Yerzhan Assel Anuarkyzy
PhD., Associate Professor
Almaty University of Power Engineering & Telecommunications named after
Gumarbek Daukeev, Republic of Kazakhstan

Nakisbekova Balausa Ryskozhaevna
master, Senior Lecturer
Almaty University of Power Engineering & Telecommunications named after
Gumarbek Daukeev, Republic of Kazakhstan

Manapova Akmaral Muratkyzy
master, Lecturer
Almaty University of Power Engineering & Telecommunications named after
Gumarbek Daukeev, Republic of Kazakhstan

ANALYSIS OF EXISTING APPROXIMATING FUNCTIONS AND DEFINITION OF A NEW TYPE OF FUNCTIONS OF CURRENT-VOLTAGE CHARACTERISTICS

Abstract*. This article analyzes various variants of the approximating functions used to describe the functional dependence of current on voltage. The unknown parameters on which these functions depend will also be defined.*
Keywords*: approximation, function, current-voltage characteristics.*

It is known that any electronic circuit in which "reactions and effects are connected by nonlinear elements" is called nonlinear [1]. The current-voltage characteristics (VAC) of circuit elements are usually determined as a result of experiments. The study of the VAC elements of electronic circuits is devoted to the works of many authors [1-3]. In these works, the experimental results are mainly presented in the form of graphs, and in practical calculations, graphical methods, piecewise linear approximation, and others are widely used [1-3]. For theoretical research and analysis of electronic circuits, it is advisable to have an analytical representation of the VAC of nonlinear elements. Therefore, it is relevant to define analytical formulas that describe the relationship between current and voltage in circuits.

In this regard, there is a need to study various types of functions used to approximate the VAC of nonlinear elements of electronic circuits.

Statement of the problem. In this paper, we propose to study the possibility of using one type of function to approximate a nonlinear element of an electronic circuit. To do this, the results of experiments are considered, and the results are mathematically processed using the least squares method in order to determine a specific type of approximating function.

Experimental or statistical data is the main information for determining the analytical relationships between the variables (indicators) under consideration. It is necessary to define a function that describes such a relationship between these variables, which are in good agreement with the experimental data.

Transition to dimensionless variables. Before proceeding to the analysis of these functions, it is advisable to use dimensionless quantities. The transition to dimensionless quantities and the use of dimensionless parameters in calculations provide certain convenience when solving a problem on a computer. To switch to dimensionless variables, you need to select the characteristic values for this problem.

Let U_0 – some voltage that is characteristic of this component. Then $\frac{U_0}{R}$ can be characterized by the magnitude of the current to a constant value of resistance R. The transition to dimensionless quantities is carried out using the following formulas:

$$x = \frac{u}{U_0}, \quad y = \frac{i \cdot R}{U_0} \tag{1}$$

Here x *– dimensionless voltage, y – dimensionless current.*

Taking into account these formulas, the desired approximating function can be written in the following form:

$$i = \frac{U_0}{R} \cdot f(x) \quad \text{or} \quad y = f(x). \tag{2}$$

Here $f(x)$ *will be the desired function that determines the relationship between the dimensionless current and the dimensionless voltage.*

From the analysis of the existing methods of approximation of experimental data [2], it follows that linear and quadratic functions are most often used: $y = a \cdot x^2 + b \cdot x + c,$ where $a, b, c -$ unknown parameters.

In addition to these functions, the possibility of using other types of approximating functions may be considered. In this paper, we propose to use the following exponential function to approximate nonlinear dependencies:

$$y = a \cdot (1 - \exp(-\frac{x}{a})) \tag{3}$$

Linear and quadratic functions for approximating statistical or experimental data have been used for a long time and successfully in many fields of science. However, a linear function of the form $y = a \cdot x + b$ it is used only for linear problems, and its use for describing nonlinear elements of electronic circuits is impractical. The use of a quadratic function of the form is widely used $y = a \cdot x^2 + b \cdot x + c.$ A function of the form (3) can also be used to approximate dependencies. It is necessary to check the possibility of such a statement based on the results of the experiment and its mathematical processing.

The first reason for choosing this function is its graphs for different parameter values $a,$ which is included in the formula of the proposed function (3), which has graphs that are very similar to the graphs given in the literature [1-6].

In formula (3), there is a single unknown parameter whose value must be determined. The values of the unknown parameters in the proposed approximation functions may be different for different components of the electronic circuit. To determine the numerical values of these unknown parameters, experimental data and the well-known least squares method are used.

In addition, the reason for choosing this function (3) as an approximation is the fact that for relatively small values of the voltage (or argument), a linear dependence, i.e., Ohm's law, must be fulfilled. In fact, expansions of these functions into Taylor series in a neighborhood can be represented as the following power series:

$$a \cdot (1 - \exp(-\frac{x}{a})) = x - \frac{x^2}{2!a} + \frac{x^3}{3!a^2} - ... + (-1)^k \cdot \frac{x^k}{k!a^{k-1}} + ...$$

If we neglect small quantities, i.e., the terms of the series containing the second and higher powers , then keeping only the first terms in these series, we can obtain the Ohm's formula with a certain accuracy $y \approx x$ or $i = u / R$.

To determine the applicability of these functions as approximating functions of the dependence between voltage and current, specific examples should be considered. Examples for determining the approximating functions should be experiments conducted for each type of electronic circuit elements. Mathematical processing of the results of the experiment was carried out using the well-known least squares method (LSM).

Approximation of the characteristics of a field-effect transistor. For a field-effect transistor, the experimental data given in the first two rows of Table 1 are determined. Here, two functions are considered as approximating ones.

Table 1

Experimental data and values of approximating functions for a field-effect transistor

x_k	0	0,10	0,25	0,50	1,00	2,00	5,00	10,00
y_k	0	0,12	0,20	0,32	0,35	0,38	0,42	0,46
$y = a(1 - e^{-\frac{x}{a}})$	0	0,09	0,19	0,29	0,38	0.41	0,42	0,42
$u = ax^2 + bx + c$	0,16	0,17	0,17	0,21	0,26	0,34	0,50	0,44

To define an unknown parameter a for this case, the minimum condition of the following function was considered:

$$U(a) = \sum_{k=1}^{n} [y_k - a \cdot (1 - \exp(-\frac{x_k}{a}))]^2 \Rightarrow \min,$$

where $x_k, y_k -$ *experimental data,* $n -$ *the number of experimental points. A necessary and sufficient condition for the minimum of the function* $U(a)$ *is equal to zero of its first derivative by* a.

The equation obtained from this minimum condition of function is transcendental with respect to the unknown parameter a, for the solution of which the iteration method was used. Accuracy of calculating the desired parameter a was set, for which the condition for completing the iterative process is set as the following inequality: $|a_{k+1} - a_k| \leq \varepsilon$, where $\varepsilon = 0.0001$. The result is the following parameter value $a = 0{,}4187$.

Then the values of the approximating function were calculated $y = a \cdot (1 - \exp(-x/a))$ for the same argument values (Table 1). A comparison of the results shows that the values of the approximating function and the experimental data are sufficiently close. This is also confirmed by its graphical representation (Figure 1).

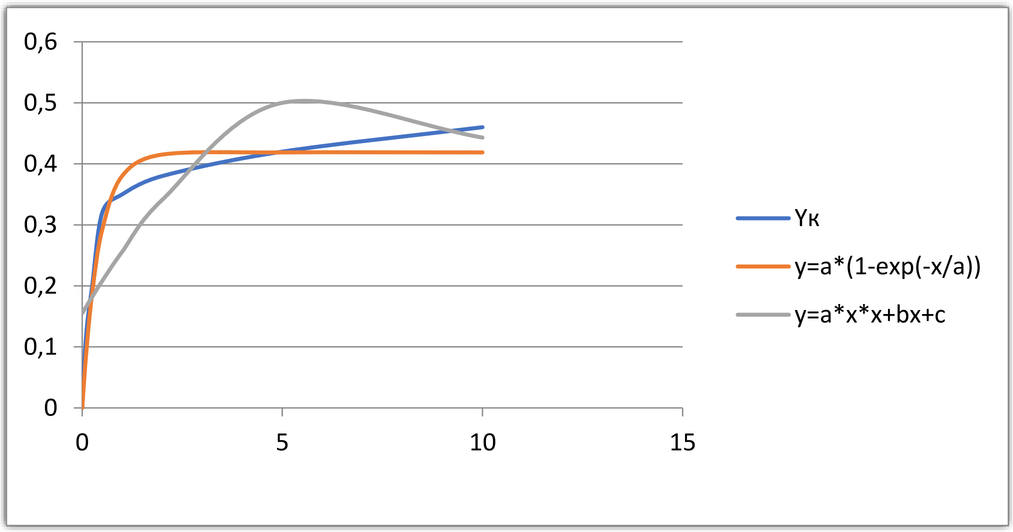

Fig. 1. **Graphs of the current-voltage characteristic of a field-effect transistor**

Conclusion. The analysis of the methods of approximation of experimental data considered in this article showed that the function proposed for approximation is $y = a \cdot (1 - e^{-\frac{x}{a}})$ they describe experimental data quite closely and can be used under certain conditions to describe the functional relationship between current and voltage. In addition, the comparative analysis showed that the values of this function and the quadratic function are quite close to the experimental values and this allows us to conclude that along with the quadratic function, the proposed function can be used as an approximating function with a fairly good approximation.

References:

1. Bakalov V. P., Dmitrikov V. F., Kruk B. E. Fundamentals of the theory of chains: A textbook for universities; Ed. by V. P. Bakalov. - 2nd ed., trans. and add. – M.: Radio and communication, 2000. – 592 p.
2. Bessonov L. A. Nonlinear electric circuits: Textbook. - M.: "Higher School", 1964. 430 p.
3. Matkhanov P. N. Fundamentals of analysis of electrical circuits. Nonlinear circuits. Textbook for universities. M.: "Higher school", 1977. - 272 p.
4. Fiedler J. K., Nightingale K. Machine design of electronic circuits: Trans. from English and preface by D. I. Panfilov, A. G. Sokolov; Edited by G. G. Kazennov. – M.: Higher School of Economics, 1985. - 216 p.
5. Assel Anuarkyzy Yerzhan, Zautbek Kuralbayevis Kuralbayev. Electronic Circuit Responsiveness Determination. World Applied Sciences Journal. 2013. – V.26 (8). – P.1011-1018.
6. Plotkin, J., Almuratova, N., Yerzhan, A., Petrushin, V. Parasitic effects of pwm-vsi control leading to torque harmonics in ac drives.Energies, 2021, 14(6), 1713.