**Research on Contactless Switching of Control Systems for Reactive Power Compensation Devices in Power Supply  
to Improve Power Quality**

Eldar Usmanov1, Raxmatillo Karimov1,4, Almukhan Nuraliyev1,2, Absaid Sulliev3, Oksana Popkova5, 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 Tashkent State Transport University, Tashkent, Uzbekistan

4 Almalyk State Technical Institute, Almalyk, Uzbekistan

5 Kazan State Power Engineering University, Kazan, Russian Federation

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

**Abstract.** This article analyzes modern methods of automatic reactive power compensation in power supply system networks with the aim of reducing power quality and energy losses. The type, capacity, and installation location of compensating devices for optimal balancing of reactive power at industrial enterprises have been determined. Non-contact switching auxiliary devices and the automatic control system, phase coordination of reactive power, and control in accordance with daily or load schedules have been analyzed. At the same time, the effectiveness of step-by-step control of capacitor banks using contactless switching devices is substantiated to improve the power factor in the electrical network, prevent overloads, and reduce temperature rise. The article scientifically substantiates the structural schemes of automatic control and contactless switching methods, and also demonstrates the possibilities of their practical application.

**INTRODUCTION**

At present, one of the pressing tasks is to increase the efficiency and reliability of the power supply system, as well as to improve the quality of electrical energy. The quality indicators of electrical energy are primarily influenced by factors such as voltage stability in the network, symmetric and asymmetric loads, higher harmonics, and reactive power. In particular, reactive power can disrupt the power balance in the network and increase losses. Therefore, the issue of effective reactive power compensation in modern power supply systems is relevant [1-5].

The main purpose of reactive power compensation is to reduce network losses, increase the efficiency of power supply, and extend the service life of electrical equipment. In the power supply system, the amount of reactive power and its transmission vary for different reasons. For example, the type of load in the network, their phase characteristics, and the inductive nature of existing transformers and lines lead to changes in reactive currents. If reactive power compensation is insufficient, the network experiences an overload of inductive reactive current. In this case, there is a possibility of an increase in the network voltage reaching its maximum value. Therefore, effective management and compensation of reactive power, as well as optimization of the operation of network devices, are considered one of the important directions [1-6].

Traditionally, capacitor banks and synchronous compensating devices are used to compensate reactive power. Capacitor banks are usually divided into sections, each of which is connected or disconnected according to the reactive power demand. This method allows monitoring the power balance in the network and achieving high efficiency. At the same time, manual control of reactive power limits the operation of the devices used in the system, whereas the use of automated control systems significantly increases efficiency [1-5, 7].

In modern power supply systems, technologies for automatic reactive power control are widely used. These technologies ensure automatic regulation of reactive power based on various parameters, and also optimize reactive power in the network according to the loads through capacitor bank sections or synchronous compensating devices. Automatic control is usually carried out based on daily variations in power, load currents, network voltage, and other electrical parameters. This method provides practical assistance in eliminating undesirable situations such as overcompensation or deficiency of reactive power in the networ [1-5, 8].

Non-contact switching devices are widely used as modern technology in the electric power supply system. They allow reactive power to be controlled automatically, more quickly and efficiently compared to contact-based devices. The use of contactless switching devices is of particular importance in the following areas: rapid interruption and connection of currents in low- and high-voltage alternating current networks, power optimization, stabilization of reactive power in transmission lines and transformers, and improving the efficiency of electrical energy in industrial processes. At the same time, they play an important role in reducing the overload on electrical equipment, preventing emergency situations, and stabilizing the energy system [1-5, 9].

Semiconductor devices with contactless switching effectively serve to monitor various electrical loads and to optimally control reactive power automatically. *For example*, the efficiency of power transmission lines, the heating of electrical equipment, and their uninterrupted operation can be ensured through voltage-regulating devices. Additionally, these technologies are used for automatically connecting and disconnecting capacitor banks by sections, as well as for controlling the startup of synchronous motors and reactive power. As a result, the stability of power in the electrical supply system is maintained, and losses are minimized [1-5, 10].

Nowadays, the development of contactless switching devices and automatic reactive power control systems serves as an important factor in enhancing the competitiveness and reliability of power systems. At the same time, effective management of reactive power in the network allows for saving electrical energy, extending the service life of transformers and power transmission lines, and improving energy efficiency. For this reason, the issue of automatic reactive power compensation in the power supply system and its control with the help of contactless switching devices is considered one of the relevant scientific directions in modern energy engineering [1-5, 11].

Moreover, technologies for automatic reactive power compensation are not limited to maintaining power balance; they are also used to eliminate unbalanced loads in the network, reduce high harmonics, and improve the quality of electrical energy. This is important for ensuring energy efficiency in industrial enterprises, railway and transport networks, and the domestic sector [1-5, 12].

At the same time, automatic compensation of reactive power in the electric power system and its control through contactless switching devices is considered a modern and effective approach to improving power quality, reducing losses, extending the service life of equipment, and increasing efficiency. Moreover, these technologies allow for controlling the reactive power balance in the network, optimizing the phase characteristics of loads, and automating the electricity supply system. Therefore, the research conducted in this article has significant scientific and practical importance for improving the efficiency of the energy system and enhancing the quality of electric power [1-5, 13].

**RESEARCH RESULTS**

In the power supply system of industrial enterprises, the task of selecting the type and capacity of compensating devices, as well as their installation location, should be solved with minimal costs to optimize the reactive power balance. Reducing losses through reactive power compensation while improving the quality of electric energy and increasing the efficiency of electrical devices is considered one of the pressing issues [1-5, 14-15].

If reactive power compensation is not deep and only partial, then the electrical network will be heavily loaded with reactive current of an inductive nature. If reactive power compensation is fully designed for the maximum reactive load mode and the compensating devices are permanently connected, then during periods of a decrease in reactive load, an overcompensation of reactive power is observed. In this case, the reactive power of the compensating devices is delivered to the electrical network, and it is heavily loaded with reactive current of capacitive nature. The voltage in the network may rise and reach unacceptable levels. To prevent such incidents, compensating devices should be equipped with devices that adjust their reactive power [1-7, 16-17].

In electrical devices where synchronous compensators and synchronous electric motors are used to compensate reactive power, the smooth adjustment of reactive power is carried out by changing their excitation current. In compensating devices, reactive power is adjusted step by step. For this purpose, capacitor banks are divided into sections. The number of sections in a capacitor bank is selected based on the reactive power consumption graph. Usually, 3-4 sections are used. When the electric load graphs are noticeably uneven, 5-6 sections may be used.

The reactive power of compensating devices can be adjusted as follows [1-7, 18-19]:

- Signed by the cashier;

- Automatically under the influence of various electrical parameters and non-electrical sensors.

Depending on the selected adjustment parameters, the automation of controlling the compensator device modes is carried out according to the open or closed control scheme (Fig.1). The elements shown in Fig.1 are described as follows: *а* - with a chain of optical effects; *b* - with an open causal chain; *TAA* - The assigning authority; *EB* - Executive body; *OM* - Object of management; *х* - Alignment parameter; *хор* - The base magnitude of the control parameter; *Δх* - The magnitude of change of the control parameter; *u* - The magnitude of the amplifying effect.



**FIGURE 1.** Structural diagram of reactive power mode control:

(a) with an open-loop control circuit; (b) with a closed-loop control circuit.

If the power of devices compensating for the leveling parameter does not change significantly or is not dependent on it, then the control structural scheme can be open (Fig.1,a). The control authority (*TAA*) responds to the input parameter of the setting (*x*), and when it reaches the reference value (*x*TK), it acts on the control object (*OM*) through the executing body (*EB*), thereby influencing the compensating devices (*KD*). The control of compensating devices in this mode is used for one- or two-section capacitor banks operating in the “on-off” mode.

If the adjustment parameter or the combination of adjustment parameters is significantly related to the operating mode of the compensating devices, then the control structural scheme can be as shown in Fig.1,b (*with a closed feedback loop*). When the control parameter (*x*TK), which needs to be taken into account in the process of adjusting the control parameter (*x*) through feedback with the object (*OM*), is designated, it is sent to the controlling authority. Such alignment is used for multi-section capacitor batteries of synchronous motors. To restore the monitored parameter, the control action is applied to the commutating apparatus of the capacitor battery sections or to the automatic aligner of the synchronous motor excitation, which acts as the executive body. Changes in the power of compensating devices lead to changes in the magnitude of the alignment parameter (*Δx*) [1-7, 20-21].

It is advisable to use automatic adjustment of compensating devices to utilize reactive power more efficiently. Automatic adjustment can be carried out as follows [1-7, 22-23]:

- Over a 24-hour period;

- Along the voltage at the load node;

- According to the load;

- According to the magnitude and nature of the reactive power;

- From non-electric sensors.

*The task of adjusting reactive power over a certain period of the day is carried out according to a specific program in accordance with the requirements of production technology*. The adjustment is based on determining the reactive load graph, and if it is stable (Fig.2). The elements shown in Fig.2 are described as follows: *Q*m - Maximum reactive load; *t*1 - The start time of the maximum load; *t*2 - Time of maximum load completion; *-* Excess compensation; - undercompensation.

з

з



**FIGURE 2.** Reactive load graph used for the daily regulation of reactive power

reactive load compensation devices can be fully compensated with a reactive power of . Let us assume that the compensating devices have two sections of equal power. One of the sections is permanently connected, while the second is connected only during the hours of maximum load, from *t*1 to *t*2. In a single-phase automatic adjustment, an EVChS-24 electric timer is used, which allows a single enterprise to control several compensating devices simultaneously, placed at relatively short distances from each other [1-7, 24-25].

In Fig.3, a schematic diagram for correcting reactive power using an EVChS-24 electric meter with one contact and two intermediate relays is shown. The elements shown in Fig.3 are described as follows: *а* - Primary connection diagram; *b* - Control scheme; *P, Q* - Active-inductive load; *QF* - A switch in the capacitor device circuit; *C*1, *C*2 - Sections of compensating devices; *K* - Contactor contacts; *KV*, *KО* - Methods for connecting and disconnecting a contactor; *KL*1, *KL*2 - Intermediate relays; *SB*1, *SB*2 - Button-type actuators; *DW* - Digital watch; *ICCS* - Impulse contact of the clockwork system.



**FIGURE 3.** Automatic control scheme of the second section of the capacitor bank according to the time of day: (a) primary connection diagram; (b) control circuit.

The (*DW*) electronic clock is connected to the synchronization system (*ICCS*) via a pulse contact. When the contact of the (*DW*) electronic clock is activated at time (*t*1) (for example, at 07:00), the (*KL*1) time-delay relay is energized and, by means of its normally open contact, completes the circuit of the (*KV*) switching coil. The (*K*) contactor engages the second section of the (*KU*) contacts. At the same time, the auxiliary contacts (K) in the circuits of the intermediate relays (*KL*1) and (*KL*2) change their state. After the contactor is energized, it becomes latched, and the contactor coil is disconnected from the power supply. Voltage is also taken from the electronic clock winding. After the maximum reactive load (*Q*) is reached, at time (*t*2) the (*DW*) contact is switched on, the intermediate relay (*KL*2) is energized, and by means of its (*KO*) switching contact it energizes the tripping coil. The contactor is disconnected and switches off the second section of the capacitor unit. The auxiliary contacts of the contactor (*K*) also change their state. The circuit provides the possibility of manually connecting and disconnecting the second section of the capacitor unit using the push-button switches (*SB*1) and (*SB*2) [1-7, 26-27].

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

At present, high-power contactless semiconductor apparatus are widely used, and they have significantly expanded the scope of application of semiconductor technology in several fields of electrical engineering, ensuring the achievement of qualitatively new results [1-7, 28-29].

The main application areas of contactless switching devices are as follows [1-7, 30-31]:

1. Rapid current interruptions in low-voltage and high-voltage alternating current networks. In medium-voltage networks, using a contactless switching semi-conductor apparatus as an ultra-fast switch allows for high-speed operation, which, in turn, is compatible with the ability to interrupt the alternating current several times during its normal and emergency reclosure. The application area of contactless switching semiconductor devices as fast switches includes power systems, electrochemical processing of metals, and the oil and mining industries. It is easy to improve the selectivity of protection using a contactless commutating semi-conducting apparatus. In high-voltage networks, it ensures the uninterrupted operation of consumers, prevents disruptions in technological processes, excludes severe accidents in networks, limits short-circuit currents, reduces the reactiveness of networks and supply sources, and protects consumers from unauthorized voltage fluctuations. It also accelerates the action of the automatic voltage regulator (AVR) that connects the backup source, ensures simultaneous connection of all phases, and in 50 Hz frequency networks, allows voltage and phase regulation within no more than 0.01 seconds from the moment of connection [1-7, 32-33].

2. Using the windings of power transformers as reconnectable sections in contactless switching semi-conductor apparatus. These allow for smooth regulation of voltage between switching reactors, resistors bypassing, non-polar reconnecting, and busbars. This increases the efficiency factor, improves the power factor, extends the service life, reduces excessive voltage, and, due to the stability of the supplied voltage, enhances the consumer's operational efficiency and enables rapid operation, which in turn facilitates the elimination of emergency modes. Field of application – a process used for metal electrolysis, rolling mills, electrochemistry, electric traction, and others [34].

3. *Power factor correction.* One of the widespread applications of power factor controllers is controlling the alternating current impedance of electrical networks. Using contactless regulators, it is possible to turn electrical circuits on and off, protect them from short circuits and overloads, and control their heating temperature both manually and automatically. Semiconductor devices with contactless switching operate with a high efficiency coefficient, and it is possible to maintain the operating temperature of the electrical circuit at a specified stability. The use of a contactless power regulator in other fields is considered as a breaker on the alternating current side for automatic contact point welding [1-7, 35-36]:

- Replacing contact control stations with asynchronous short-circuited and linear electric motors for starting, controlling the rotation frequency, electrodynamic braking and reversing, as well as managing the commutation of other three-phase loads. Field of application - machine-tool industry, agriculture, metallurgy, mining, textile industry, and others. Here, strict requirements are imposed on the number of switching devices and their operating conditions;

- Using a contactless switching semiconductor device as a thyristor switch for three-phase welding machines allows increasing the stability of the machines’ operation during the melting stage, eliminating delays at the start of melting, improving the quality of the weld, and increasing the efficiency;

- Limiting voltage with a contactless switching semiconductor device-by restricting the actual voltage value through phase control-allows increasing the service life of active energy consumers;

- Changing and adjusting reactive power allows the automatic maintenance of a given power factor or the rapid compensation of reactive power across the entire required range;

- It limits the idle operation of coupling transformers, automatically switches off the coupling transformers when the coupling circuit is stopped, and allows immediate switching on when there is contact between the coupling sample and the electrode;

- By changing the currents in the direct and reverse sequences, the contactless switching semiconductor device enables rapid polarity reversal during the accelerated charging of accumulator batteries.

*4. Contactless switching of a capacitor bank in voltage function.* Using the above-mentioned voltage relays, it is possible to create contactless automatic switching devices for various consumers. In this article, we will examine the automatic contactless switching of a capacitor battery in relation to the load current and the supply network voltage, considering the initial phase voltages and their shifting functions [1-7, 37-38].

The schematic of the *T*R regulating transformer consists of a sensitive part and an executive part. In turn, the sensitive part consists of two sections: *I* – a contactless relay for maximum voltage without an executive element; *II* – a contactless relay for minimum voltage with its own executive element *III*, and a *VU*3 interrelay with normally closed contacts that coordinates the operation sequence of the contactless relays for minimum and maximum voltage. The executive element, *VD*3-*VD*6, is based on a bridge of power diodes, with a *VS*3 power thyristor connected diagonally. The contactless maximum voltage relay I consists of resistors *R*1series, *R*2, and *R*3, a low-power diode *VD*1, a low-power thyristor *VS*1, and a normally open contact of the relay *VU*1. The contactless minimum voltage relay II consists of four resistors *R*2 series, *R*4, *R*5, and *R*6, a low-power diode *VD*2, a low-power thyristor *VS*2, a normally open contact of the relay *VU*2, and a capacitor *C* [1-7, 39-40].

It should be emphasized that the executive body is consecutively connected to the supply network with a *C*2 capacitor bank.

*The circuit operates as follows*: when the nominal voltage of the supply network is exceeded, a control current flows through the circuit to the *V*S1 thyristor, causing *VS*1 to turn on, and current flows through the circuit, that is, through the *VU*1 and *VU*3 optocoupler LEDs. In this case, the *VU*3 optorelay interrupts its normal closed contact, preventing the control current of the *VS*2 thyristor from passing, and the (*KB*) capacitor battery remains disconnected. At the same time, *VU*1 ortorelay closes its normal open contact and shunts the additional resistor *R*1series, changing the return coefficient of the maximum voltage relay *I* [1-7, 41-42].

When the supply network voltage drops, the control signal amplitude applied to the *VS*1 thyristor is not sufficient to keep the *VS*1 thyristor in the on state, and this thyristor turns off. The *VU*3 relay closes its normally open contact and connects the control circuit () of the *VU*2 thyristor. The *VS*2 thyristor turns on, allowing current to flow through the circuit and charge the *C* capacitor. The *VS*2 thyristor turns on, and the current flows through the dd’ circuit, charging the *C* capacitor. At the same time, the *VU*2 optorelay closes its normally open contact and shunts the *R*4 resistor, which reduces the reset coefficient of the minimal voltage relay. A signal in the form of a constant control current (Fig.4) is supplied from the *C* capacitor clamps to the *VS*3 thyristor, causing it to turn on, thereby connecting the (*KB*) capacitor battery to the network [1-7, 43-44].

This scheme can be used both for compensating reactive power and for reducing phase asymmetry in reactive power or voltage.

In the scheme considered for reactive power compensation in a three-phase network, three sets of voltage relays connected to the secondary windings of three two-winding three-phase matching transformers and the secondary windings of the correspondingly matched transformer are provided [1-7, 45-46].

*5. Contactless switching of capacitor banks as a function of the angle.* If the signal *φ* supplied to the capacitor batteries of the switching device depends on the phase shift of the load current and the initial phases of the supply network voltage, it is considered an effective scheme for switching the capacitor batteries [1-7, 47].

Controlling the capacitor battery in this way allows reducing the number of commutations in order to simplify the setup of the automatic capacitor battery control scheme. Because it allows explaining the operation of the scheme using the device that records the *φ* angle present at the stations and substations [1-7, 48].

Fig.5 shows the single-phase circuit of a secondary voltage source, where the output voltage value depends on the phase shift angle of the load current and the supply network voltage.

|  |  |
| --- | --- |
|  |  |
| **FIGURE 4.** Single-phase diagram of contactless switching of a capacitor battery operating in the voltage function | **FIGURE 5.** Single-phase diagram of the secondary voltage source device |

The device consists of a transformer with two secondary windings (*T*R), two anti-parallel connected thyristors *VS*1 and *VS*2, two diodes *VD*1 and *VD*2, and two resistors *R*1 and *R*2.

To get acquainted with the operation of the device, we first familiarize ourselves with the operation of the transreactor. A transreactor (from the words “transformer” + “reactor” or “transformer reactor”) is a type of device consisting of a transformer with a gapped magnetic core made of non-ferromagnetic material, in which the primary winding of the transreactor is connected in series with the load (similar to a current transformer) [1-7, 49-50].

It has primary and one or several secondary windings installed on a core-type magnetic conductor with slots made of a non-ferromagnetic material (“air-slot” magnetic conductor). Due to such a device, the secondary winding of a transreactor can operate without damage in “no-load” mode and sequentially connected with a load alongside the primary winding, a mode that would be considered exceptional for an electromagnetic current transformer.

The operating principle of a transreactor is based on the law of electromagnetic induction, according to which the secondary current is so small due to the non-magnetic gap that the magnetic flux *F* in the magnetic conductor can be considered to be produced solely by the primary current (the magnetomotive force of the primary winding) [51].

*Advantages*: the ability to convert current and current output proportionally to voltage, the presence of galvanic isolation, reduction of the aperiodic component (this can be used to reduce unbalanced current surges during the connection of transformers in differential protection), and the possibility of operation in 'no-load' mode and under high-resistance loads without damage [1-7, 52].

*Disadvantages*: the relatively low value of the output voltage (due to the presence of slots in the magnetic core, the electromotive force induced in the secondary winding is small), and the increase in the number of higher harmonics in the secondary voltage (the transreactor acts as a differential element that passes high-frequency components) [1-7, 53].

Based on Fig.6, we examine the operation of the single-phase scheme of the secondary voltage source device, where the output voltage value depends on the angle *φ*.

It is known that the magnitude of the voltage obtained with the help of a thyristor depends on the firing angle of the thyristor.



**FIGURE 6.** Curves of the input–output and control voltages of the thyristors: (a) dependence of the turn-on signal on the angle φ1; (b) dependence of the turn-on signal on the angle φ2

As can be seen from Fig.6,a, the angle of the signal at the turn-on of the thyristor is equal to *φ*1, which, as indicated above, corresponds to the phase shift of the load current and the supply voltage initial phases. Thus, the *VS*1 and *VS*2 thyristors turn on at this angle, and an average rectified voltage is observed at the output of the device

When the initial phase displacement angle, load current, and supply network voltage increase to the angle *φ*2, the control signal *U*man is applied to the *VS*1 and *VS*2 thyristors at an angle equal to *φ*2 (Fig.6,b). The output voltage of the device, *U*ave.2, will correspond to the average corrected voltage. Comparing these voltages shows that as the firing angle of the thyristors increases, the output voltage decreases, i.e., *U*ave.1 > *U*ave.2 when *φ*1 < *φ*2 [1-7, 53-60].

Thus, the device under consideration allows obtaining a voltage that depends on the load current, the initial phase displacement values, and the supply network voltage.

**EXPERIMENTAL RESEARCH**

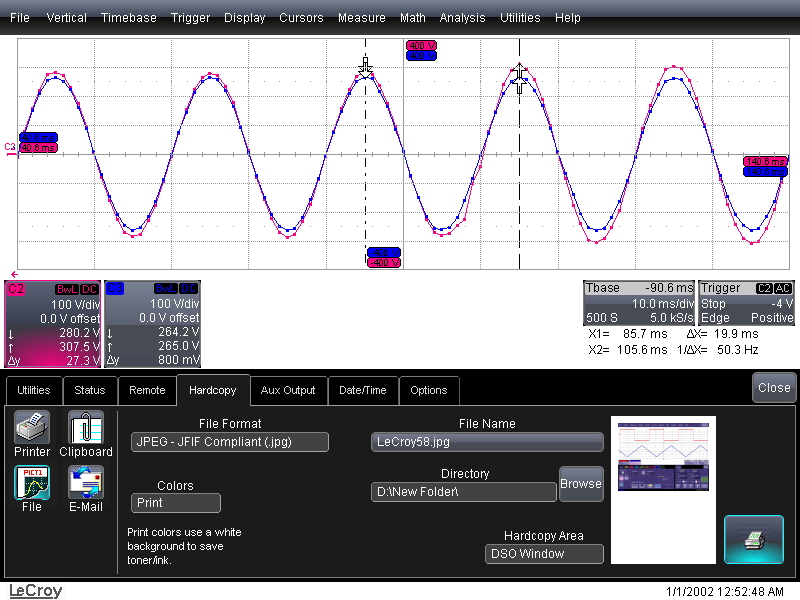
Experiments were conducted in the research laboratory of the Department of Electrical Power Supply at Tashkent State Technical University named after Islam Karimov, using a LeCroy WaveRunner 64 Xi-A oscilloscope, and all experimental results were obtained in terms of voltage amplitude.

The WaveRunner 64 Xi-A 64 MXi-A type oscilloscope was developed by LeCroy, a leading American manufacturer of digital oscilloscopes.

The experimental results of the scientific article show that in the control system of the capacitor banks, the time-delay optoelectronic contactless voltage relay switches the capacitor bank clamps contactlessly with a delay time of 0.32 seconds at a voltage of 18 V.

Accordingly, based on the objectives and tasks outlined in the article, a time-delay optoelectronic contactless voltage relay was developed, and using it, a new scheme for contactless switching of capacitor bank clamps in the control system was implemented, introducing an energy-saving technology and achieving a reduction in energy and resource consumption. Thus, it can be said without exaggeration that the experimental version of the proposed capacitor battery control system with a contactless switching device fully meets the requirements for localization of electrical equipment and contributes to the improvement of electric energy quality [1-7].

Fig.7 shows the experimental oscillogram of the optoelectronic contactless voltage relay obtained using a LeCroy WaveRunner 64 Xi-A oscilloscope, illustrating the changes in the source voltage and the device’s output voltages during the contactless switching of the capacitor battery control system.



**FIGURE 7.** Oscillogram of the output voltage variations of a source-free and contactless switching device

**CONCLUSION**

Based on the results of the conducted research, the following conclusions were drawn regarding the article on “Research on Contactless Switching of Control Systems for Reactive Power Compensation Devices in Power Supply to Improve Power Quality”:

- The article discusses the importance and methods of automatic reactive power control for improving the quality of electrical energy;

- The existing and new types of contactless switching devices, as well as their role in reactive power regulation, were studied;

- As a result of the conducted studies, new technological solutions and devices for automatic reactive power control were analyzed;

- The operating principle and performance efficiency of contactless switching devices were studied, which is important for future scientific research and practical developments;

- It has been established that the technologies for compensating reactive power in electrical networks can be further improved, and their overall efficiency can be increased. This, in turn, makes it possible to enhance the quality of electric energy and to manage the operation of the power system consistently and reliably.

**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. 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>

10. 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>

11. 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>

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. 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>

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. 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>

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.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>

29. 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>

30. 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>

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, S.Samatov, A.Sanbetova. *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>