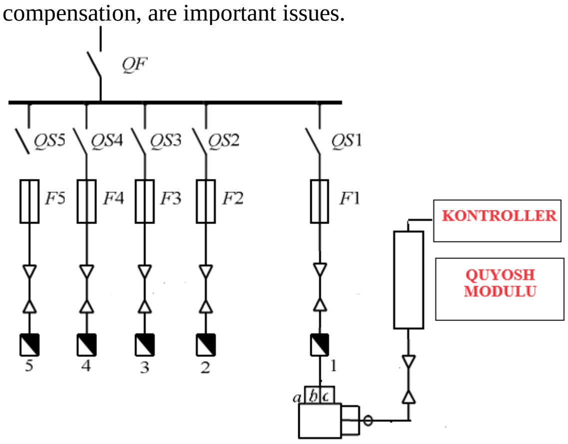



**Fig. 2. Installation diagram of a device designed to control and manage reactive power consumption**

Based on the installation diagram of a device designed to control and manage reactive power consumption, a measurement control system was developed to control and manage the balance of active and reactive power for a solar power plant power supply system. The measurement control system designed to control and manage the balance of active and reactive power in the power supply system is shown in Figure 3.

The measurement control system consists of three parts, the first part is the electrical part, the second part is the measurement-transformer part, and the third part is the software written in the microcontroller for processing the measurement results.

In the electrical part of the measurement control system, current signals are converted from the traditional power supply in the phase section by a special current transformer device and transmitted to the measurement-transformer unit. At the same time, a voltage signal is also supplied to the measuring and converting unit of the system. In the same way, current and voltage signals are obtained from the inverter of the solar power plant in the same order by phase.

In the measuring and converting unit, the current and voltage signals measured in the phase section are separated into current, voltage and frequency signals by phase and converted into a signal form and size that the microcontroller can read.

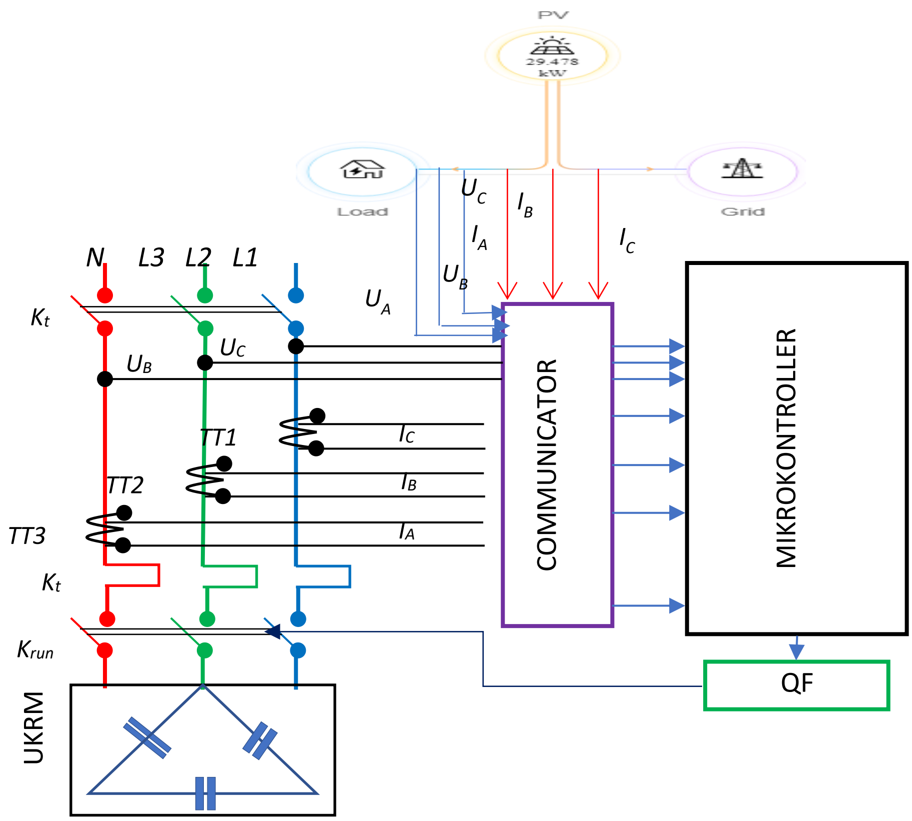



**Fig. 3. Measurement and control system for monitoring and controlling the balance of active and reactive power**

The microcontroller processes electrical quantities in the following sequence. Measuring electrical energy provides information about the change in power over time, and multiplies its signals in the form of voltage and current over time. If there is a difference between current and voltage, active power factor and phases, then active power is calculated as follows [2-3]:

$$p(t) = Ucos(wt) * Icos(wt + F), if\ F = 0$$

$$p(t) = \frac{UI}{2}(1 + cos2(wt))$$

$$if\ F \neq 0$$

$$p(t) = \frac{UI}{2}(1 + cos2(wt))$$

$$p(t) = Ucos(wt) * Icos(wt + F) =$$

$$= Ucos(wt) * [Icos(wt)\cos(F) + \sin(wt)\sin(F)$$

$$= \frac{UI}{2}(1 + cos(2wt)\cos(F)$$

$$+ UIcos(wt)\sin(\mathrm{wt})\sin(F)$$

$$= \frac{UI}{2}(1 + cos(2wt)\cos(F)$$

$$+ \frac{UI}{2}\sin(2\mathrm{wt})\sin(F)$$

The input voltage of the two channels of voltage and current is multiplied by the current and obtained through signal processing.

The active power data is converted to frequency, and in this process, the effective value of the voltage and the effective value of the current are calculated at the same time and converted to frequency. The effective values of the active power, voltage and current are outputted from the CF and CF1 channels, respectively, in a highly efficient manner.

The formula for calculating the frequency of the active power based on the output pulse is defined as follows [4]:

$$F_{CF} = 1721506 \frac{U(U) * U(I)}{U_{ref}^2}$$

where 1721506 is the calibration coefficient.

The voltage at the phase intersection is determined as follows [7]:

$$U_f = K_{kU}\frac{\sqrt{\sum_{i=1}^{n} U_i^2}}{n};$$

The current in the phase section is defined as follows[7]:

$$I_f = K_{kI}\frac{\sqrt{\sum_{i=1}^{n} I_i^2}}{n}$$

The active power and total active power in the phase section are defined as follows [7]:

$$P_f = K_{kU} \cdot K_{kI}\frac{\sqrt{\sum_{i=1}^{n} U_i I_i}}{n}; \qquad P_\Sigma = P_{fA} + P_{fB} + P_{fC}$$

The apparent power and total apparent power in the phase section are defined as follows [7]:

$$S_f = I_f \cdot U_f; \qquad S_\Sigma = I * U$$

The reactive power and total reactive power in the phase section are determined as follows: [7]:

$$Q_f = \sqrt{S_f^2 - P_f^2}; \qquad Q_\Sigma = Q_{fA} + Q_{fB} + Q_{fC}$$

The active power factor is defined as follows [7]:

$$\cos\varphi_{ABC} = \frac{P_{fABC}}{S_{fABC}}$$

Active and reactive electrical energy are defined as follows [7]:

$$W = P_\Sigma * t, \qquad Q = Q_\Sigma * t$$

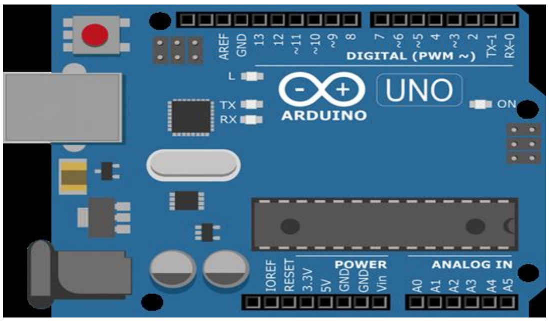
Based on the above mathematical expressions, the algorithm of the software for the operation of the measurement control system was formed, and this algorithm is a one-condition algorithm.

For the operation of the measurement control system, an Arduino microcontroller with an Atmega microprocessor was selected.

The basis of the Arduino Uno integrated circuit is the ATmega328 microcontroller. The characteristics of the Arduino Uno are given in Table 1 [4-5].

**Table 1**

**Characteristics of the Arduino Uno microcontroller**

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|---|---|
| Microcontroller type | ATmega328 |
| Operating voltage | 5 Volts |
| Supply voltage | 7-12 Volts |
| Voltage range | 6-20 Volts |
| Digital inputs and outputs | 14, of which 6 are for PWM |
| Analog inputs and outputs | 6 |
| Specified current per output channel | 40 mAmperes |
| Memory | 32 kB, of which 0.5 kB is for programming |
| SRAM | 2 kB |
| EEPROM | 1 kB |
| Frequency | 16 MHs |

The connection diagram of the active and reactive power balance monitoring and control device and the Arduino Uno integrated circuit is shown in Figure 4.

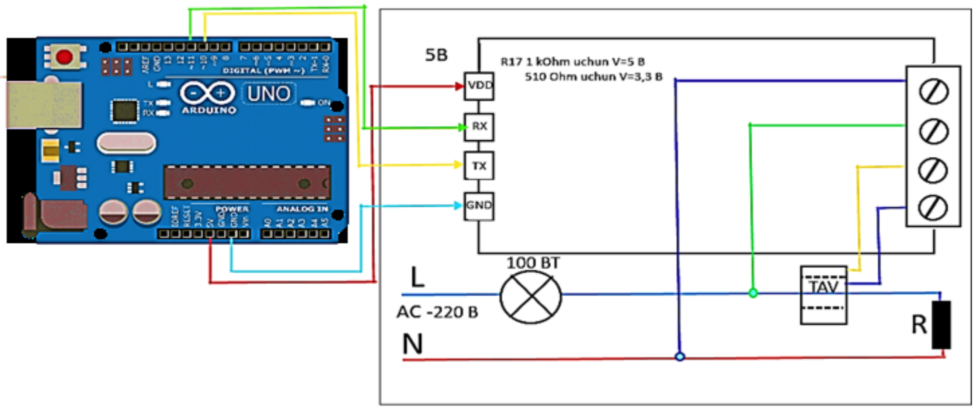


**Fig. 4. Connection diagram of the active and reactive power balance control and management device and Arduino Uno integrated circuit**

In the general scheme, the connection of the remaining phases of the electrical network is carried out in the same order as one phase is connected. The scheme presented in Figure 5 shows the connection of the active and reactive power balance control and management device and Arduino Uno integrated circuit.

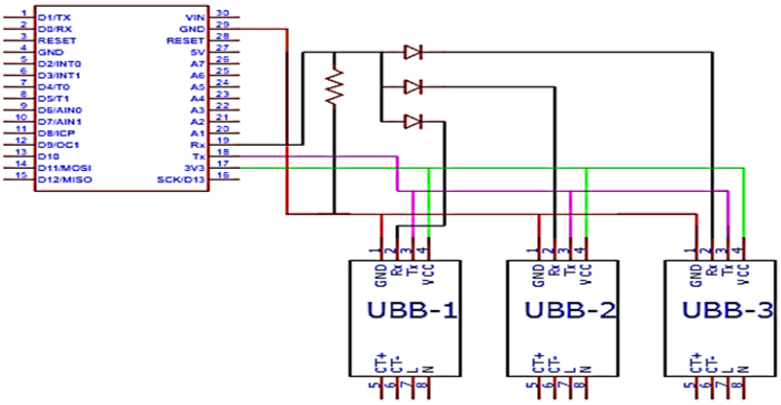


**Fig. 5. Connection diagram of the three-phase active and reactive power balance control and control device and Arduino Uno integrated circuit**

The measuring and control unit designed for the three-phase active and reactive power balance control and control is mainly assembled on the basis of the elements we have shown above, and its schematic diagram is shown in Figure 6.

The current and voltage signals at the output of the solar power plant inverter and the three-phase section of the traditional power grid are measured in the block for measuring data on the solar power plant and the power grid.

These measured signals are calculated in the block for processing the measurement results of the main electrical quantities of the power grid based on the equations given above [6-7].

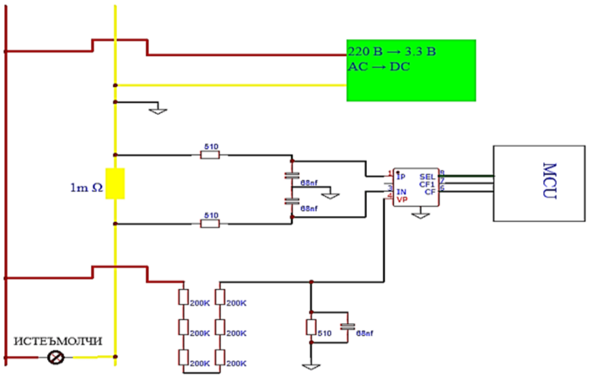


**Fig. 6. Structural diagram of the measuring connection block**

A control and control algorithm for the balance of active and reactive power was developed for the Arduino Uno selected for the three-phase active and reactive power control and management device. The control and control algorithm for the balance of active and reactive power is presented in Figure 4.

In order to compensate for the reactive power required by the power supply system network, the following additional reactive power amounts were determined for the minimum and maximum consumption modes and proposed for practical use [8]:

$$Q_{qop}^{min} = P_{o'rn} * (tg\varphi + tg\varphi_{tar}) = 43 * (3{,}792 + 0{,}38) = 179{,}392\ VAR$$

$$Q_{qop}^{max} = P_{o'rn} * (tg\varphi + tg\varphi_{tar}) = 43 * (0{,}505 + 0{,}38) = 38{,}055\ VAR$$

## 3. Conclusion

1. Ensuring the quality of electricity generated by solar power plants is one of the important tasks when transmitting electricity to the power supply system.

2. A solar power plant with a capacity of 80 kW installed in the educational laboratory building of the Bukhara Engineering and Technological Institute was taken as the object of research. By installing a measurement and control system created to monitor and control the reactive power consumption at the output of the solar power plant inverter, the reactive power to be compensated was calculated and reactive power sources were installed. According to the results of the research, it was justified that the reactive power consumption to be compensated with an installed average active power of the power supply system is 43 kW is as follows:

$$tg\varphi = tg\varphi(arccos\varphi) = tg\varphi(\arccos 0{,}255) = 0{,}3792$$

$$Q_{qop} = P_{o'rn} * tg\varphi = 43 * 3{,}792 = 16{,}31\ kVAR$$

3. The requirements for the power supply system indicate that consumers of electricity must be provided with high-quality active and reactive power in sufficient quantities. The results of the research have shown that one of the main factors affecting the quality indicators of active and reactive power of electricity is the automatic adjustment and compensation of reactive power in the power supply system based on the measurement and control system, since reactive power is an indicator of the efficiency of electricity.

4. The effective use of measurement and control systems in controlling the balance of active and reactive power in the power supply system with solar power plants allows you to control the minimum and maximum consumption of reactive power in real time, improve the quality of electricity, and also provides monitoring and digitization of the indicators of generated and consumed electricity.

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# CONTEXT / MUNDARIJA