E3S Web of Conferences **384**, 01052 (2023)
RSES 2022
https://doi.org/10.1051/e3sconf/202338401052

Application of numerical and graphical methods of analysis in nonlinear resistive circuits of electronic devices

Erkin Abduraimov [1*], *Baxtiyor* Nurmatov [1]

[1]Tashkent State Technical University named after Islam Karimov, 100095, Uzbekistan, Tashkent, University St. 2A

Abstract. The article discusses the research issues and methods of analysis of semiconductor circuits used in electronic circuits of contactless switching devices, provides analytical, graphic and numerical methods for the analysis of nonlinear semiconductor resistive circuits. The approximations of the Volt-Ampere characteristics (VACh) of semiconductor elements and the solution of the differential equations of state of electrical circuits by a numerical method using a computer are given. Diode, thyristor semiconductor nonlinear resistive circuits with active and inductive loads are considered. In the analysis of steady-state modes and transient processes, numerical methods for solving differential equations of states by the Euler method were used.

1 Introduction

In connection with the widespread automation of production processes, the introduction of automatic control systems, the requirements for reliability, speed and durability of electrical devices and apparatus have significantly increased. These requirements are largely met by devices based on the use of properties and phenomena inherent in nonlinear resistive circuits. Therefore, the theory of nonlinear resistive circuits and systems is of great importance in the creation of highly efficient electrical devices. Currently, semiconductor circuits are usually used as power switches for switching, regulating and converting devices [1-4]. To improve existing and create new highly efficient and energy-saving technical devices, it is necessary to theoretically and experimentally investigate semiconductor resistive circuits. On the basis of theoretical analyzes and experimental studies of nonlinear resistive circuits, it has been established that in order to ensure high-quality power supply to consumers, it is necessary to use such circuits as power contactless switching devices, current and voltage regulators. Circuits based on nonlinear resistive circuits allow switching power loads at the best dynamic modes, namely, when a sinusoidal current passes through zero, which improves the transient process mode [5-8].

2 Analysis of diode resistive circuits

An uncontrolled semiconductor diode, as an element of an electrical circuit, is a nonlinear asymmetric active resistance, its value depends on the polarity and the magnitude of the potential applied to it. Quite often, when considering the operation of rectifier circuits, in which, as a rule, diodes are used, they use the term "ideal diode", this concept means some kind of asymmetric resistance, the value of which in the positive direction of the current is zero, and in the opposite direction is equal to infinity [6-8]. The VACh of a diode can be obtained experimentally or from reference data for a given semiconductor element. In the analytical study of circuits with valves, an important issue is the choice of the approximating function of the nonlinear element [10]. The VACh of the forward current of a semiconductor diode can be described by a function of the form $i = au_d^2$ (fig.1).

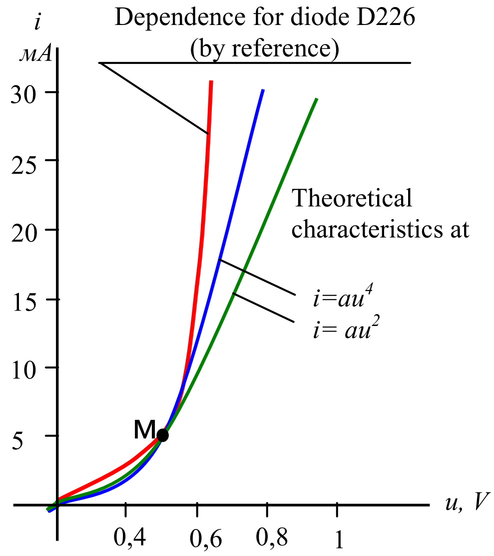

Fig.1. Volt-ampere characteristics

Here, a - coefficient of the approximating function, which is determined by the method of selected points.

* Corresponding author: *abduraimoverkin69@gmail.com*

Taking into account the VAC of the diode, type D226 for the selected point M, we have, a=0,41 [11-14].

Suppose that a diode with a series-connected resistance R (Fig.2) is connected to a network with a voltage $u = U_m Sin\omega t$

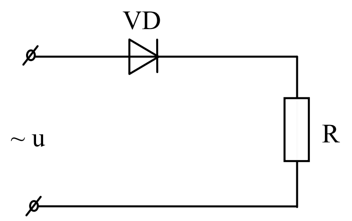

Fig. 2. Diode-resistor circuit

According to the second Kirchhoff's law:

$$u = u_d + Ri \quad (1)$$

in the approximating function, you can write:

$$u = \sqrt{\frac{i}{a}} + Ri \quad (2)$$

After some transformations, we get the following equation:

$$R^2 i^2 - i\left(2Ru + \frac{1}{a}\right) + u^2 = 0$$

where

$$i = \frac{(2Rau+1) - \sqrt{4Rau+1}}{2R^2 a} \quad (3)$$

Here the minus sign, taken before the radical, takes into account that under stress u=0 the current will also be zero [15-18]. On the basis of equation (3) with the use of a computer, a graph of the change in current as a function of time is calculated and built. Figure 3. these dependences are presented for various values of the load resistance R for input voltage u=*100Sin wt.*

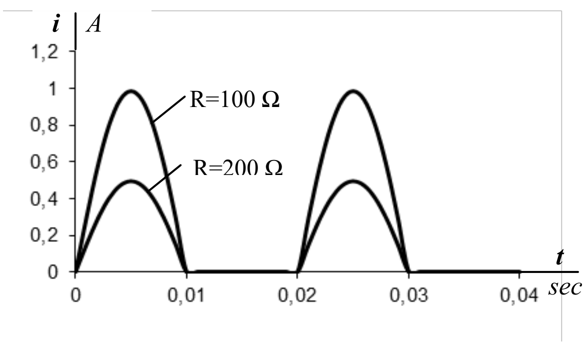

Fig. 3. Current ramps

Let us carry out a theoretical analysis of the circuit shown in Fig. 4, where a diode, inductive and active resistance are connected in series. To analyze this chain, it is proposed to use the numerical solution of the equation of state of the chain by the Euler method [19].

The equations for this chain are as follows:

$$u = u_d + L\frac{di}{dt} + iR \quad (4)$$

Using a more accurate approximating function $i = au_d^4$, where a=0,8 we get [3-4].

$$\mathrm{u} = \sqrt[4]{\frac{i}{a}} + L\frac{di}{dt} + iR \quad (5)$$

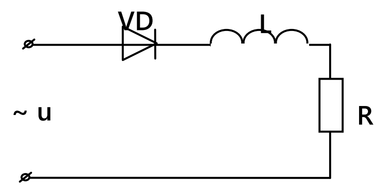

Fig. 4. Half-wave circuit

While $u = U_m Sin\omega t$ we have:

$$\frac{di}{dt} = \frac{1}{L}\left(U_m Sin\omega t - \sqrt[4]{\frac{i}{a}} - iR\right) \quad (6)$$

To solve this equation, according to Euler's method, we take:

$$i_n = i_{n-1} + \frac{1}{L}\left(U_m Sin\omega t_{n-1} - 4\sqrt{\frac{i}{a}} - Ri_{n-1}\right)h \quad (7)$$

where h-step of integration; $\boldsymbol{i_n}$- instantaneous current value for a step n; i_{n-1} - instantaneous current value for the n-1 step Figure 5. the current curves are shown, constructed on the basis of solving the equation by a numerical method, using a computer [20-24]. From this dependence it can be seen that there is a relative smoothing of the current curve. The shape of the current curve depends on the ratio of the parameters of the L and R circuit.

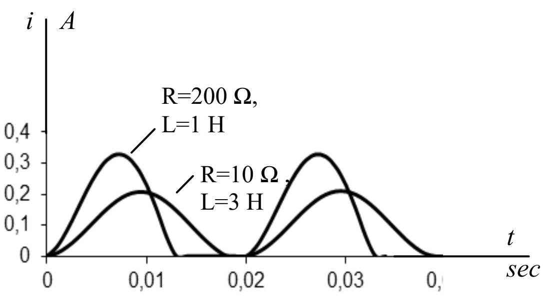

Fig. 5. Current curves

The proposed technique makes it possible to analyze the steady-state modes and transient processes of such circuits for various variations of the parameters L and R.

Let us analyze the circuit shown in Fig. 6, where inductive and active resistances are connected in series to a full-wave diode bridge circuit. To analyze this chain, we propose to use the numerical solution of the equation of state for the chain [25-26].

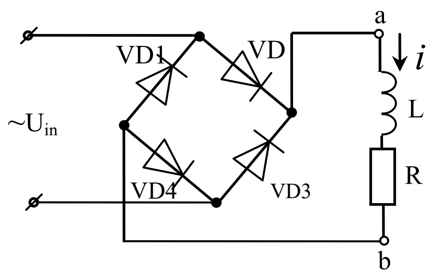

Fig. 6. Bridge rectifier circuit

The equation for this chain is as follows:

$$u_{ab} = L\frac{di}{dt} + Ri \tag{8}$$

Hence

$$\frac{di}{dt} = \frac{1}{L}(u_{ab} - Ri)$$

To solve this equation, we use the numerical Euler method.

$$i_n = i_{n-1} + \frac{1}{L}(U_m Sin\,\omega t_{n-1} - Ri_{n-1})h \tag{9}$$

Based on the results of solving this equation, the current and voltage curves were obtained (Fig. 7).

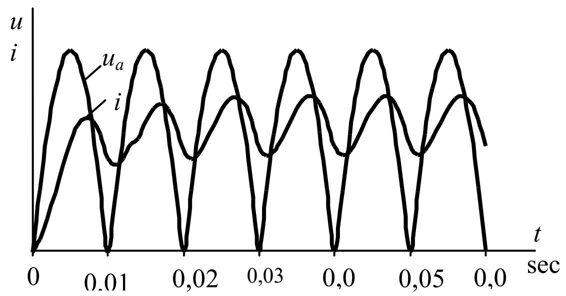

Fig. 7. Curves of current and voltage

When calculating on a computer, the following were taken: u_{ab}=100*Sin wt*; *R*=200 Ohm; *L*=1 H.

3 Analysis of thyristor resistive circuits

Thyristor semiconductor circuits have two stable electrical states (open and closed), have high speed and can switch large load currents. The main property of a thyristor is the ability to delay the moment of its firing in the presence of direct voltage on it. This property of the thyristor makes it possible to create devices with regulation of the value of the output voltage. Using the control current, you can control the moment when the thyristor turns on. The on-state current of the thyristor also flows after the control current is removed. It is possible, among other things, to turn off the anode current and restore the off state of the thyristor by reducing the current in the semiconductor device below the critical value. For thyristors, in the same way as for diodes, there is the concept of "ideal thyristor" [5-7]. Therefore, we can assume that the resistance of an ideal thyristor in the opposite direction, as well as in the forward closed state, is equal to infinity. In the open state, the forward resistance of an ideal thyristor is zero.

The way thyristors are switched by the gate current is of great importance. First, it allows, due to the control signal, to turn on the thyristor at different values of the anode voltage. Secondly, this method makes it possible to switch large currents with a low-power control signal.

We are investigating a circuit consisting of a series-connected thyristor and an active resistance (Fig. 8.) which is connected to an alternating voltage source. To analyze the operation of the considered circuit, you should use the load characteristic and the characteristic of the thyristors [12-14].

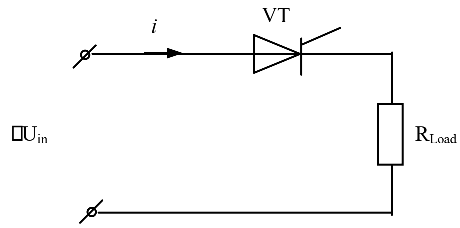

Fig. 8. Thyristor-resistive circuit

An analytical expression of the load characteristic can be obtained based on the second Kirchhoff's law.

$$I = \frac{U_{in}}{R_L} - \frac{U_{thy}}{R_L} \tag{10}$$

This is the equation of a straight line cutting off segments on the coordinate axes $U = U_L$ while $I = 0$ and $I=U_{in}/R_{Load}$ при $U = 0$. (Fig.9.). The points of intersection of the load lines with the thyristor characteristic determine the operating modes of the circuit.

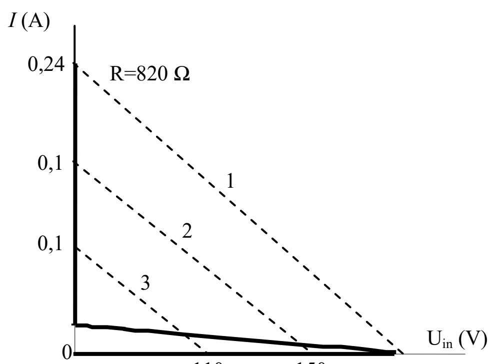

Fig. 9. VACh thyristor and load lines

To display the load line and current-voltage characteristics, consider the operating mode of the KU 202K thyristor with an active load of 820 Ohm. In the absence of a control signal, the thyristor is blocked in both directions and is under the influence of the source voltage. When the voltage of the source reaches a certain value, the thyristor turns on at the moment *1/2*. In this case, the voltage across the resistance will change abruptly to the amplitude value of the alternating voltage [22-23]. The voltage across the thyristor at the moment of switching on changes abruptly to almost zero. The duration of the current through the thyristor and the voltage across the load resistance is a quarter of the period. The values of the currents are determined by the following formulas:

$$i = \frac{U_{\text{in max}}}{R} Sin\omega t = I_m Sin\omega t \tag{11}$$

for $\alpha < \omega t < \pi$

$$I_{ave} = \frac{1}{2\pi}\int_{\alpha}^{\pi} I_m Sin\omega t\, d\,\omega t = \frac{1}{2\pi} I_m (1 + Cos\alpha) \tag{12}$$

in our case for $\alpha = 90^o$ $\quad I_{ave} = \frac{I_m}{2\pi}$

RMS current value:

$$I = I_m \frac{1}{\sqrt{2\pi}} \sqrt{\frac{1}{2}(\pi - \alpha) + \frac{1}{4} Sin 2\alpha} \tag{13}$$

for $\alpha = 90^0$ we get, $I = \frac{I_m}{2\sqrt{2}}$

Thus, the considered circuit can be analyzed using the characteristics of the thyristor and load lines.
Consider the operating mode of a circuit consisting of a series-connected thyristor, an inductive coil and an active resistance (Fig. 10).

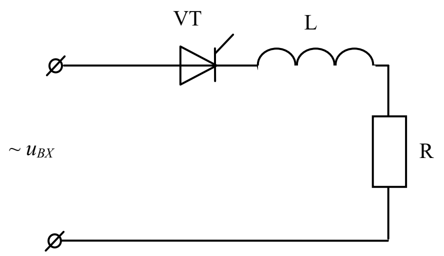

Fig. 10. The investigated scheme

The equation for this chain is as follows:

$$u_{in} = u_{thy} + L\frac{di}{dt} + Ri \tag{14}$$

We accept the characteristic of the thyristor ideal for the open state of the thyristor, while equation (14) will take the form:

$$u_{in} = L\frac{di}{dt} + Ri = U_m Sin(\omega t + \psi)$$

for $\psi = \pi / 2$

$$L\frac{di}{dt} + Ri = U_m Cos\omega t \tag{15}$$

Or

$$\frac{di}{dt} = \frac{U_m Cos\omega t}{L} - \frac{R}{L} i \tag{16}$$

For different values of t, setting the integration step *h,* we have:

$$i_n = i_{n-1} + \left(\frac{U_m Cos\omega t_{n-1}}{L} - \frac{R}{L} i_{n-1}\right) h \tag{17}$$

The curves of voltage and current at the terminals of the elements L and R and current, constructed by solving equation (17) by a numerical method, are presented.

It can be seen from the figure that the current gradually increases and the moment of termination of the current is delayed relative to the moment of transition of the phase voltage through the zero value. It should be noted that the shape of the current curve depends on the ratio of the circuit parameters *L* and *R* [7-8, 17-18].

4 Conclusions

Thus, a diode-resistor circuit can be investigated analytically, using an even-order power function to approximate the VACh of a diode, using the obtained expression for constructing a change in the load current over time, and a theoretical analysis of a circuit consisting of a series-connected diode, inductance and active resistance is given which is carried out using the fourth-order power function as an approximation of the diode characteristics.

By studying the circuit of a thyristor resistive circuit, it was found that the graphical method of analysis used in calculating transistor circuits can also be recommended for calculating a circuit consisting of a series-connected thyristor and an active resistance. In this case, the VACh of the thyristor is considered to be known for various control currents, and load lines are drawn on it. For the case of active-inductive load, the ideal characteristic of the thyristor is adopted. In this case, the nonlinear differential equations of state of the circuit in all cases were solved by the numerical Euler method using a computer. The proposed methods allow for a qualitative analysis of steady-state modes and transient processes in semiconductor circuits.

References

1. E.Abduraimov, M.Peysenov, N.Tairova. AIP Conference Proceedings, 2552, **040012**, (2022), https://doi.org/10.1063/5.0116235
2. E.Kh.Abduraimov, D.Kh.Khalmanov. Journal of Physics: Conference Series, 2094(2), **022072**, (2021), DOI 10.1088/1742-6596/2094/2/022072
3. E.Kh.Abduraimov, D.Kh.Khalmanov, and ofters. E3S Web of Conferences, 289, **07026**, (2021), https://doi.org/10.1051/e3sconf/202128907026
4. E.Kh.Abduraimov, D.Kh.Khalmanov. E3S Web of Conferences, 216, **01106**, (2020), https://doi.org/10.1051/e3sconf/202021601106
5. E.Kh.Abduraimov. E3S Web of Conferences, 216, **01105**, (2020), https://doi.org/10.1051/e3sconf/202021601105
6. E.Kh.Abduraimov, D.Kh.Khalmanov. Journal of Physics: Conference Series, 1515(2), **022055**, (2020), DOI 10.1088/1742-6596/1515/2/022055
7. E.Kh.Abduraimov. Journal of Physics: Conference Series, 072009, **2373,** (2022), DOI 10.1088/1742-6596/2373/7/072009
8. E.Kh.Abduraimov, D.Kh.Khalmanov. Journal of Physics: Conference Series, 072010, **2373,** (2022), DOI 10.1088/1742-6596/2373/7/072010
9. R.Karimov. AIP Conference Proceedings, 2552, **030014**, (2022). https://doi.org/10.1063/5.0111533
10. R.Karimov. AIP Conference Proceedings, 2552, **050012**, (2022). https://doi.org/10.1063/5.0111524
11. S.Dzhuraev, R.Karimov, and ofters. ElConRus, (2022), pp. 1166-1169, doi: 10.1109/ElConRus54750.2022.9755782
12. R.Karimov, A. Kuchkarov, and ofters. Journal of Physics: Conference Series 2094, **052050**, (2021). doi:10.1088/1742-6596/2094/5/052050
13. R.Karimov, N.Kurbanova, and ofters. Journal of Physics: Conference Series 2094(5), **052042**, (2021). doi:10.1088/1742-6596/2094/5/052042
14. K.G.Abidov, O.O.Zaripov, and ofters. AIP Conference Proceedings, 2552, **030023**, (2022), https://doi.org/10.1063/5.0112385
15. K.G.Abidov, O.O.Zaripov, and ofters. AIP Conference Proceedings, 2552, **030022**, (2022), https://doi.org/10.1063/5.0112384
16. K.G.Abidov, O.O.Zaripov, and ofters. E3S Web of Conferences, 289, **07003**, (2021), https://doi.org/10.1051/e3sconf/202128907003
17. K.G.Abidov, and ofters. E3S Web of Conferences, 289, **07004**, (2021), https://doi.org/10.1051/e3sconf/202128907004
18. K.Abidov, N.Khamudkhanova. E3S Web of Conferences, 216, **01111**, (2020), https://doi.org/10.1051/e3sconf/202021601111
19. 19. K.G.Abidov, O.O.Zaripov, and ofters. E3S Web of Conferences, 216, **01110**, (2020), https://doi.org/10.1051/e3sconf/202021601111
20. K.G.Abidov, O.O.Zaripov. E3S Web of Conferences, 139, **01088**, (2019), https://doi.org/10.1051/e3sconf/201913901088
21. A.A.Khashimov, K.G.Abidov. Elektrotekhnika, **7**, pp. 34-38, (2001).
22. A.A.Khashimov, K.G.Abidov. Elektrotekhnika, **10**, pp. 22-26, (2001).
23. 20. K.G.Abidov, A.K.Nuraliev, and ofters. Journal of Advanced Research in Dynamical and Control Systems, **12(7)**, pp. 2167-2171, (2020).
24. A.K.Nuraliev, and ofters. E3S Web of Conferences, 216, **01108**, (2020), https://doi.org/10.1051/e3sconf/202021601108
25. M.Ibadullaev, A.Nuraliev, A.Esenbekov. IOP Conference Series: Materials Science and Engineering, 862(6), **062031**, (2020), DOI 10.1088/1757-899X/862/6/062031
26. S.Begmatov, D.Khalmanov, and ofters. AIP Conference Proceedings, 2552, **040011**, (2022), https://doi.org/10.1063/5.0130666