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Simulation of the Functional Characteristics of Low-Voltage Switching Devices, Based on the Example of Automatic Circuit Breakers

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***Abstract* — The article discusses the main features of mechanical, chemical, thermal, and electrical processes occurring in the contact zones of the surfaces of contact connections of electrical devices. The parameters determining the value of power losses and power consumption in low voltage switching equipment are analyzed. The main features of the characteristics of the topology and technical condition in the operating conditions of the equipment of shop low-voltage industrial power supply networks are shown. A comparative analysis of the technical characteristics of automatic circuit breakers. Using catalog data, the dependences of active power losses in circuit breakers on rated currents are established. Algorithms have been developed and the obtained dependencies have been modeled using approximating functions. The standard deviation of the compiled approximating functions is calculated. Analytical expressions of the dynamics of power losses per pole in the studied machines of some companies of the function of the rated current are presented. The graphical dependencies of the investigated parameters of low-voltage equipment are presented. The developed models are recommended to be used to increase the reliability of the assessment and refinement of the amount of active power and electricity losses in low-voltage electrical networks of industrial power supply systems.**

***Keywords* — circuit breakers, rated current, contact connections, approximating functions, design features.**

I. INTRODUCTION

Currently, in Russia and around the world, a significant proportion of low-voltage power grids require detailed analysis and identification of the sources of the greatest losses and possible further modernization and implementation of energy-saving measures [1].

In modern conditions of power engineering, the development of electrical complexes requires, on the one hand, an increase in the electricity produced, and, on the other hand, stricter control over the efficiency of electricity use [27; 28]. Power losses, when considering production processes and power consumption, are a part of total power consumption. Therefore, the study and analysis of power and electric power losses in the elements of intra-shop power supply have the same technical and economic principles as the analysis of useful consumed electric power [32; 33].

The value of power and electric power losses significantly affects the efficiency of electric grid operation. The cost of losses is a component of both the total estimated cost (reduced costs) and a component of the cost price (annual operating costs) of power transmission and distribution processes. Thus the share of losses in total cost of process of electric power transmission has considerable value (35-45%), therefore for power efficient operation of systems of intra-factory electric supply it is required to support rational parity between cost of losses and cost of total power consumption [6].

Currently, the requirements for accounting for power and electricity losses in shop power supply systems are changing. This is due to the complexity of determining the parametric and regime data of power supply systems [25; 26]. The reliability of information about the elements of electrical equipment significantly increases the energy efficiency of the operation of the power supply system [9].

II. MATERIALS AND METHODS

In industrial electrical complexes, there are tendencies, on the one hand, to increase energy consumption and, on the other hand, to decrease it. In the first case, measures such as, for example, the use of automation of production processes or the replacement of steam with electricity in technological cycles contribute to an increase in electricity consumption [34]. And in the second case, the use of "smart grids", "intelligent electricity meters", energy-saving technologies help to reduce electricity consumption [16]. At the same time, it becomes relevant to apply new approaches to finding a reserve for saving

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electricity based on increasing the reliability of information on power and electricity losses in the elements of shop power supply systems.

At the same time, the requirements for both energy efficiency and maximum efficiency are imposed on the structure and equipment of shop power supply. Of great importance is the development of algorithms for assessing the technical parameters of low-voltage electrical equipment [35]. At the same time, it is rational to apply methods of direct search for the optimum wherever possible. The solution of the tasks set should be based on the analytical dependencies between the reduced costs of electricity supply and the transmitted power [11]. For rational regulation of power consumption modes, it is necessary to improve the accuracy of power consumption forecasting with the identification of the main factors that determine the amount of power consumption, taking into account the level of losses in all elements of the power supply system [29; 30].

The topology of shop low-voltage networks of industrial power supply is determined, as a rule, by a significant length and branching, and a significant amount of low-voltage switching equipment [2]. Therefore, in order to analyze and evaluate power and electricity losses in low-voltage electrical networks, data on the magnitude of losses in the contact connections of low-voltage electrical devices are needed, which significantly affects the level of total losses [4].

Low-Voltage switching electrical devices are characterized, as a rule, by complex design features. The effectiveness of the functioning of devices is determined by their reliability and the quality of their operation [31].

Circuit breakers are designed to work with a long-term closed state of contacts, which determines the need for a stable level of the resistance value of the contact groups of devices [21].

For certain solutions, it is required to reliably assess the technical condition of the equipment and, on the basis of this, conduct a system analysis of the data [36; 37]. To improve the efficiency of the functioning of electrical equipment of shop power supply systems, a reliable analysis of the elements of equipment of shop networks and factors that determine the performance of the work process is necessary [7; 8]. At the same time, a detailed analysis is required for such technical characteristics as active power losses in low voltage switching equipment. The main factors determining the magnitude of power losses and power consumption in Low-Voltage switching devices can be considered as follows [10; 12]:

- the value of the rated current of electrical apparatus, A;
- the shape and dimensions of the contact, determined by the rated current, the structure of the contact groups, the resource of the apparatus and the number of on-off cycles [22-24];
- material of the contact parts;
- sections of the conductive parts of the apparatus.

Consider cast automatic circuit breakers, which are most popular in the domestic electrical equipment market.

A molded case circuit breaker is a switching device designed to conduct current in normal mode, protect equipment and the power circuit in the event of an overload or short circuit [3].

Table I presents the main technical catalog data of machines manufactured by the Kursk Electrical Apparatus Plant (KEAZ), Schneider Electric, Legrand, ABB.

TABLE I. MAIN TECHNICAL CATALOG DATA OF MACHINES

Type and manufacturer of the circuit breaker	**The value of active power losses per pole, W**	**Switching wear resistance, cycles**	**Mechanical wear resistance, cycles**	**Overall dimensions (WxHxD), mm**	**I_n, A**	**U_n, V**
Russian						
VA57-31 (KEAZ)	7.5	10000	16000	75x125x117	100	690 AC
Foreign						
NSX100TM-D (Schneider Electric)	8.8	10000	50000	140x160x86	100	690 AC
DPX^3 160 (Legrand)	7.8	8000	25000	81x115x100	100	690 AC
Tmax XT1TMD (ABB)	10	8000	25000	76.2x130x70	100	690 AC

An analysis of the data in Table I showed that the main technical parameters of the studied circuit breakers of the manufacturers under consideration have similar values, however, it should be noted that the circuit breakers of the VA57-31 series have the lowest power loss per pole - 7.5 W, and the automatic switches Tmax XT1 TMD – the highest value is 10 W [18]. Consequently, during operation, the smallest power losses will occur in low-voltage shop networks with VA57-31 circuit breakers, and the largest - with Tmax XT1 TMD automatic circuit breakers.

Depending on the rated current of the device, its power losses will be different. Based on the catalog data, we construct the dependencies of power losses on the rated current I (Fig. 1) for circuit breakers (VA57-31, NSX100 TM-D, DPX^3 160, Tmax XT1 TMD).

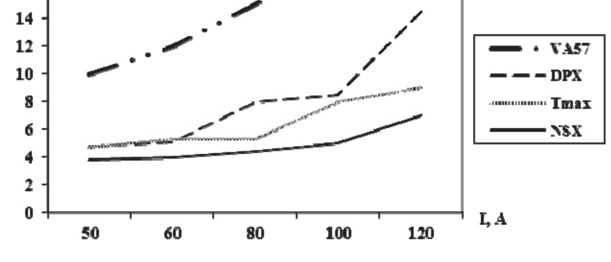

Fig.1. Graphs of dependences of active power losses as a function of rated currents of automatic machines of manufacturers

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In the catalogs for low-voltage electrical devices VA57-31, NSX100 TM-D, DPX^3 160, Tmax XT1 TMD, as a rule, there is no reliable data on contact resistance and power losses in contact systems, as a result of which a detailed analysis and identification of functional dependencies is necessary dynamics of active power losses from the main technical characteristics.

We approximate the obtained graphical dependencies of the power loss value as a function of the rated current [13-15].

So, the function graph for the VA57-31 circuit breaker can be represented by the following functions:

$$F_{1VA}(I) = -1.95 + 0.28 \cdot I - 7.4 \cdot 10^{-4} \cdot I^2 \tag{1}$$

$$F_{2VA}(I) = 20.26 - 37.95 \cdot e^{-0.025 \cdot I} \tag{2}$$

$$F_{3VA}(I) = -4.12 + 143.98 \cdot e^{-0.1 \cdot I} - 8.4 \cdot 10^{-4} \cdot I^2 + 0.31 \cdot I \tag{3}$$

where $F_{1VA}(I)$, $F_{2VA}(I)$, $F_{3VA}(I)$ - functional dependences of the values of active power losses in the VA-57 machine on the value of the rated current; I - the value of the rated current VA-57.

Graphic dependences $F_{1VA}(I)$, $F_{2VA}(I)$, $F_{3VA}(I)$ are shown in Fig. 2.

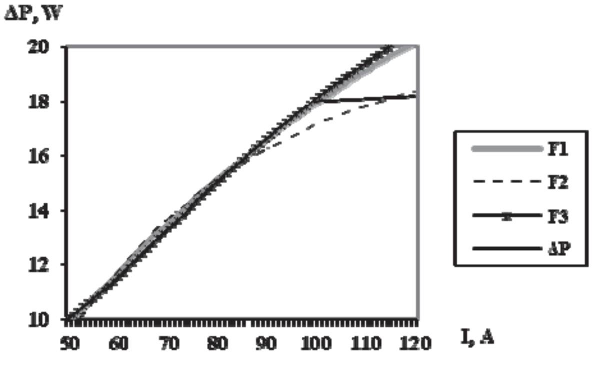

Fig.2. Graphical approximation of the functional characteristics for VA57-31

Then determine the approximating functions of the dependences of the magnitude of power losses on the values of the rated currents of the automatic machines VA57-31, NSX100 TM-D, DPX^3 160, Tmax XT1 TMD [5].

The approximating function can be represented by the following expressions:

For the NSX100 TM-D circuit breaker:

$$F_{1NSX}(I) = 0.78 + 0.11 \cdot I - 1.23 \cdot 10^{-4} \cdot I^2 \tag{4}$$

$$F_{2NSX}(I) = 29.42 - 29.18 \cdot e^{-4.001 \cdot 10^{(-3)} \cdot I} \tag{5}$$

$$F_{3NSX}(I) = 17 - 1067 \cdot e^{-0.1 \cdot I} + 5.97 \cdot 10^{-4} \cdot I^2 - 0.14 \cdot I \tag{6}$$

For the circuit breaker DPX^3 160:

$$F_{1DPX}(I) = 7.46 - 0.13 \cdot I + 0.15 \cdot 10^{-4} \cdot I^2 \tag{7}$$

$$F_{2DPX}(I) = 2.23 \cdot 10^6 - 2.23 \cdot 10^6 \cdot e^{-6.298 \cdot 10^{(-8)} \cdot I} \tag{8}$$

$$F_{3DPX}(I) = 20.37 - 516.21 \cdot e^{-0.1 \cdot I} + 0.28 \cdot 10^{-4} \cdot I^2 - 0.39 \cdot I \tag{9}$$

For the circuit breaker Tmax XT1 TMD:

$$F_{1T\max}(I) = -0.55 + 0.12 \cdot I - 2.95 \cdot 10^{-4} \cdot I^2 \tag{10}$$

$$F_{2T\max}(I) = 13.97 - 15.34 \cdot e^{-9.692 \cdot 10^{(-3)} \cdot I} \tag{11}$$

$$\begin{gathered} F_{3T\max}(I) = 5.48 - 241.05 \cdot e^{-0.1 \cdot I} + \\ +2.94 \cdot 10^{-4} \cdot I^2 - 4.65 \cdot 10^{-3} \cdot I \end{gathered} \tag{12}$$

where $F_1(I)$, $F_2(I)$, $F_3(I)$ - are functional dependencies of the values of active power losses in the machine NSX100 TM-D, DPX^3 160, Tmax XT1 TMD on the value of the rated current; I - the value of the rated current.

III. RESULTS AND DISCUSSIONS

It can be determined the standard deviation of the obtained functions from the passport data by the expression [19; 20]:

$$S = \sqrt{\sum (F(I_i) - \Delta P_i)^2} \tag{13}$$

where $F(I_i)$ is the value of the obtained function at a given value of the rated current; ΔP_i - passport value of active losses.

Graphic dependencies $\Delta P = F(I_n)$ for NSX100 TM-D, DPX^3 160, Tmax XT1 machines are shown in Fig. 3-5. The results of the calculation of S are presented in the Table II.

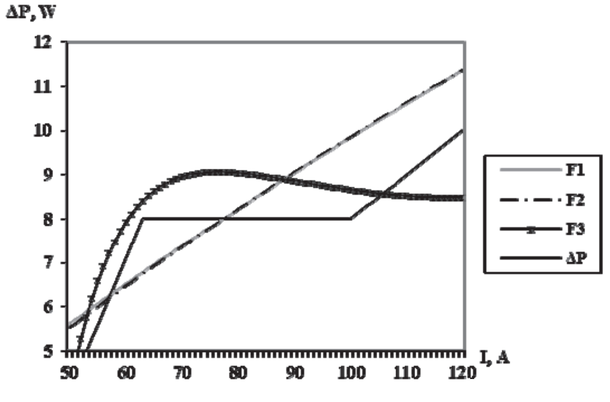

Fig.3. Graphical functional approximations for NSX 100

In Fig. 6 the graphs show the changes in the power losses for circuit breakers with a current load of 0.5 *I$_n$* [17].

Thus, the dependencies of the changes in the power losses per pole at the rated current are determined - these are approximating functions that have the smallest standard deviation.

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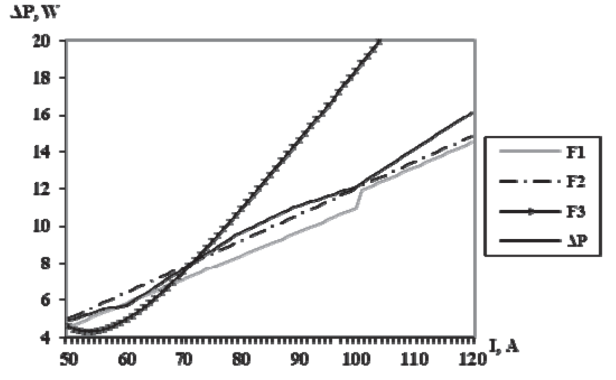

Fig.4. Graphical functional approximation for DPX ^{3} 160

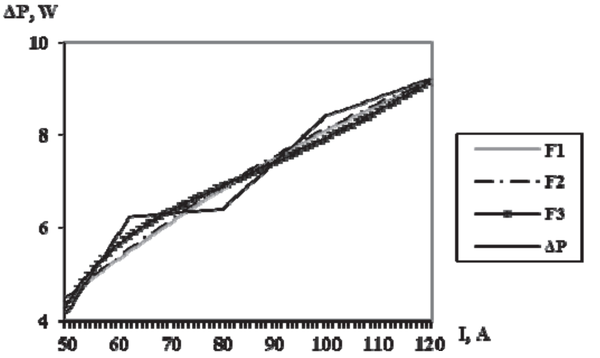

Fig.5. Graphical functional approximation characteristics for Tmax XT1

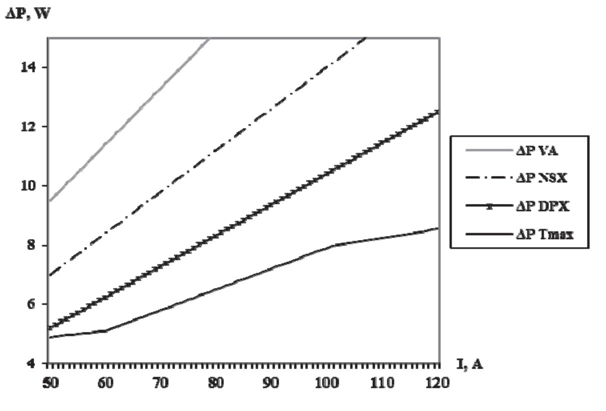

Fig.6. Graphical functional characteristics $\Delta P = F(I_n)$ for automatic machines of the VA57-31, NSX100 TM-D, DPX^3 160, Tmax XT1 TMD series

IV. CONCLUSION

In the presented article, a study was made of the dependencies of the value of the active power losses in circuit breakers on the main parameters of the equipment. A comparative analysis of the technical characteristics of the automatic devices VA57-31, NSX100 TM-D, DPX^3 160, Tmax XT1 TMD showed that their main parameters have similar values, but there are differences in the values of active power losses per device pole. This discovery makes easier the task to choose the proper construction, both reliable and economic.

TABLE II. THE RESULTS OF CALCULATING THE VALUE S FOR THE AUTOMATIC CIRCUIT BREAKERS UNDER STUDY

Approximation function type	**S**
VA57-31	
$F_{1VA}(I) = -1.95 + 0.28 \cdot I - 7.4 \cdot 10^{-4} \cdot I^2$	0.38
$F_{2VA}(I) = 20.26 - 37.95 \cdot e^{-0.025 \cdot I}$	0.14
$F_{3VA}(I) = -4.12 + 143.98 \cdot e^{-0.1 \cdot I} - 8.4 \cdot 10^{-4} \cdot I^2 + 0.31 \cdot I$	1.15
NSX100TM-D	
$F_{1NSX}(I) = 0.78 + 0.11 \cdot I - 1.23 \cdot 10^{-4} \cdot I^2$	2.65
$F_{2NSX}(I) = 29.42 - 29.18 \cdot e^{-4.001 \cdot 10^{(-3)} \cdot I}$	0.37
$F_{3NSX}(I) = 17 - 1067 \cdot e^{-0.1 \cdot I} + 5.97 \cdot 10^{-4} \cdot I^2 - 0.14 \cdot I$	2.63
DPX^3 160	
$F_{1DPX}(I) = 7.46 - 0.13 \cdot I + 0.15 \cdot 10^{-4} \cdot I^2$	1.46
$F_{2DPX}(I) = 2.23 \cdot 10^6 - 2.23 \cdot 10^6 \cdot e^{-6.298 \cdot 10^{(-8)} \cdot I}$	1.16
$F_{3DPX}(I) = -20.37 - 516.21 \cdot e^{-0.1 \cdot I} + 0.28 \cdot 10^{-4} \cdot I^2 - 0.39 \cdot I$	7.76
Tmax XT1 TMD	
$F_{1T\max}(I) = -0.55 + 0.12 \cdot I - 2.95 \cdot 10^{-4} \cdot I^2$	0.81
$F_{2T\max}(I) = 13.97 - 15.34 \cdot e^{-9.692 \cdot 10^{(-3)} \cdot I}$	0.69
$F_{3T\max}(I) = 5.48 - 241.05 \cdot e^{-0.1 \cdot I} + 2.94 \cdot 10^{-4} \cdot I^2 - 4.65 \cdot 10^{-3} \cdot I$	0.80

For the investigated circuit breakers of low-voltage equipment manufacturers - Kursk Electrical Appliance Plant, Schneider Electric, Legrand, and ABB , in accordance with the nameplate data, developed functional dependences of active losses on the rated current $\Delta P = F(I_n)$.

Algorithms and approximating functions of these characteristics were compiled and the value of the root-mean-square deviations of the obtained functions from the nameplate value of active losses was calculated. The dependences of the change in power losses in circuit breakers on the rated current are modeled - approximating functions that have the smallest standard deviation. The conducted studies have shown that the most energy-efficient in terms of active power losses are devices of the VA57-31 series with the lowest active power losses per pole - 7.5 W. The shop power supply systems of large industrial complexes, as a rule, include tens of thousands of units of low-voltage electrical devices, therefore, when assessing and analyzing the level of power and electricity losses in such systems, it is advisable to take into account the influence of electrical equipment to improve the accuracy and reliability of loss data.

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