Analysis of dynamic circuits of contactless switching devices

E Kh Abduraimov¹, D Kh Khalmanov, B A Nurmatov, M B Peysenov and N J Toirova
Tashkent State Technical University named after Islam Karimov, Department of "Electrical Engineering" of the Electrical Energy Faculty, Tashkent, 2A, University St., 100095, Uzbekistan

¹E-mail: abduraimoverkin69@gmail.com

Abstract. The main content of the study is the analysis of theoretical and virtual-experimental studies and methods of analysis of transients in semiconductor nonlinear dynamic circuits of contactless switching devices, presents transient graphs constructed using a virtual computer model. In addition, presents solutions of differential equations of the state of such circuits by the numerical Euler method.

1. Introduction
In connection with the development of reliable high-quality contactless switching devices on the basis of semiconductor elements, nonlinear dynamic circuits are widely used in various fields of automation, electronics, computer technology and power supply systems. When creating powerful contactless semiconductors of switching devices, non-autonomous nonlinear dynamic circuits consisting of nonlinear resistive semiconductors can be used in the control circuit of power thyristors [1-4].

2. Analysis of diode dynamic circuits
In the control circuit of thyristor switching devices, various dynamic circuits can be used as a pulse generator of the control signal, connected both in series and in parallel. Currently, various methods of analysing such circuits are widely used. Nonlinear dynamic circuits consisting of a diode, active resistance and capacitance are shown in figure 1 [2-3].

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure1.png}
\caption{The investigated scheme.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure2.png}
\caption{The form of voltage across the capacitance.}
\end{figure}
For this circuit we propose to use Euler’s numerical method to solve the equation of state of the circuit. For this, it is necessary to determine on some interval an approximate solution of the equation.

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

(1)

We take the diode characteristics 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:

\[
U_m \sin \omega t = R_i + u_c
\]

Considering, that \( i = C \frac{du_c}{dt} \) we have:

\[
\frac{du_c}{dt} = \frac{U_m}{RC} \sin \omega t - \frac{u_c}{RC}
\]  

(2)

where \( u_c \) – capacitance voltages.

The solution of equation (2) according to Euler looks as follows:

\[
u_{c_{k+1}} = u_{c_k} + f(u_{c_k}, t_k) \ast h
\]  

(3)

here

\[
f(u_{c_k}, t_k) = \frac{U_m}{RC} \sin \omega t_k - \frac{u_{c_k}}{RC}
\]

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

Until the moment \( t = t_1 \), the voltage across the capacitance is determined by (3), taking into account the initial conditions. From the moment \( t = t_1 \), the diode opens and until the moment \( t_2 \) the voltage across the capacitance remains at the voltage level for the moment \( t_1 \), from the moment \( t_2 \) the diode opens again and the voltage across the capacitance is again described by the dependence (2 and 3) with a different initial condition.

In figure 1b shows the curve of the voltage change across the capacitance, obtained by solving equation (3) on a computer. It is assumed that \( U_m = 100 \text{ V}, R = 300 \text{ Ohm}, C = 200 \mu\text{F} \).

In figure 3 shows the dependence of the change in the voltage across the capacitor on time for different values of the active resistance \( R \).

As can be seen from this figure, a change in the value of the active resistance \( R \) leads to a change in the charging time of the capacitor. Thus, by changing the parameters of the circuit, it is possible to regulate the time of the steady-state voltage across the capacitor and its value.

Figure 3. The dependence of the change in voltage across the capacitor on time for different values of the active resistance \( R \).

Figure 4. Curves obtained virtually experimentally.

Figure 4 shows the same curves obtained by virtual - experimental research on the basis of the system of circuit simulation "MS-01". Comparison of figure 3 and figure 4 shows their insignificant difference, which is explained by the accepted assumptions in the theoretical analysis.
Figure 5 shows a circuit consisting of a diode and a parallel connected resistor and capacitance. Consider a numerical method for solving the equation of state of the chain for this case. Considering $u_{in} = U_m \sin \omega t$ and taking the characteristic of the diode to be ideal, it can be assumed that from the moment $t = 0$ to $t_1$, the diode is open, and the voltage across the capacitance changes according to a sinusoidal law. From the moment $t = t_1$, the diode opens and the capacitor begins to discharge to the resistor. To determine the law of change in the voltage across the capacitance, it is necessary to solve the following equation of state of the circuit:

$$\frac{du_c}{dt} = -\frac{u_c}{RC}.$$  

Let us determine the value of $u_c$ for various points from $t_1$ to $t_2$ by setting the integration step $h$.

$$u_{cn} = u_{cn-1} + \left(-\frac{u_{cn-1}}{RC}\right) \cdot h \quad (4)$$

For intervals, $0 \leq t \leq t_1$, $t_2 \leq t \leq t_3$, $u_c = U_m \sin \omega t$.

The value $t_2$ is determined by the following ratio $\omega t_2 = \pi - \arctg(\omega RC)$.

![Figure 5. The investigated scheme.](image1)

![Figure 6. The form of voltage across the capacitance.](image2)

In figure 5 a graph of the voltage across the capacitance obtained by solving equation (4) on a computer for the parameters of the circuit $C = 6.25 \, \mu F$ is presented; $R = 100$ ohms. Thus, the analysis of dynamic circuits can be successfully carried out by numerically solving the equations of state on a computer.

2.1. Analysis of thyristor dynamic circuits

We can also carry out a theoretical analysis of a non-autonomous dynamic circuit consisting of a thyristor connected in series with a parallel circuit containing a capacitance and an active resistance, which is influenced by an external sinusoidal voltage (figure 7).

![Figure 7. The investigated scheme.](image3)

![Figure 8. The form of voltage across the capacitance.](image4)

Let us assume that the voltage of the power supply changes according to the sinusoidal law and the thyristor has an ideal characteristic. It is obvious that until the moment $t = t_1$ the thyristor will be closed,
the voltage across the capacitance \( C \) will be equal to zero. At the moment \( t = t_1 \), the thyristor abruptly opens and a voltage will be applied to the capacitance \( u = U_m \sin \omega t \quad (t_1 \leq t \leq t_2) \)

from time \( t_2 \), the current through the thyristor takes a zero value. Write the expression of the current flowing through the thyristor

\[
i = i_R + i_C = \frac{U_m}{R_i} \sin \omega t + U_m \omega C \cos \omega t = U_m \sqrt{\omega^2 C^2 + 1/R^2} \sin(\omega t + \beta_i),
\]

where \( \beta_i = -\arctg \omega CR_i \).

Current will turn to zero at \( \omega t + \beta_i = 0 \) i.e. at \( t_2 = \pi - \arctg \omega CR_i \)

At time \( t_2 \), the voltage across the capacitor \( C \) will be equal to the voltage of the source, i.e. \( u_C = U_m \sin \omega t_2 \) and the thyristor VT is closed, therefore, the capacitor is discharged to the resistance \( R_n \).

To determine the law of voltage change across the capacitance, it is necessary to solve the following equation of state of the circuit:

\[
\frac{du_C}{dt} = -\frac{u_C}{RC}
\]

Let us determine the value of \( u_C \) for various points from \( t_2 \) to \( t_3 \) by setting the integration step \( h \).

\[
u_{Cn} = u_{Cn-1} + \left(-\frac{u_{Cn-1}}{RC}\right) h.
\]

Figure 8 the graph of the voltage across the capacitance, obtained by numerical solution of equations (7), is presented.

2.2. Analysis of thyristor power circuits

The need to increase labour productivity and the steady complication of technical processes determines the widespread use of power semiconductor devices at industrial enterprises, which allow for a smooth voltage sweep across loads, which helps to limit shock currents when the load is turned on and reduce the negative impact on the network; limit short-circuit currents, reduce over voltages during the switching period.

Let us consider the operating mode of a circuit consisting of a series-connected thyristor, an inductive coil and an active resistance (figure 9).

![Figure 9. The investigated scheme.](image)

The equation for this chain is as follows:

\[
u_{in} = u_{mup} + L \frac{di}{dt} + Ri
\]
We take the characteristic of the thyristor ideal for the open state of the thyristor, while equation (8) will take the form:

\[
\begin{align*}
\frac{u_{in}}{L} & = \frac{di}{dt} + Ri = U_m \sin(\omega t + \Psi) \\
\text{for } \Psi = \pi/2 & \\
\frac{L}{di} + Ri & = U_m \cos \omega t \\
\text{Or} & \\
\frac{di}{dt} & = \frac{U_m \cos \omega t}{L} - \frac{R}{L} i
\end{align*}
\]

(9)

(10)

For different values of \(t\), setting the integration step \(h\), we have:

\[
i_n = i_{n-1} + \left(\frac{U_m \cos \omega t_{n-1}}{L} - \frac{R}{L} i_{n-1}\right) h
\]

(11)

Figure 10 shows the curves of voltage and current at the terminals of elements L and R and current, constructed by solving equation (11) by the numerical method. As can be seen from this figure, the current gradually increases and the moment of termination of the current relative ratio of the transition of the phase voltage through the zero value is delayed. It should be noted that the shape of the current curve depends on the ratio of the parameters of the circuit L and R.

3. Conclusion

Thus, the analysis of nonlinear semiconductor dynamic circuits can be successfully carried out by numerically solving the equations of state of the circuit using a computer. Theoretical and virtual-experimental studies have shown that the proposed technique allows for a qualitative analysis of steady-state modes and transient processes in semiconductor circuits with various variations of parameters.

References

[1] Matkhanov P N 1977 Basis analysis of electric chains (M: the Higher school) 271
[2] Abduraimov E Kh, Rasulov A N, Khalmanov D Kh and Khamidova N E 2020 A program for calculating the dynamic processes of nonlinear electrical circuits with the improved Euler method Copyright certificate No. DGU 07731 Registered in the State Register of Programs for Electronic Computing Machines of the Republic of Uzbekistan in Tashkent
[3] Abduraimov E Kh and Khalmanov D Kh 2020 Development of contactless solid state voltage relay Rudenko International Conference «Methodological problems in reliability study of large energy systems” E3S Web of Conferences
[4] Abduraimov Erkin 2020 Research of the trigger effect in diode-thyristor circuits of contactless relay devices Rudenko International Conference “Methodological problems in reliability study of large energy systems” E3S Web of Conferences
[5] Abduraimov E Kh, Khalmanov D Kh, Nurmatov B A, Dusmukhamedova S A and Khamidova N E 2020 Theoretical research and development optoelectronic communication devices Journal of Physics: (JPCS) for further publishing Conf.Series 1515(02) 2055
[6] Abduraimov E Kh, Khalmanov D Kh and Dusmukhamedova S A 2020 Analysis of Semiconductor Circuits International journal of Advanced Science and Technology 29(11) 1655-859
[7] Usmanov E G, Abduraimov E Kh, Halmanov D Kh and Karimov R Ch 2020 Optoelectronic reloading with high-speed (Republic of Uzbekistan) Official Bulletin of the Intellectual Property Agency (Tashkent) 1 112
[8] Sapaev X B, Abduraimov E Kh and Umarov Sh B 2020 Numerical calculation of electronic circuits with nonlinear elements J Technical science and innovation TSTU (Tashkent) 4