Theoretical research and development optoelectronic communication devices

E Kh Abduraimov, D Kh Khalmanov, B A Nurmatov, S A Dusmukhamedova and N E Khamidova
Tashkent State Technical University named after Islam Karimov, University St. 2A, Tashkent, 100095, Uzbekistan

E-mail: ilider1987@yandex.com

Abstract. Nowadays, with the wide automation of production processes and the introduction of automatic control systems, the requirements for the creation of contactless electric devices have substantially increased. The development of power semiconductor electronics allows the solution of complex technical problems aimed at improving the efficiency of electrical devices. The leading role in this direction is given to optoelectronic devices and thyristor devices, which provide contactless switching processes and galvanic isolation, and have improved transient and frequency characteristics. The article deals with the creation of compact, reliable, high-speed optoelectronic contactless voltage relays with an extended service life, combining a sensitive system and a powerful actuator having a sinusoidal shape of the voltage curve at the load. Theoretical, experimental studies and the principle of operation of an optoelectronic contactless voltage relay with time delay are given.

Currently, with the wide automation of production processes and the introduction of automatic control systems, the requirements for the creation of contactless electric devices have substantially increased, and the care of these devices during operation should be minimized.

Achievements of power semiconductor electronics made it possible to use more compact, durable, high-speed analogs in solving complex technical problems aimed at increasing the efficiency of electrical devices, instead of transformers, reactors, relays, electromechanical switching devices, rheostats, autotransformers, and reactive power controllers. The leading role in this direction is given to optoelectronic devices and thyristor devices, which provide contactless switching processes and galvanic isolation, and have improved transient and frequency characteristics.

Advantages of contactless devices are their speed, response time, greater selectivity in protection, increased service life and reliability, technological design, lack of accurate assembly requirements, an almost unlimited switching frequency, the ability to control output parameters according to a given law, the possibility of using similar devices in networks of different voltages by replacing thyristors with thyristors of another class, permissible operation in the most difficult climatic conditions, simply and design in an explosive performance. [1-5].

One of the circuit solutions for thyristor contactless devices is a controlled resistive circuit, shown in figure 1.
Current in this circuit only flows when the thyristor is open. This is possible with certain values of the source voltage and thyristor control current. For this circuit, when the input voltage is greater than the thyristor turn-on voltage and the control current is greater than the minimum thyristor control current, a thyristor with a turn-on angle of 90° is turned on, i.e. this phenomenon can be called the trigger effect of the resistive circuit.

This picture shows the shapes of the voltage and load current curves, where at a sinusoidal voltage of the source and when opening the thyristor with an angle $\alpha = \pi / 2$, the resistance voltage will change abruptly to the amplitude value of the alternating voltage. Therefore, for an angle of 90°, the average and effective current values in the circuit are determined as follows:

$$i = \frac{U_{\text{em}} \max}{R} \sin \omega t = I_m \sin \omega t, \text{ with } \alpha < \omega t < \pi$$

$$I_{cp} = \frac{1}{2\pi} \int_{\alpha}^{\pi} I_m \sin \omega t \, d\omega t = \frac{1}{2\pi} I_m (1 + \cos \alpha)$$

in our case for $\alpha = 90^\circ$,

$$I_{cp} = \frac{I_m}{2\pi}$$

Effective current value:

$$I = I_m \frac{1}{\sqrt{2\pi}} \left[ \frac{1}{2} (\pi - \alpha) + \frac{1}{4} \sin 2\alpha \right]$$

for $\alpha = 90^\circ$ we get,

$$I = \frac{I_m}{\sqrt{2}}$$

Let us conduct a theoretical analysis of the circuit shown in figure 2, where the resistance, diode and capacitance are connected in series, and the resistance is connected in parallel to the capacitance.

To analyze this circuit, we propose to use a numerical solution of the equation of state of the circuit [6,7].

Supply voltage varies according to the following law:
Consider the transients during periods of open state of the diode VD, the voltage across the capacitance is described by the following equation:

\[ U_C = U_m \frac{R_2}{R_1 + R_2} \left(1 - e^{-\frac{R_1 + R_2}{R_1 R_2 C} t}\right) \]  

Here \( U_m \) is the rated mains voltage.

Currently, various methods of analysis of such chains are widely used. We propose to use for this circuit a numerical solution of the equations of state of the circuit by the Euler method. In this case, it is necessary to determine an approximate solution of the equation

\[ \frac{dy}{dt} = f(t, y) \]  

We take the characteristic of the diode as ideal and assume that \( u = U_m \sin \omega t \). Then, from the moment \( t=0 \) to \( t_1 \), the diode is open, and the circuit equation has the following form:

\[ U_m \sin \omega t = R_1 \left(C \frac{dU_C}{dt} + \frac{U_C}{R_2}\right) + U_C \]  

or

\[ \frac{dU_C}{dt} = \frac{1}{R_1 C} \left[U_m \sin \omega t - U_C \left(1 + \frac{R_1}{R_2}\right)\right] \]  

Where \( U_C \) is the voltage at the capacitance.

The solution of equation (4) according to Euler is as follows:

\[ U_{C(k+1)} = U_{Ck} + f(U_{Ck}, t_k) \cdot h \]  

Here

\[ f(U_{Ck}, t_k) = \frac{1}{R_1 C} \left[U_m \sin \omega t - U_C \left(1 + \frac{R_1}{R_2}\right)\right] \]

\( k=0, 1, 2 \ldots \ h – \) integration step.

From the moment \( t=0 \) to \( t=t_1 \), the voltage across the capacitors is determined by (8) with a zero initial condition. From the moment \( t=t_1 \), the diode goes into a closed state and the voltage at the capacitors is determined as:

\[ C \frac{dU_C}{dt} = -\frac{U_C}{R_2} \]  

\[ u = U_m \sin(\omega t + \varphi) \]  

(4)
From the moment \( t = t_3 \), the diode again goes into the open state and the voltage across the capacitors is again described by dependence (8), only with the initial conditions corresponding to the time \( t = t_2 \) [8].

In Figure 3 a) shows a circuit diagram of an optoelectronic non-contact voltage relay with a sinusoidal voltage at the load and figure 3 b) the experimental characteristics of the input and output of this voltage relay, based on the thyristor-resistive circuit and optocouple considered above.

**Figure 3.** a) Time-delayed optoelectronic contactless voltage relay  b) «Input-output» characteristic.

The non-contact voltage relay contains a diode bridge 1 connected to a power source in series with a diode 2, a resistor 3 and a capacitance 4, the first thyristor 5 is included in its diagonal. The relay is equipped with a capacitor 6, a thyristor 7, four resistors 8,9,10,11 thyristor optocouplers 12, 13 and a diode 14. The control electrode of the first thyristor 5 is connected through the first resistor 10 to the capacitor plate 6 and the cathode of the optocoupler thyristor 12. The second capacitor plate 6 is connected to the cathodes of the first thyristor 5, the cathode of the second thyristor 7 and the first terminal my mains supply. The anode of the second thyristor 7 is connected to the cathode of the diode of the optocoupler 12, the anode of which is connected to the output of the second resistor 8. The second output of the resistor 8 is connected to the anode of the thyristor of the optocouple 12 and the first output of the third resistor 9 and is connected to the second terminal of the supply network. The second terminal of the third resistor 9 is connected to the anode of the diode 14, the cathode of which is connected to the control electrode of the second thyristor 7. The first terminal of the resistor 11 is connected to the first plate of the capacitor 4, and the second terminal is connected to the anode of the diode of the optocoupler 13, the cathode of which is connected to the second plate of the capacitor 4.

Optoelectronic contactless voltage relay with time delay operates as follows. Upon reaching a certain value of the input voltage, the unlocking signal on the control electrode will be sufficient to unlock the thyristor 7, with an opening angle of 90° and closes the diode circuit of the optocoupler 12 into the network through the resistor 8. This leads to the flow of current through the diode part of the optocoupler 12 and thereby opens the thyristor part of the optocoupler 12, and a capacitor 6 is connected to the network. Since a direct current signal is supplied to the control electrode of the thyristor 5, from the capacitor 6 through the resistor 10, it remains constantly open, and the circuit diode 11, resistor 3 capacitor 4 will be connected to a source of sinusoidal voltage. The response time of the thyristor of the optocoupler 13 is regulated by selecting the parameters of the resistor 3 and 11, and the shutdown time by selecting the parameter of the resistor 11.

This contactless voltage relay has been tested in the laboratory of the energy department of Tashkent State Technical University. In this case, thyristors of type KU 202 I, KU 201I were used as thyristors 5, 7, D 226 B as diodes, 2,8,9,10,11 active resistances, respectively 3 kOhm, 15 kOhm, 3 resistors, 8 kOhm, 16 kOhm, 1.2 kOhm as the capacitance 5 - a capacitor with a capacity of 1 μF, the
thyristor optocouple AOU103V, the diode bridge KTs 402E were used as optocouplers. Experimental studies have shown that the relay turns on at a voltage of 100 V with a time delay of 2-3 seconds.

Based on the foregoing, the following conclusions can be made:

The analysis of the dynamic circuit shown in figure 2, where the active resistance, diode and capacitance are connected in series and the active resistances are connected in parallel to the capacitance, can be carried out by numerically solving the equations of state of the circuit.

The proposed method allows a qualitative analysis of steady-state modes and transients of circuits with various variations of the parameters.

Using the circuit shown in figure 1 and figure 2, an optoelectronic contactless, high-speed and compact voltage relay with a time delay was developed, an experimental characteristic is given figure 3 a, b), the response, which can be changed by changing the parameters of the active resistance (3) or changing capacitance parameters (4).

References
[1] Abduraimov E 2016 J.Bulletin of Tashkent State Technical University B 3 73-8
[2] Rakhmonov I and Reymov K 2019 J. ENERGETIKA B 62(6) 528-35
[3] Abduraimov E and Khalmanov D 2018 J.Problems of energy and resource conservation B 3 145-9
[4] Rakhmonov I, Reymov K and Shayumova Z 2019 E3S Web of Conferences B 139 010
[5] Taslimov A and Rakhmonov I 2019 J. Phys.: Conf. Ser. 1399 055046
[6] Abduraimov E and Khalmanov D 2019 J. Theoretical analysis of semiconductor circuits B 3 60-3
[7] Usmanov E and Abduraimov 2016 J. Problems of energy and resource conservation B 3 84-7
[8] Usmanov E, Abduraimov E and Karimov R 2015 J. Problems of energy and resource conservation B 12 32-4