**Analysis and Investigation of Contactless Switching Devices for Automatic Reactive Power Regulation  
to Improve Electric Energy Quality**

Eldar Usmanov1, Maxsud Bobojanov1, Raxmatillo Karimov1,3, Almukhan Nuraliyev1,2, Oksana Popkova4, Dilmurod Xushvaktov1,a), Nigora Tairova1, Mokhira Idriskhodjaeva1

1 Tashkent state technical university named after Islam Karimov, Tashkent, Uzbekistan

2 "Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" NRU, Tashkent, Uzbekistan

3 Almalyk State Technical Institute, Almalyk, Uzbekistan

4 Kazan State Power Engineering University, Kazan, Russian Federation

*a) Corresponding author:* [*dilmurodxushvaktov5@gmal.com*](mailto:dilmurodxushvaktov5@gmal.com)

**Abstract.** This article analyzes the role and significance of contactless switching devices in the automatic regulation of reactive power for improving the quality of electrical energy and reducing energy consumption. Methods for improving energy efficiency in industrial enterprises through proper reactive power compensation, capacitor bank sections, and automatic regulators have also been analyzed. At the same time, the article examines schemes for stabilizing voltage and reactive loads in power supply systems through step-by-step phase- and current-based reactive power regulation, using thyristor contactless relays and ARKON-type automatic regulators. In addition, methods for automatic regulation and compensation of reactive power in unbalanced and variable-load electrical networks have been studied. The proposed contactless switching devices ensure high reliability, rapid response, and long-term stability in the power supply system.

**INTRODUCTION**

Effective management of reactive power plays an important role in ensuring the quality of electric energy and reducing energy consumption in industrial enterprises. Various compensating devices are used in the power supply system to balance and optimize reactive power. The type, capacity, and installation location of these devices should be selected with minimal costs [1-5].

In the case of incomplete or partial compensation of reactive power, the electrical network is loaded with inductive reactive current. This, in turn, negatively affects the efficiency of transformers and electrical equipment. Therefore, the issue of efficient reactive power management and its automatic regulation is considered relevant.

Reactive power compensation is also carried out through synchronous compensator generators and synchronous electric motors (mainly at power plants). In the case of compensating devices, capacitor banks are managed in sections, and their connection and disconnection are carried out automatically according to the load schedule. These systems make it possible to maintain stable power and voltage conditions in the electrical network [1-7].

Nowadays, contactless switching devices are widely used. They have several advantages over traditional electromechanical devices in terms of speed, reliability, and resources. Moreover, they can be used for a long time, offer extensive automatic control capabilities, and possess high efficiency. These features are of significant importance for saving electrical energy and effectively distributing power in industrial facilities [1-9].

Based on this, the article examines the analysis of contactless switching devices for automatic reactive power regulation and their application in industrial networks.

**RESEARCH RESULTS**

As noted above, such a control system is used in cases where the voltage regime in the network is mainly determined by the reactive load conditions. In such cases, it is required to regulate reactive power and voltage simultaneously. The voltage at the connection point of compensating devices depends not only on the load supplied from this point, but also on the loads of other consumers at the power supply node, as well as on the measures for regulating voltage at the main substation of the energy system or the enterprise. When adjusting the power of compensating devices, it should be taken into account that if the reactive load remains unchanged, the active power (*KU*) increases with an increase in voltage and decreases with a decrease in voltage [1-5, 10-13].

Fig.1 shows the schematic diagram for controlling the reactive power mode of the capacitor device along the voltage in the busbars of the load node. The elements shown in Fig.1 are described as follows: *а* - Primary connection diagram; *b* - Control scheme; *P, Q* - Active-inductive load; *QF* - Break in the capacitor device circuit; *C*1, *C*2 - Sections of compensating devices; *KV* - Voltage relay; *R*add - Additional resistance; *K* - Contacts; *KT*1, *KT*2 - Time relay; *SB*1, *SB*2 - Students with disabilities; *S* - Control key.



**FIGURE 1.** Automatic reactive power control scheme as a function of voltage: (a) primary connection diagram; (b) control diagram.

A minimal *KV* voltage relay, connected to the load node through busbars or a voltage transformer, is used as a task-giving body. If necessary, the relay *R*add can be connected through an additional resistor. When the voltage in the network drops below the set limit, the *KV* voltage relay operates (releases), and when the relay is pulled in, it closes its separating *KV* contact in the *KT*1 time relay coil circuit. The *KT*1 time relay, with a given holding time (2-3 minutes), closes the *KT*1 contact in the *K* contactor control circuit and automatically connects the *S*2 auxiliary section of the capacitor device to the network [1-5].

The generated reactive power increases, and the voltage in the network also rises. Even when a reactive load is applied, the voltage increases and may exceed the specified limit. The *KV* voltage relay operates (is pulled in) and connects its *KV* contact in the *KT*2 time relay series circuit; by holding for 2-3 minutes, it separates its isolating contact in the *K* contactor series and automatically disconnects the additional section of the compensating devices from the network. Maintaining time is necessary to protect against random short-term increases and decreases in voltage. The *SB*1 and *SB*2 push-button switches allow manual control of the reactive power mode. The selection of manual or automatic mode is carried out through the S control key [1-5, 14-18].

Reactive power can be regulated stepwise using the automatic regulator of ARKON-type capacitor banks. It operates by adjusting either the voltage function or the current according to voltage and the phase shift angle between them. It consists of another control software block that includes several additional elements, depending on the number of alignment stages and the command block (Fig.2) [1-5, 19-20].



**FIGURE 2.** Structural diagram of the ARKON automatic regulator

The command block gives instructions to turn on and off the sections of compensating devices in the software block depending on the amplitude of the input signal. For example, there are three additional options available for logically selecting turning on and off. Sections of compensating devices with a power ratio of 1:2:4 make it possible to obtain a seven-step adjustment [1-5, 21-22].

In voltage-based reactive power regulation, the voltage of the network section being monitored at the command unit input is provided. When it is necessary to take into account the phase shift angle between current and voltage, the load current monitored at the input of the command block is also provided [1-5, 23-24].

*Reactive power compensation along the load current.* If the load changes sharply during the day, it is appropriate to adjust the reactive power (*KU*) according to the function of the consumed current. Step-by-step automatic load adjustment along the load current can be implemented using two *KA*1 and *KA*2 electromagnetic current relays installed at the input of the load node busbars (Fig.3). One of them connects when the load increases, and the other disconnects when the load decreases. The elements shown in Fig.3 are described as follows: *а* - Primary connection diagram; *b* - Control scheme; *P+jQ* - Active-inductive load; *QF* - Breaker in the capacitor device circuit; *C*1, *C*2 - Section of compensating devices; *KА*1, *KА*2 - Current relay; *K* - contactor; *SB*1, *SB*2 - Switched capacitors. The powers at which the sections of the compensating devices are switched on are proportioned as follows: 1:2:(1+2):4:(1+4):(2+4):(1+2+4) [1-5, 25-27].



**FIGURE 3.** Automatic reactive power control scheme based on load current: (a) primary connection diagram; (b) control diagram.

The settings of the DC relays are adjusted for different values of the currents. *For example*, the *KA*1 current relay is set to 5 amperes, and the *KA*2 current relay is set to 3 amperes. When the load is small, an additional section is disconnected, even though the *KA*2 current relay operates and its connecting contacts are closed, the connecting contacts of the *K* contactor remain open. When the load increases and the current reaches 5 amperes, the *KA*1 current relay operates. The *KL* intermediate relay, through its contact, closes the *K* contactor and the second section of the capacitor compensation devices [1-5, 28-29].

When the current decreases, first the *KA*1 relay operates and its contacts open, but the *KL* relay does not open because the *KA*2 and K contacts remain closed. When the current drops below 3 amperes, the *KA*2 current relay breaks the *KL* relay circuit and disconnects the *K* contactor. The compensation devices allow the circuit to be adjusted manually [1-5, 30-31].

*Reactive power compensation according to changes in reactive load.* The load in an electrical network is constantly changing, and primarily its reactive component varies. To control the operation of a capacitor device based on the reactive load, the *B2201*-type automatic reactive power regulator is used (Fig.4). The elements shown in Fig.4 are described as follows: *P+jQ* Active-inductive load; *C*1, *C*2 - Sections of the capacitor battery; *QF* - change; *K* - contactor contact; *TА* - current transformer; *I, U* - Current from the current transformer and voltage from the line [1-5, 32-35].

The compensator has two input terminals. The first receives the voltage of one phase, while the second receives the line voltage of the other two phases. The reactive power to be controlled is calculated using the following expression:

(1)

Here, is the reactive power of the phase; is the single-phase current; is the line voltage of the remaining two phases; *φ* is the phase displacement angle between the current and the line voltage.

It is provided with an indicator of a non-sensitive zone system to prevent the frequent alternating connection of the stages of the capacitor device regulator [1-5, 36-37]. The operation time of the regulator depends on the difference between the actual reactive power and the specified consumption. The greater this difference, the faster the regulator operates, and the more quickly the reactive power mode is maintained.



**FIGURE 4.** Scheme for controlling the reactive power mode using the *B2201* regulator

A reactive power regulator can be used in electrical devices with non-symmetric loads; it first balances the load and then provides reactive power compensation in the electrical device. The reactive power regulator has three pairs of inputs, each of which receives the line current of the corresponding phase and the line voltage of the remaining two phases. It allows monitoring the variation of reactive power in each phase of a non-symmetrical loaded electric network. The capacitor device has two single-phase and up to six three-phase sections in each phase. The regulator includes a block for selecting the phase with the highest reactive power load, to which a single-phase section of the capacitor device is connected. If the load symmetry is not restored, a second single-phase section is connected. When the reactive load decreases, the sections are disconnected. In the three-phase network, as the reactive load increases, the three-phase sections of the capacitor device are connected sequentially. When the reactive load decreases, they are automatically disconnected [1-5, 38-40].

**CONTACTLESS SWITCHING DEVICES IN THE POWER SUPPLY SYSTEM**

Nowadays, powerful contactless semiconductor devices are widely used, significantly expanding the application of semiconductor technology in several fields of electrical engineering and enabling the achievement of new results in terms of quality [1-5].

The achievements of power semiconductor electronics have made it possible to master a new class of electrotechnical devices - contactless switching semiconductor equipment. The equipment presented, together with traditional electromechanical devices, enables solving numerous problems of supplying industrial facilities with electrical energy. Contactless switching, synchronous control, high speed, and practically unlimited service life open fundamentally new possibilities in power supply [1-5, 41-42].

At the same time, it serves to solve the problem of limiting the rapid current in high-voltage contactless switching semi-conducting apparatus, in particular: creating 6-10 kV reactorless circuits with short-circuit capacity up to 1500 MVA; limiting surge fault currents; reducing thermal and dynamic impacts on the elements of the power supply system; simplifying the connection of electrical receivers subjected to sharply variable surge loads; ensuring the autonomous start-up of large electric machines and transferring synchronous motors to a backup source without de-energizing their fields; controlling reactive elements of the network such as reactors and capacitor banks; rationally utilizing transformer capacity at 0.4, 6, and 10 kV; and improving the quality of electricity in distribution networks, as well as reducing capital costs in building power supply systems [1-5, 43-44].

*1. Contactless thyristor voltage relays.* Switching devices with a known number of contacts, assembled on the basis of semiconductor elements, are well known. However, in this article, we examine the simple and reliable circuit of a thyristor contactless relay developed at the 'Energy-Saving Technologies' Research Laboratory of the Tashkent State Technical University, Department of Electric Power Supply. Thyristor semiconductor devices have two stable states (on and off). These features provide wide possibilities in creating switching devices, allowing for turning on and off, as well as reconnecting variable current [1-5, 45-46].

When a control signal is received in an alternating current (AC) thyristor switch, the thyristors turn on automatically when the voltage polarity at their anode changes, that is, during each half-cycle of the supply voltage. In direct current (DC) circuits, special firing circuits are required to turn off the thyristors [1-5, 47].

Let us pay attention to the general basic rules for thyristors.

To reliably maintain a locked state for a long period, the correct (anode) voltage on the thyristors should be as follows:

(2)

Here, is the maximum direct voltage, which ensures that the device can remain in the open state for a long time (as specified in the manuals).

After a short-term triggering signal is applied, if the forward (anode) current is greater than the holding current , the thyristor remains in the conducting state. Thus, the condition for maintaining the thyristor in the on state is as follows:

(3)

The value of the holding current limits the maximum resistance of the anode load, allowing the thyristor to be in the open state, that is:

Here, - The nominal voltage of the supply source.

To trigger the thyristors, the correct current should be briefly reduced to a small value, that is, the following condition must be met:

(4)

According to expression (4), the value in the breakdown can be set to zero by briefly interrupting the anode circuit [1-5, 48-49].

*2. Voltage relay in a single thyristor.* We consider a circuit in which the thyristor is connected to the network in series through an active resistance, while the control circuit receives current from the network through an *R* active resistance and a *VD* diode (Fig.5,a). The elements shown in Fig.5 are described as follows: *а* - single-line diagram; *b* - voltage graph across the load , i.e., the thyristor conducts a full half-wave of the source voltage [1-5, 50-51].



**FIGURE 5.** Series connection of a thyristor to the power supply through an active resistance:

(a) single-line diagram; (b) voltage waveform across the load *Rnom*

In this circuit, the firing angle of the thyristor depends on the amplitude of the control signal. If the input voltage is gradually increased, the thyristor will turn on with a jump at a firing angle of =900 when the input voltage reaches a certain amplitude value (as shown in Fig.5,b - this phenomenon is called the trigger effect). Any further increase in the input voltage causes a decrease in the firing angle α to zero, providing stable operation. The magnitude of the voltage at which the thyristor jumps on depends on the values of the parameters *R* and [1-5].

To reduce ripple under the nominal load , we consider the circuit in which a capacitor 𝐶 is connected in parallel with the load (Fig.6,a). The elements shown in Fig.6 are described as follows: (a) single-line diagram; (b) voltage waveform across the capacitance *C.*

We carry out a theoretical analysis of the circuit under the influence of an external sinusoidal voltage. Various methods for analyzing such circuits are known; in this article, the circuit under consideration is analyzed using a numerical solution of the circuit state equation [1-5, 52-53].

In this case, it is necessary to determine an approximate solution of the equation over a certain interval.

(5)

Let us assume that the supply voltage varies according to a sinusoidal law and that the thyristor has ideal characteristics. As is known, up to the time , the thyristor remains in the blocking (off) state, and the voltage across the capacitor 𝐶 is equal to zero. At the moment , the thyristor switches on abruptly, and voltage is applied to the capacitor 𝐶 [1-5].

Here, 𝑡2 is the moment of time when the current flowing through the thyristor becomes equal to zero.



**FIGURE 6.** Connecting the capacitance *C* in parallel to the network:

a – single-line diagram; b – voltage graph across the capacitance *C*.

We write the expressions of the current flowing through the thyristor.

(6)

Here, .

At , the current becomes zero, that is:

At time 𝑡2, the voltage across the capacitor 𝐶 becomes equal to the source voltage, that is . The *VS* thyristor is in the conducting (on) state; therefore, the capacitor is discharged through the resistance 𝑅nom. To determine the law of variation of the voltage across the capacitor, it is necessary to solve the following state equation of the circuit [1-5]:

(7)

Using the integration step *h*, we determine the value of for various points from 𝑡1 to 𝑡2:

(8)

Fig.6,b shows the voltage across the capacitance obtained from the numerical solution of equation (7).

3. *Alternating current voltage relay*. We will examine the circuit of an AC voltage relay with a VS thyristor connected diagonally to a bridge of diodes *VD*1-*VD*4 on the side of the rectified current (Fig.7). The AC voltage source is connected in series with the diode bridge and the load [1-5].

|  |  |
| --- | --- |
|  |  |
| **FIGURE 7.** Diagram of a variable current relay | **FIGURE 8.** The waveforms of the control current and voltage in the load |

In the load circuit, current flows only when the diode bridge is connected in series with a diagonally oriented shorted thyristor. The diode bridge rectifies the alternating voltage and provides a half-sine positive voltage to the anode and the control electrode of the thyristor during each half-cycle of the network. If the signal at the thyristor's control electrode is insufficient, the thyristor remains off, and therefore no current flows through the load. If the control signal at the gate is sufficient, the thyristor will turn on at the beginning of the positive half-cycle and remain in the conducting state throughout the entire half-cycle of the alternating voltage. When the thyristor is on, both half-cycles of the alternating voltage pass through the load. The half-cycle of the voltage (according to the source circuit, the positive upper terminal) passes through the following circuit: *VD*1 diode, *VS* thyristor, *VD*4 diode, and load; during the second half-wave (the positive lower half according to the source circuit diagram), the current flows along the following path: load - *VD*3 diode - *VS* thyristor - *VD*2 diode (in Fig.10, in both cases, the current path is shown continuously and with dashed arrows) [1-5, 25-30].

The simplest method of controlling the thyristor state is to transmit a portion of the anode current required to supply the control current through an additional resistance 𝑅add selected appropriately for the control electrode. In the circuit under consideration, this method of controlling the thyristor state is applied. Thus, the additional resistance 𝑅add in the control circuit provides the current necessary for triggering. The thyristor’s turn-on occurs within a few microseconds [1-5, 35-38].

When the network voltage 𝑈1 is lower than the supply voltage, the control signal is not sufficient to turn on the thyristor. In this case, the thyristor turns off at the end of the next half-cycle of the network, when the anode voltage decreases to zero, and the load is disconnected from the power source. In this circuit, the thyristor turns off within one half-cycle after receiving the control signal [1-5, 45-65].

However, the disadvantage of this relay is the non-sinusoidal nature of the current and voltage in the load. The turn-on angle of the thyristor depends on the magnitude of the additional resistance, and similarly, the moment the relay operates is also explained by the magnitude of the additional resistance. Fig.8 shows the forms of the control impulses for the thyristor and the shape of the voltage curve in the load.

*4. Voltages in the load of a voltage relay whose characteristic curve is sinusoidal.* It is known that by changing the turn-on moment of the thyristor, it is possible to influence the shape of the current waveform in the load. If the initial phase shift *φ* between the start of the positive half-cycle of the anode voltage and the beginning of the forward current is zero, then the shape of the load current waveform will be sinusoidal. Therefore, to achieve a sinusoidal shape of the voltage and current waveforms in the load, it is necessary to aim for *φ=*0 [1-5].

Above, the circuit of a thyristor power relay that provides a non-sinusoidal voltage curve was considered, which can represent a quarter of a sinusoidal period. For visible devices, this is not considered the nominal operating mode. To ensure the sinusoidal shape of the current and voltage curves in the load, it is necessary to use the property of the thyristor that switches on with a jump when the thyristor current passes through zero.

Fig.9 shows the schematic diagram of a contactless voltage relay whose current and voltage curves in the load have a sinusoidal shape.



**FIGURE 9.** A contactless voltage relay with sinusoidal voltage and current in the load

This relay consists of two parts: I - a sensitive part that responds to changes in the supply voltage magnitude (made from low-power elements), and II - an actuating part that performs the function of the load commutator, made from power elements. The relay consists of four resistors *R*1, *R*2, *R*3, and *R*add, a low-power thyristor *VS*1, a capacitor *C*, a normally open contact *VU* of the intermediate relay, a high-power thyristor *VS*2, and a bridge with high-power diodes *VD*1-*VD*4. In this case, the power thyristor *VS*2 is connected to the diagonal of the power diode bridge. This relay operates using the trigger connection of the low-power *VS*1 thyristor. At a certain value of the input voltage, the signal passing through the *R*add, *R*1, and *VD* resistors is sufficient to turn on the low-power *VS*1 thyristor. The thyristor fires, allowing a constant current to flow through its circuit, which activates the *VU* optorelay’s light-emitting diode. This closes its normally open contact and shunts the *R*add resistor, thereby reducing the voltage drop across the *R*add, *R*1, and *VD* circuits. At the same time, it charges the *C* capacitor, from whose terminals a control signal is supplied to the *VS*2 power thyristor [1-5].

Thus, a constant control positive signal, which has a rectangular shape, is applied to the control electrode of the *VS*2 thyristor, which causes the *VS*2 thyristor to remain continuously on. Since the *VS*2 power thyristor is connected to the diagonal of the power diode bridge, a variable current flows through the *Z*load load that corresponds to the current of the supply source. The operating voltage of the relay is increased by adjusting the *R*1 resistor. It should be noted that the power consumed by the sensitive part is related to the power of the elements of the executive part and does not exceed 10 watts.

The advantages of this relay are as follows [1-5]:

- Commutation of high-power loads is carried out using low-power elements, which reduces the overall weight and size of the relay, while ensuring that the current and voltage curves in the load have a sinusoidal shape;

- It allows the commutation of the load without using high-contact intermediate relays.

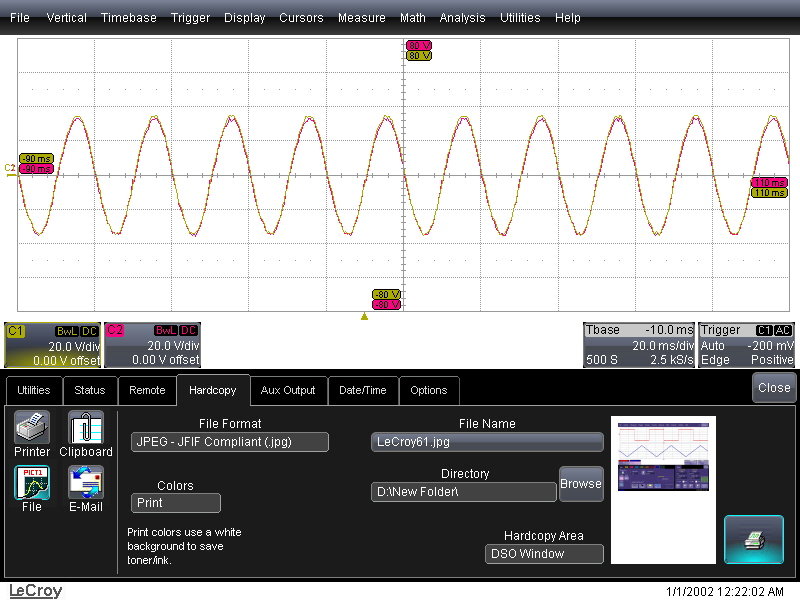
**EXPERIMENTAL RESEARCH**

At the Scientific Research Laboratory of the Department of 'Electric Power Supply' of Tashkent State Technical University named after Islam Karimov, experimental work was carried out using a LeCroy WaveRunner 64 Xi-A oscilloscope, and all experimental results were recorded based on the amplitude values of the voltage. The WaveRunner 64 Xi-A oscilloscope is a high-precision measuring instrument created by LeCroy, a leading American company in the production of digital oscilloscopes.

The results of the experimental research conducted within the framework of the scientific article showed that the time-delay optoelectronic contactless voltage relay used in the capacitor bank control system switches the capacitor bank clamps in a contactless manner with a 0.32-second delay at an input voltage of 18 V.

Moreover, based on the objectives and tasks defined in the article, a time-delay optoelectronic non-contact voltage relay was developed. Using it, a new electrical circuit was proposed for the capacitor bank control system, designed for non-contact switching of its clamps. As a result, an energy-efficient technology was implemented, achieving a reduction in energy and resource consumption. In this regard, it can be concluded that the experimental model of the proposed non-contact switching control device for capacitor banks fully meets the requirements for localization of electrical equipment and contributes to the improvement of electrical energy quality indicators [1-5].

Fig.10 shows the experimental oscilloscope waveform of the optoelectronic contactless voltage relay obtained using the LeCroy WaveRunner 64 Xi-A, which reflects the time variation of the source voltage and the output voltages of the device during contactless commutation in the capacitor bank control system.



**FIGURE 10.** Oscillogram of the variations of the output voltages of the source and the contactless switching device

**CONCLUSION**

Based on the results of the conducted research, the following conclusions were drawn regarding the article on “Analysis and Investigation of Contactless Switching Devices for Automatic Reactive Power Regulation to Improve Electric Energy Quality”:

1. *Regarding the scientific significance of reactive power compensation*: It has been established that proper compensation of reactive power in the electrical supply systems of industrial enterprises can improve the quality of electrical energy, increase efficiency, and reduce losses. The possibility of automatic adjustment and control of reactive power using compensating devices has also been analyzed.

2. *Regarding the advantages of automatic regulation*: it is justified that contactless switching devices and automatic regulators (using devices such as ARKON and B2201) provide practical assistance in quickly and accurately controlling reactive power under various operating modes, thereby preventing its overcompensation and the occurrence of high voltage in the network.

3. *Regarding step-by-step adjustment and sectionalization*: It was proposed that the capacitor banks be divided into sections and automatically connected or disconnected step by step according to the reactive power demand. This, in turn, provides the basis for effectively managing load conditions and phase imbalances in the network.

4. *Regarding non-contact switching*: The use of capacitor banks control systems based on non-contact switching devices for automatic reactive power compensation is justified by the fact that these devices, which control direct current, are distinguished by their speed, reliability, and long service life. It has also been studied that they reduce the harmful effects of short-circuit currents and overloads in the network.

5. *Regarding practical applications*: The effectiveness of implementing automatic reactive power compensation systems in networks with unbalanced and dynamic loads has been justified. It has been studied that these devices play an important role in improving the quality of electrical energy in the power supply system, saving energy, and ensuring the continuity of supply.

6. *In terms of scientific and practical significance*: the methods and circuits developed based on contactless switching automatic adjustment devices provide the basis for optimal reactive power management in the power supply system, reducing losses and increasing the efficiency of electrical equipment.

**REFERENCES**

1. M.Sadullaev, E.Usmanov, R.Karimov, D.Xushvaktov, D.Xalmanov, Y.Shoyimov, D.Khimmataliev. *Mathematical Models and Calculation of Elements of Developed Schemes of Contactless Devices*. AIP Conference Proceedings, 3331(1), **040043**, (2025), <https://doi.org/10.1063/5.0305748>

2. M.Sadullaev, E.Usmanov, R.Karimov, D.Xushvaktov, N.Tairova, A.Yusubaliev. *Development of Contactless Device Schemes for Automatic Control of the Power of a Capacitor Battery*. AIP Conference Proceedings, 3331(1), **040042**, (2025), <https://doi.org/10.1063/5.0305879>

3. M.Sadullaev, E.Usmanov, R.Karimov, D.Xushvaktov, N.Tairova, A.Yusubaliev. *Review of Literature Sources and Internet Materials on Contactless Devices for Reactive Power Compensation*. AIP Conference Proceedings, 3331(1), **040041**, (2025), <https://doi.org/10.1063/5.0305878>

4. M.Sadullaev, M.Bobojanov, R.Karimov, D.Xushvaktov, Y.Shoyimov, H.Achilov. *Experimental Studies of Contactless Devices for Controlling the Power of Capacitor Batteries*. AIP Conference Proceedings, 3331(1), **040044**, (2025), <https://doi.org/10.1063/5.0307195>

5. E.Usmanov, M.Bobojanov, R.Karimov, D.Xalmanov, N.Tairova, S.Torayev. *Contactless Switching Devices Using Nonlinear Circuits*. AIP Conference Proceedings, 3331(1), **040031**, (2025), <https://doi.org/10.1063/5.0305744>

6. E.Yuldashev, M.Yuldasheva, A.Togayev, J.Abdullayev, R.Karimov. *Energy efficiency research of conveyor transport*. AIP Conference Proceedings, 3331(1), **040030**, (2025), <https://doi.org/10.1063/5.0305742>

7. A.Nuraliyev, I.Jalolov, M.Peysenov, A.Adxamov, S.Rismukhamedov, R.Karimov. *Improving and Increasing the Efficiency of the Industrial Gas Waste Cleaning Electrical Filter Device*. AIP Conference Proceedings, 3331(1), **040040**, (2025), <https://doi.org/10.1063/5.0305751>

8. K.Abidov, A.Alimov, M.Gafurova. *Transients in Devices of Control Systems With Excitation Winding*. AIP Conference Proceedings, 3331(1), **040033**, (2025), <https://doi.org/10.1063/5.0305756>

9. O.Ishnazarov, N.Khamudkhanova, K.Kholbutayeva, K.Abidov. *Energy Efficiency Optimization in Irrigation Pump Installations*. AIP Conference Proceedings, 3331(1), **040036**, (2025), <https://doi.org/10.1063/5.0305844>

10. K.Abidov, E.Abduraimov, M.Gafurova. *Possibility of Applying Methods of Analysis and Synthesis of Linear Electrical Circuits to Some Nonlinear Circuits*. AIP Conference Proceedings, 3331(1), **040034**, (2025), <https://doi.org/10.1063/5.0305757>

11. A.Alimov, K.Abidov, E.Abduraimov, F.Akbarov, H.Muminov. *Generalized Model of Nonlinear Inductance and its.* AIP Conference *Parameters*, 3331(1), **040035**, (2025), <https://doi.org/10.1063/5.0305883>

12. F.Akbarov, R.Kabulov, A.Alimov, E.Abduraimov, D.Nasirova. *Dependence of Output Parameters of Photovoltaic Module Based on CIGS Solar Cells on External Temperatures*. AIP Conference Parameters, 3331(1), **040046**, (2025), <https://doi.org/10.1063/5.0305885>

13. K.Abidov, A.Alimov, N.Khamudkhanova, M.Gafurova. *Determination of the Permissible Number of Pumping Units Supplied From the Transformer of the Amu-Zang-I Substation, Selection of the Power of Static Capacitors*. AIP Conference Proceedings, 3331(1), **040029**, (2025), <https://doi.org/10.1063/5.0305754>

14. E.Abduraimov, M.Peysenov, N.Tairova. *Development of Contactless Device for Maintaining the Rated Voltage of Power Supply Systems*. AIP Conference Proceedings, 2552, **040012**, (2022). <https://doi.org/10.1063/5.0116235>

15. E.Abduraimov. *Automatic control of reactive power compensation using a solid state voltage relays*. Journal of Physics Conference Series, 2373(7), **072009**, (2022). DOI 10.1088/1742-6596/2373/7/072009

16. E.Abduraimov, D.Khalmanov. *Invention of a contactless voltage relay with an adjustable reset ratio*. Journal of Physics Conference Series, 2373(7), **072010**, (2022). DOI 10.1088/1742-6596/2373/7/072010

17. E.Abduraimov, D.Khalmanov, B.Nurmatov, M.Peysenov, N.Toirova. *Analysis of dynamic circuits of contactless switching devices*. Journal of Physics Conference Series, 2094(2), **022072**, (2021). DOI 10.1088/1742-6596/2094/2/022072

18. Y.Adilov, A.Nuraliyev, M.Abdullayev, S.Matkarimov. *Dynamic Performance Model of a Hybrid Power System*. AIP Conference Proceedings, 3331(1), **040038**, (2025). <https://doi.org/10.1063/5.0305909>

19. Y.Adilov, M.Khabibullaev. *Application of fiber-optic measuring current transformer in control and relay protection systems of belt conveyor drives*. IOP Conference Series Earth and Environmental Science, 614(1), **012022**, (2020), doi:10.1088/1755-1315/614/1/012022

20. R.Yusupaliyev, N.Musashayxova, A.Kuchkarov. Methods of Purification of Polluted Water from Ammonia Compounds at Nitrogen Fertilizer Plants. E3S Web of Conferences, 563, **03085**, (2024). <https://doi.org/10.1051/e3sconf/202456303085>

21. M.Azimova, N.Kurbanova, D.Rakhmatov. Large-scale environmental benefits of biogas technology. AIP Conference Proceedings, 3152(1), **060007**, (2024), <https://doi.org/10.1063/5.0218937>

22. M.Jalilov, M.Azimova, A.Jalilova. On a new technology of preparation of hot drinking water. Energetika Proceedings of Cis Higher Education Institutions and Power Engineering Associations, **60(5)**, (2017), pp.484-492. <https://doi.org/10.21122/1029-7448-2017-60-5-484-492>

23. R.Yusupaliev, N.Kurbanova, M.Azimova, N.Musashaikhova, A.Kuchkarov. Establishing a Water-chemical Regime and Increasing the Efficiency of Combustion of a Mixture of Fuel Oil and Gas in a DE 25-14 GM Boiler: A Case Study of the Kokand Distillery. AIP Conference Proceedings, 2552, **030026**, (2022). <https://doi.org/10.1063/5.0130471>

24. P.M.Matyakubova, P.R.Ismatullaev, N.I.Avezova, M.M.Makhmudzhonov. *Block Diagram of APCS of Installations for Wet-Heat Processing of Grain Products*. Journal of Engineering Physics and Thermophysics, 96(6), (2023), pp.1652-1657. DOI: 10.1007/s10891-023-02835-5

25. R.Yusupaliev, B.Yunusov, M.Azimova. The composition of natural waters of some source rivers of the republic of Uzbekistan, used in the thermal power engineering and the results of the experimental researches at preliminary and ion exchange treatment of water. E3S Web of Conferences, 139, **01083**, (2019), <https://doi.org/10.1051/e3sconf/201913901083>

26. S.Amirov, A.Sulliev, U.Mukhtorov. *Resonance sensors of motion parameters*. AIP Conference Proceedings, 3256(1), 050028, (2025). <https://doi.org/10.1063/5.0267548>

27. K.Turdibekov, A.Sulliev, O.Iskandarova, J.Boboqulov. *Experimental and statistical methods for studying the modes of electric power systems under conditions of uncertainty*. E3S Web of Conferences, 452, **04002**, (2023), <https://doi.org/10.1051/e3sconf/202345204002>

28. S.Amirov, A.Sulliev, S.Sharapov. *Study on differential transformer displacement sensors*. E3S Web of Conferences, 434, **02011**, (2023), <https://doi.org/10.1051/e3sconf/202343402011>

29. S.Amirov, A.Sulliev, K.Turdibekov. *Investigation of biparametric resonance sensors with distributed parameters*. E3S Web of Conferences, 377, **01002**, (2023), <https://doi.org/10.1051/e3sconf/202337701002>

30. S.Kasimov, A.Sulliev, A.Eshkabilov. *Optimising Pulse Combustion Systems for Enhanced Efficiency and Sustainability in Thermal Power Engineering*. E3S Web of Conferences, 449, **06006**, (2023), <https://doi.org/10.1051/e3sconf/202344906006>

31. M.Yakubov, A.Sulliev, A.Sanbetova. *Modern methods of evaluation of metrological indicators of channels for measurement and processing of diagnostic values of traction power supply*. IOP Conference Series Earth and Environmental Science, 1142(1), **012010**, (2023), doi:10.1088/1755-1315/1142/1/012010

32. K.Turdibekov, A.Sulliev, I.Qurbanov. *Voltage Symmetration in High Speed Transport Power Supply Systems*. AIP Conference Proceedings, 2432, **030084**, (2022), <https://doi.org/10.1063/5.0089958>

33. K.Turdibekov, M.Yakubov, A.Sulliev, A.Sanbetova. *Mathematical Models of Asymmetric Modes in High-Speed Traffic*. Lecture Notes in Networks and Systems, **247**, (2022), pp.1051-1058. DOI:10.1007/978-3-030-80946-1\_95

34. S.K.Shah, L.Safarov, A.Sanbetova, and etc. *Investigation on composite phase change materials for energy-saving buildings*. E3S Web of Conferences, 563, **01003**, (2024), <https://doi.org/10.1051/e3sconf/202456301003>

35. A.Sanbetova, A.Mukhammadiev, A.Rakhmatov, Z.Beknazarova. *Study on cultivation of environmentally friendly seed potatoes based on electrical technology*. E3S Web of Conferences, 377, **03001**, (2023), <https://doi.org/10.1051/e3sconf/202337703001>

36. J.Safarov, A.Khujakulov, Sh.Sultanova, U.Khujakulov. S.Verma. *Research on energy efficient kinetics of drying raw material*. E3S Web of Conferences, 216, **01093**, (2020). <https://doi.org/10.1051/e3sconf/202021601093>

37. J.Safarov, Sh.Sultanova, G.Dadayev, Sh.Zulponov. *Influence of the structure of coolant flows on the temperature profile by phases in a water heating dryer*. IOP Conf. Series: Materials Science and Engineering, 1029(1), **012019**, (2021). doi:10.1088/1757-899X/1029/1/012019

38. Sh.Sultanova, A.Artikov, Z.Masharipova, A.Tarawade, J.Safarov. *Results of experiments conducted in a helio water heating convective drying plant*. IOP Conf. Series: Earth and Environmental Science, 868(1), **012045**, (2021). doi:10.1088/1755-1315/868/1/012045

39. Sh.Sultanova, J.Safarov, A.Usenov, D.Samandarov, T.Azimov. *Ultrasonic extraction and determination of flavonoids*. AIP Conference Proceedings, 2507, **050005**, (2023). <https://doi.org/10.1063/5.0110524>

40. Dj.Saparov, S.Sultonova, E.Guven, D.Samandarov, A.Rakhimov. *Theoretical study of characteristics and mathematical model of convective drying of foods*. E3S Web of Conferences, 461, **01057**, (2023). <https://doi.org/10.1051/e3sconf/202346101057>

41. Sh.Sultanova, J.Safarov, A.Usenov, T.Raxmanova. *Definitions of useful energy and temperature at the outlet of solar collectors*. E3S Web of Conferences, 216, **01094**, (2020). <https://doi.org/10.1051/e3sconf/202021601094>

42. G.Boboyev, N.Nurmukhamedov, O.Zaripov. *Improvement of Means of Measuring the Main Parameters of Electricity*. AIP Conference Proceedings, 3331(1), **040039**, (2025). <https://doi.org/10.1063/5.0305861>

43. A.Tarawade, D.Samandarov, T.Azimov, Sh.Sultanova, J.Safarov. *Theoretical and experimental study of the drying process of mulberry fruits by infrared radiation*. IOP Conf. Series: Earth and Environmental Science, 1112, **012098**, (2022). doi:10.1088/1755-1315/1112/1/012098

44. M.Mirsadov, B.Fayzullayev, I.Abdullabekov, A.Kupriyanova, D.Kurbanbayeva, U.Boqijonov. *The mutual influence of electromagnetic and mechanical processes in dynamic modes of inertial vibrating electric drives*. IOP Conference Series Materials Science and Engineering, 862(6), **062081**, (2020). doi:10.1088/1757-899X/862/6/062081

45. I.Abdullabekov, M.Mirsaidov, F.Tuychiev, R.Dusmatov. *Frequency converter – asynchronous motor – pump pressure piping system mechanical specifications*. AIP Conference Proceedings, 3152, **040007** (2024). <https://doi.org/10.1063/5.0218880>

46. I.Abdullabekov, M.Mirsaidov, Sh.Umarov, M.Tulyaganov, S.Oripov. *Optimizing energy efficiency in water pumping stations: A case study of the Chilonzor water distribution facility*. AIP Conference Proceedings, 3331, **030107**, (2025). <https://doi.org/10.1063/5.0305780>

47. M.Bobojanov, F.Tuychiev, N.Rashidov, A.Haqberdiyev, I.Abdullabekov. *Dynamic simulation of a three-phase induction motor using Matlab Simulink*. AIP Conference Proceedings, 3331, **040012**, (2025). <https://doi.org/10.1063/5.0305750>

48. M.Tulyaganov, Sh.Umarov, I.Abdullabekov, Sh.Adilova. *Optimization of modes of an asynchronous electric drive taken into account thermal transient processes*. AIP Conference Proceedings, 3331, **030084**, (2025). <https://doi.org/10.1063/5.0305786>

49. Sh.Umarov, Kh.Sapaev, I.Abdullabekov. *The Implicit Formulas of Numerical Integration Digital Models of Nonlinear Transformers*. AIP Conference Proceedings, 3331, **030105**, (2025), <https://doi.org/10.1063/5.0305793>

50. G.Boboyev, N.Inatova. *The Importance of Implementing Energy Management Systems for Manufacturing Enterprises in the Republic of Uzbekistan*. AIP Conference Proceedings, 3331(1), **04004**7, (2025). <https://doi.org/10.1063/5.0305865>

51. Sh.Zulpanov, D.Samandarov, G.Dadayev, S.Sultonova, J.Safarov. *Research of the influence of mulberry silkworm cocoon structure on drying kinetics*. IOP Conf. Series: Earth and Environmental Science, 1076, **012059**, (2022). doi:10.1088/1755-1315/1076/1/012059

52. A.T.Rakhmanov, G.G.Boboev. *Developing the Technology for Manufacturing Ohmic Contacts and Sealing Semiconductor Temperature Converters*. Journal of Engineering Physics and Thermophysics, 98(3), (2025), pp.841-845. <https://doi.org/10.1007/s10891-025-03163-6>

53. N.I.Avezova, P.R.Ismatullayev, P.M.Matyakubova, G.G Boboyev. *Multifunctional Heat Converter Moisture Content of Liquid Materials*. International Conference on Information Science and Communications Technologies Applications Trends and Opportunities Icisct 2019, 9012041, (2019). DOI: 10.1109/ICISCT47635.2019.9012041

54. Sh.Kuchkanov, M.Adilov, B.Abduraxmanov, A.Kamardin, S.Maksimov, S.Nimatov, and Kh.Ashurov. *Thermovoltaic effect in Si/Si epitaxial film structures treated by neon ions*. AIP Conference Proceedings, **3331,** **040045**, (2025). <https://doi.org/10.1063/5.0305887>

55. M.Atajonov, Q.Mamarasulov, O.Zaripov, S.Nimatov, U.Bo’riyev. *Study of Solar Photoelectric Plant in Matlab (Simulink) Package*. AIP Conference Proceedings, 3244(1), **060001**, (2024). <https://doi.org/10.1063/5.0241783>

56. S.J.Nimatov, D.S.Rumi*. Investigation of the dose dependence of the amorphization of a Si(111) surface bombarded with low-energy Na+ ions*. Journal of Surface Investigation, 8(2), (2014), pp.404-407. DOI: 10.1134/S1027451014020396

57. S.J.Nimatov, D.S.Rumi. *Submonolayer films on a Si(111) surface under low-energy ion bombardment*. Bulletin of the Russian Academy of Sciences Physics, 78(6), (2014), pp.531-534. DOI: 10.3103/S1062873814060215

58. S.J.Nimatov, I.A.Garafutdinova, B.G Atabaev, D.S.Rumi. *Low energy electron diffraction investigation of the defect formation in the electron-beam stimulated solid phase epitaxy of Ge on Si(111)*. Surface Investigation X Ray Synchrotron and Neutron Techniques, 16(5), (2001), pp.775-779.

59. D.S.Rumi, S.Zh.Nimatov, I.A.Garafutdinova, B.G.Atabaev, S.V.Shevelev. *The investigation of the structure and anisotropy of emission characteristics of (111) zone of a cylindrical tungsten single crystal*. Surface Investigation X Ray Synchrotron and Neutron Techniques, 16(6), (2001), pp.941-948.

60. A.Udaratin, A.Alyunov, A.Krutikov, L.R.Mukhametova, O.O.Zaripov, I.V.Bochkarev. *Efficiency study of the reactive shunt compensation device in power lines*. E3S Web of Conferences, 124, **02020**, (2019), <https://doi.org/10.1051/e3sconf/201912402020>

61. O.Khakimov, P.M.Matyakubova, G.A.Gaziev, R.R.Jabbarov. *Evaluation of ultrasound reflection coefficient measurement result and its uncertainty by the method of linearization.* Proceedings of the International Conference on Advanced Optoelectronics and Lasers Caol, 9019476, (2019), pp.721-723, DOI: 10.1109/CAOL46282.2019.9019476

62. S.M.Turabdzhanov, J.M.Tangirov, P.M.Matyakubova, N.S.Amirkhulov, S.S.Khabibullaev. *Methods of providing metrological supply when pumping water into wells in oil fields.* AIP Conference Proceedings, 3045(1), **030073**, (2024), <https://doi.org/10.1063/5.0197355>

63. P.Matyakubova, P.Ismatullaev, J.Shamuratov. *Development of vibration viscometer for industry purpose and experience of its practical*. E3S Web of Conferences, 365, **05012**, (2023), <https://doi.org/10.1051/e3sconf/202336505012>

64. N.I.Avezova, P.M.Matyakubova, P.R.Ismatullaev, S.A.Kodirova. *Design and Practical Application of Thermal Humidity Converters for Liquid Materials.* Journal of Engineering Physics and Thermophysics, 96(1), (2023), pp.206-214. DOI: 10.1007/s10891-023-02677-1

65. N.I.Avezova, P.R.Ismatullaev, P.M.Matyakubova, Sh.A.Kodirova. *Mathematical model of a heat transducer with a cylindrical heat pipeline and with a focused heat source.* Journal of Physics Conference Series, 1686(1), **012063**, (2020), DOI: 10.1088/1742-6596/1686/1/012063