Comparison Of Methods Of Calculation Of The Electrical System Of In-Plant Power Supply

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***Abstract*—The proposed article is devoted to the study of reliability of operation of electrical equipment of low-voltage shop-floor network schemes. With the development of digitalization in industry and energy, the use of new technological processes and the introduction of new types of equipment, the requirements for the reliability of in-plant power supply systems are becoming more stringent. The paper presents methods for assessing the reliability of electrical equipment in the shop-floor power supply systems on the example of the scheme of a section of the shop network, including the main elements - power transformer, low-voltage cable lines, distribution points, circuit breakers, magnetic starters, contactors, switches. Reliability parameters of the scheme are calculated with respect to each connection; with respect to the power distribution cabinet (SHRs) and power distribution point (PRs). The considered methods are recommended to use for specification of periodicity and terms of maintenance and repair of electrical equipment of the system of intra-workshop power supply, and also for analysis of reliability of work and revealing of the least reliable sections of schemes of networks. The algorithm of calculation with the use of logical-probabilistic method by means of construction of a tree of failures for an estimation of frequency of power loss of SHRs and PRs, and also separate connections is presented. Graphical dependences of probability of failure-free operation and occurrence of failure in time for the studied schemes are shown.**

Keywords—scheme of in-shop power supply, power distribution systems, electrical apparatuses, cable lines, reliability assessment methods.

I. Introduction

At present, with the development of new types of equipment [17, 20, 27] it becomes expedient to develop, as well as to refine the existing algorithms and determine the main indicators of reliability and efficiency of operation of the equipment of the in-plant power supply systems.

For example, the work [1] is devoted to the study and analysis of the main technical and economic indicators of some production facilities of industrial enterprises, the composition of electrical equipment and modes of operation of facilities, which can be further used to assess and analyze the energy efficiency of such facilities.

The paper [2] considers the calculation of reliability of computing complexes and systems of technical means.

The article [3] presents an assessment of the reliability of electrical equipment and electrical networks of consumer power supply systems. The main causes of damage of 0.38 kV and 6-10 kV overhead and cable lines, 10/0.4 kV transformer substations and distribution points are considered. The main reliability indices, namely the failure rate and equipment restoration time, have been determined. The damage from the under supply of electric power to consumers has been estimated. Comparison of statistical parameters of reliability of the considered electric networks with the data of literature sources is carried out. The main measures to improve the reliability of power supply to consumers by reducing the number of failures of electrical equipment are presented.

The paper [4] presents an algorithm for determining the laws of distribution of probability characteristics of reliability of low-voltage switching devices on the example of contactors of PML series of the manufacturer KEAZ on the basis of random samples when observing the failures of devices in the same operating conditions of a number of industrial enterprises of Kazan. A simulation model performed in Matlab-Simulink program is presented, which allows to calculate fixed failure rates of apparatuses based on random samples.

The study [5] presents an algorithm for estimating reliability parameters – the probability of operable state of low-voltage devices in time based on statistical data on failures of circuit breakers installed in control and protection circuits of consumers of industrial enterprises. The theoretical and statistical functions of the probability of failure-free operation of circuit breakers depending on the service life and operating modes are investigated. The type of distribution of reliability parameters of low-voltage devices on the example of circuit breakers VA-57 is determined. Analytical and graphical dependences of the main reliability parameters are obtained.

The work [6] is devoted to the study of the reliability of the functioning of the in-house power supply system based on the distribution cabinet and distribution point of a production enterprise using analytical and static calculation methods.

The authors [7] investigate the problem of reliability of power supply systems. According to the results of the analysis, a number of mathematical expressions are proposed for the construction of automation systems, which allow at the design stage to assess the fault tolerance of the power supply system with selected protection devices, thereby simplifying the process of selecting the most preferable system based on the obtained indicators.

In [13-14] an algorithm and methodology for assessing reliability indicators in the technical and economic comparison of options for industrial power supply schemes are proposed. Dependences of the time-to-failure of the power supply scheme on the rated capacity of transformers of two-transformer substations in the presence and absence of redundancy at the low-voltage switchgear are obtained.

In the researches carried out by scientists [15, 21] the laws of change of probabilistic characteristics of reliability of low-voltage electrical equipment - power transformers, circuit breakers, magnetic starters and contactors on the basis of statistical data of operation have been determined. The conformity of probabilistic characteristics of electrical equipment to the normal distribution law using the Kolmogorov criterion has been checked. The types of functions of change of the main parameters of electrical equipment reliability have been determined and the corresponding graphical dependences have been presented. Comparison of the obtained results of the values of probability of failure-free operation with the requirements of GOST is carried out.

The work [16] is devoted to the study of the methodology for assessing the reliability indicators of the operation of the in-house power supply system on the example of radial schemes. When processing statistical data, the change in the probability of failure-free operation time of switchgear depending on the number of load connections is modeled using the ratio of the probability of connections.

The research results in the paper [18] are devoted to the reliability assessment of power supply systems at the stages of planning, design and construction. On the basis of statistical information on failures, the resulting reliability parameters and probabilities of failure-free operation for the studied schemes are calculated. A simulation model for modeling the current technical condition of electrical equipment has been developed and implemented.

In the articles [19, 22] the impacts of external and internal factors affecting the reliability of electrical equipment of power supply systems during operation, such as: excessive air humidity, aggressive media, dust, adverse atmospheric phenomena, mechanical and electrical loads, etc., have been analyzed. Changes in the basic properties of materials of electrical installations depending on various factors have been investigated.

At present, new approaches to the assessment of reliability indicators of electrical equipment elements and shop-floor power supply systems as a whole are required. The purpose of this study is to assess and analyze the main characteristics of reliability of electrical equipment of low-voltage shop networks. Object of the study: systems of in-plant power supply.

Fig. 1 shows the scheme of the workshop network section, for which the reliability parameters are calculated. The system consists of highly reliable elements, when the time of failure-free operation exceeds the recovery time of the electrical installation, and the failure of more than two independent elements is an unlikely event.

II. Materials and Methods

Description of the scheme (Fig. 1) and initial data [8-12]:

- cable lines: L_1=10 m, L_2=10 m, L_3=5 m, L_4=5 m, L_5=5 m, L_6=5 m, L_7=5 m, L_8=5 m, L_9=5 m, L_{10}=5 m, L_{11}=5 m;
- transformers: T_1 – 10/0,4 kV; T_2 – 10/0,4 kV;
- circuit breakers: QF_1, QF_2, QF_3 – sectional, QF_4, QF_5, QF_6, QF_7, QF_8, QF_9, QF_{10}, QF_{11}, QF_{12}, QF_{13}, QF_{14}, QF_{15};
- switch QS_1;

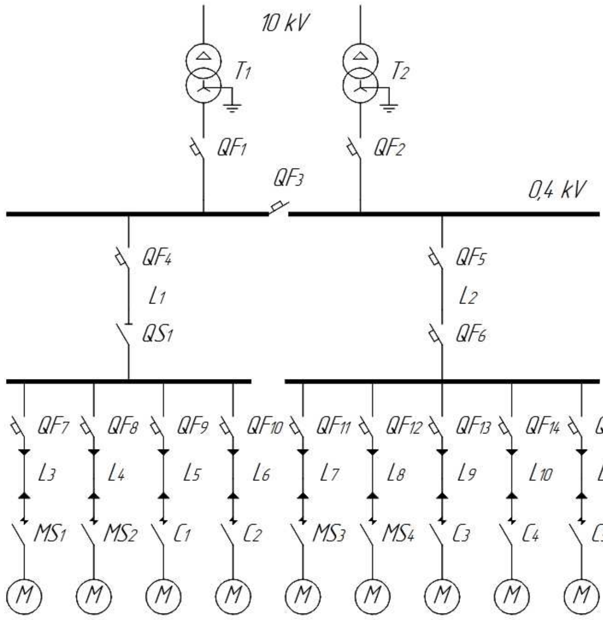

Fig 1. Scheme of the in-plant power supply system

- power distribution cabinet: SHRs;
- power distribution point: PRs;
- magnetic starters: MS_1, MS_2, MS_3, MS_4;
- contactors: C_1, C_2, C_3, C_4, C_5;
- load: M_1, M_2, M_3, M_4, M_5, M_6, M_7, M_8, M_9;
- observation time t = 6 years;
- minimum permissible level of reliability for switching low-voltage devices according to GOST 12434-83: P = 0,85 [23, 25];

The reliability parameters of the scheme (Fig. 1) by the following methods:

1. with respect to the distribution cabinet (SHRs) and distribution point (PRs);

2. with respect to each connection;

3. logical-probabilistic method.

Table I shows reference and catalog data of electrical products of various manufacturers.

TABLE I. Results of Calculation of Failure Rate Estimation by Circuit Elements

Elements	Background data	Elements	Background data	Calculation data
	λ – failure rate, defects/ year		λ – failure rate, defects/year	λ* – failure rate, defects/year
T_1	0.015	L_1	0.026	0.0026
T_2	0.015	L_2	0.026	0.0026
QF_1	0.051	L_3	0.026	0.0013
QF_2	0.051	L_4	0.026	0.0013
QF_3	0.051	L_5	0.026	0.0013
QF_4	0.051	L_6	0.026	0.0013
QF_5	0.051	L_7	0.026	0.0013
QF_6	0.051	L_8	0.026	0.0013
QF_7	0.051	L_9	0.026	0.0013
QF_8	0.051	L_{10}	0.026	0.0013
QF_9	0.051	L_{11}	0.026	0.0013
QF_{10}	0.051	MS_1	0.095	
QF_{11}	0.051	MS_2	0.095	
QF_{12}	0.051	MS_3	0.095	

Elements	Background data	Elements	Background data	Calculation data
	λ – failure rate, defects/ year		λ – failure rate, defects/year	λ* – failure rate, defects/year
QF_{13}	0.051	MS_4	0.095	
QF_{14}	0.051	C_1	0.098	
QF_{15}	0.051	C_2	0.098	
QS_1	0.038	C_3	0.098	
SHRs	0.001	C_4	0.098	
PRs	0.001	C_5	0.098	

Failure intensity of cable line 0,4 kV depends on the length and calculated per 100 m [24, 26]:

For L_1, L_2: λ* = 0.026·(10 m/100 m) = 0.0026 per year;

For $L_3...L_{11}$: λ* = 0.026·(5 m/100 m) = 0.0013 per year.

A structural scheme of reliability (Fig. 2).

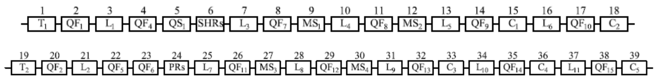

Fig 2. Reliability structural diagram

III. Results and Discussions

Failure intensity of the in-plant power supply system scheme is determined by the sum of failure intensities of each element:

$$\lambda_S = \lambda_1 + \lambda_2 + \lambda_3 + ... + \lambda_n + \\ + \lambda_{l1} + \lambda_{l2} + \lambda_{l3} + ... + \lambda_{ln} \quad (1)$$

where λ_s – the failure intensity of the system;

$\lambda_1, \lambda_2, \lambda_3, ..., \lambda_n$ – failure intensities of circuit elements;

$\lambda_{l1}, \lambda_{l2}, \lambda_{l3}, ..., \lambda_{ln}$ – failure rates of cable lines.

Failure intensity of the circuit with respect to SHRs:

$$\lambda_{S1} = \lambda_{T1} + \lambda_{QF1} + \lambda_{L1} + \lambda_{QF4} + \lambda_{QS} + \lambda_{SHRs} + \lambda_{L3} + \lambda_{QF7} + \lambda_{MS1} + \\ + \lambda_{L4} + \lambda_{QF8} + \lambda_{MS2} + \lambda_{L5} + \lambda_{QF9} + \lambda_{C1} + \lambda_{L6} + \lambda_{QF10} + \lambda_{C2} = \\ = \lambda_T + 6\cdot\lambda_{QF} + 5\cdot\lambda_L + \lambda_{QS} + \lambda_{SHRs} + 2\cdot\lambda_{MS} + 2\cdot\lambda_C$$

Failure intensity of the circuit with respect to PRs:

$$\lambda_{S2} = \lambda_{T2} + \lambda_{QF2} + \lambda_{L2} + \lambda_{QF5} + \lambda_{QF6} + \lambda_{PRs} + \lambda_{L7} + \lambda_{QF11} + \lambda_{MS3} + \\ + \lambda_{L8} + \lambda_{QF12} + \lambda_{MS4} + \lambda_{L9} + \lambda_{QF13} + \lambda_{C3} + \lambda_{L10} + \lambda_{QF14} + \lambda_{C4} + \\ + \lambda_{L11} + \lambda_{QF15} + \lambda_{C5} = \lambda_T + 8\cdot\lambda_{QF} + \lambda_{PRs} + 6\cdot\lambda_L + 2\cdot\lambda_{MS} + 3\cdot\lambda_C$$

Table II summarizes the failure intensities of the structural circuits with respect to SHRs and PRs.

TABLE II. Data for Calculating the Reliability Parameters of the Scheme With Respect to SHRs and PRs

Schematic in relation to SHRs			Schematic in relation to PRs		
№	Elements	λ – failure rate, defects/ year	№	Elements	λ – failure rate, defects/ year
1	T_1	0.015	19	T_2	0.015
2	QF_1	0.051	20	QF_2	0.051
3	L_1	0.0026	21	L_2	0.0026
4	QF_4	0.051	22	QF_5	0.051
5	QS_1	0.038	23	QF_6	0.051
6	SHRs	0.001	24	PRs	0.001
7	L_3	0.0013	25	L_7	0.0013
8	QF_7	0.051	26	QF_{11}	0.051
9	MS_1	0.095	27	MS_3	0.095
10	L_4	0.0013	28	L_8	0.0013
11	QF_8	0.051	29	QF_{12}	0.051
12	MS_2	0.095	30	MS_4	0.095
13	L_5	0.0013	31	L_9	0.0013
14	QF_9	0.051	32	QF_{13}	0.051
15	C_1	0.098	33	C_3	0.098
16	L_6	0.0013	34	L_{10}	0.0013
17	QF_{10}	0.051	35	QF_{14}	0.051
18	C_2	0.098	36	C_4	0.098
Sum of intensities λ_{S1}		0.7538	37	L_{11}	0.0013
			38	QF_{15}	0.051
			39	C_5	0.098
			Sum of intensities λ_{S2}		0.9171

To determine the change in the values of the probability of failure and failure probability functions over time, the following is used:

$$P_{1...18}(t) = e^{-\lambda_{S1}\cdot t} = e^{-(\lambda_1+\lambda_2+...+\lambda_{18})t} \quad (2)$$

$$Q_{1...18}(t) = 1 - e^{-\lambda_{S1}\cdot t} = 1 - e^{-(\lambda_1+\lambda_2+...+\lambda_{18})t} \quad (3)$$

where λ_{S1} – failure intensity of the circuit with respect to SHRs;

t – observation time equal to 6 years.

For the scheme relative to SHRs for the first year of operation:

$$P_1(t=1) = e^{-0.7538\cdot 1} = 0.471$$

$$Q_1(t=1) = 1 - e^{-0.7538\cdot 1} = 1 - 0.471 = 0.529$$

The results of calculations of reliability parameters for the given operation interval by years are given in Table III.

TABLE III. Forecasting of Reliability Indicators of the Schemes in Relation to SHRs and PRs for a Period of 6 Years

	Σλ	Year of operation of the scheme					
		1	2	3	4	5	6
$P_1(t)$	0.7538	0.471	0.221	0.104	0.049	0.023	0.011
$Q_1(t)$		0.529	0.779	0.896	0.951	0.977	0.989
	Σλ	Year of operation of the scheme					
		1	2	3	4	5	6
$P_2(t)$	0.9171	0.400	0.160	0.064	0.026	0.010	0.004
$Q_2(t)$		0.600	0.840	0,936	0.974	0.990	0.996

The frequency of maintenance in accordance with the condition:

$$P(t) = P \quad (4)$$

The data of Table III show that criterion (4) is violated in the second year of operation, then P > P(1), for the scheme with respect to SHRs: 0.85 > 0.471; for the scheme with respect to PRs: 0.85 > 0.400.

Therefore, t = 1 and maintenance should be annual, which satisfies the requirements of GOST 30852.16-2002 on maintenance at least once every 12 months.

According to the data in Table III, the change in the function of probability of failure-free operation and probability of occurrence of failure in time for the schemes relative to SHRs (1) and PRs (2) (Fig. 3).

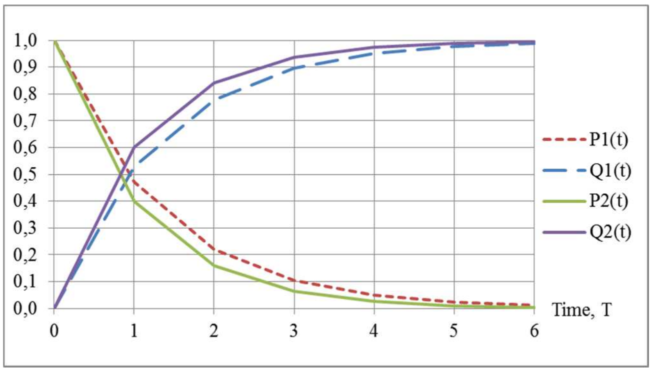

Fig 3. Graphs of change of functions of probability of failure-free operation and failure occurrence in time

In Fig. 3: $P_1(t)$, $Q_1(t)$ – probabilities of failure-free operation and occurrence of failure in time for the scheme with respect to SHRs; $P_2(t)$, $Q_2(t)$ – for the scheme with respect to PRs.

The graphs of Fig. 3 show that the probabilities of time of failure-free operation for the schemes relative to SHRs and PRs differ in the first year of operation – by 17.75 %, in the second – by 38.13 %, in the third – by 62.5 %, which is explained by the decrease in the reliability level of the scheme by years and, starting from the fourth year are practically equal to zero. The investigated characteristics correspond to the exponential law of distribution of reliability parameters.

This method of parameter estimation is recommended to be used to specify the frequency of maintenance and repair of electrical equipment in the system of in-plant power supply.

Further consider the method of estimation of reliability parameters of schemes concerning each connection for SHRs and PRs.

Fig. 4 shows the estimated reliability schemes with respect to each connection for SHRs.

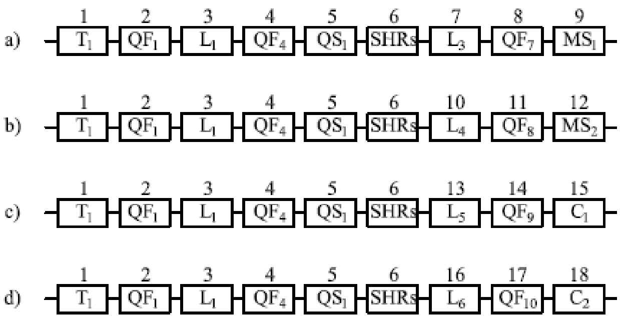

Fig 4. Calculated reliability diagrams for a) the first, b) the second, c) the third and d) the fourth connections of SHRs

The failure rates of the circuit with respect to each bay using the data in Table I.

1. For the first bay

$$\lambda_1 = \lambda_{T1} + \lambda_{QF1} + \lambda_{L1} + \lambda_{QF4} + \lambda_{QS} + \lambda_{SHRs} + \lambda_{L3} + \lambda_{QF7} + \lambda_{MS1} =$$
$$= \lambda_T + 3\cdot\lambda_{QF} + 2\cdot\lambda_L + \lambda_{QS} + \lambda_{SHRs} + \lambda_{MS} =$$
$$= 0.015 + 3\cdot 0.051 + 2\cdot 0.026 + 0.038 + 0.001 + 0.095 = 0.354$$

2. For the second bay

$$\lambda_2 = \lambda_{T1} + \lambda_{QF1} + \lambda_{L1} + \lambda_{QF4} + \lambda_{QS} + \lambda_{SHRs} + \lambda_{L4} + \lambda_{QF8} + \lambda_{MS2} =$$
$$= \lambda_T + 3\cdot\lambda_{QF} + 2\cdot\lambda_L + \lambda_{QS} + \lambda_{SHRs} + \lambda_{MS} =$$
$$= 0.015 + 3\cdot 0.051 + 2\cdot 0.026 + 0.038 + 0.001 + 0.095 = 0.354$$

3. For the third bay

$$\lambda_3 = \lambda_{T1} + \lambda_{QF1} + \lambda_{L1} + \lambda_{QF4} + \lambda_{QS} + \lambda_{SHRs} + \lambda_{L5} + \lambda_{QF9} + \lambda_{C1} =$$
$$= \lambda_T + 3\cdot\lambda_{QF} + 2\cdot\lambda_L + \lambda_{QS} + \lambda_{SHRs} + \lambda_C =$$
$$= 0.015 + 3\cdot 0.051 + 2\cdot 0.026 + 0.038 + 0.001 + 0.098 = 0.357$$

4. For the fourth bay

$$\lambda_4 = \lambda_{T1} + \lambda_{QF1} + \lambda_{L1} + \lambda_{QF4} + \lambda_{QS} + \lambda_{SHRs} + \lambda_{L6} + \lambda_{QF10} + \lambda_{C2} =$$
$$= \lambda_T + 3\cdot\lambda_{QF} + 2\cdot\lambda_L + \lambda_{QS} + \lambda_{SHRs} + \lambda_C =$$
$$= 0.015 + 3\cdot 0.051 + 2\cdot 0.026 + 0.038 + 0.001 + 0.098 = 0.357$$

Probabilities of failure-free operation and occurrence of failure over time:

$$P_{1,2}(t=1) = e^{-\lambda_1\cdot t} = e^{-0.354\cdot 1} = 0.702$$

$$Q_{1,2}(t=1) = 1 - e^{-\lambda_1\cdot t} = 1 - e^{-0.354\cdot 1} = 0.298$$

Fig. 5 shows the calculated reliability diagrams with respect to each connection for the PRs.

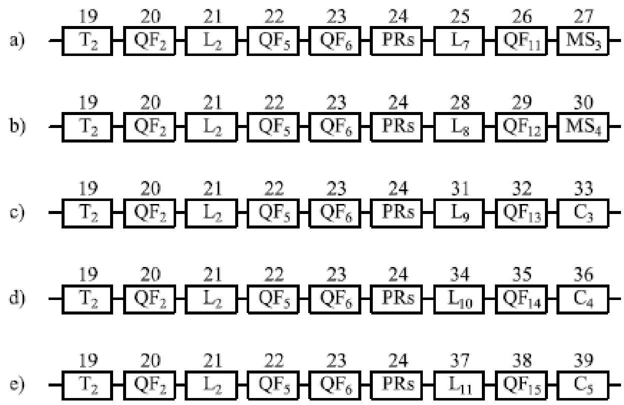

Fig 5. Calculated reliability diagrams for a) the fifth, b) the sixth, c) the seventh, d) the eighth and e) the ninth connections of the PRs

Failure intensities with respect to each feeder PRs are calculated in the same way. The results of calculations of schemes with respect to each bay of SHRs and PRs are shown in Table IV.

TABLE IV. RESULTS OF CALCULATIONS OF CIRCUIT PARAMETERS WITH RESPECT TO EACH CONNECTION OF SHRS AND PRS

№ of connect in relation to SHRs	**Failure rate, defects/ year**		Year					
			1	2	3	4	5	6
1, 2	**0.354**	$P_{1,2}(t)$	0.702	0.493	0.346	0.243	0.170	0.120
		$Q_{1,2}(t)$	0.298	0.507	0.654	0.757	0.830	0.880
3, 4	**0.357**	$P_{3,4}(t)$	0.700	0.490	0.343	0.240	0.168	0.117
		$Q_{3,4}(t)$	0.300	0.510	0.657	0.760	0.832	0.883
№ of connect in relation to PRs	**Failure rate, defects/ year**		Year					
			1	2	3	4	5	6
5, 6	**0.367**	$P_{5,6}(t)$	0.693	0.480	0.333	0.230	0.160	0.111
		$Q_{5,6}(t)$	0.307	0.520	0.667	0.770	0.840	0.889
7, 8, 9	**0.37**	$P_{7,8,9}(t)$	0.691	0.477	0.330	0.228	0.157	0.109
		$Q_{7,8,9}(t)$	0.309	0.523	0.670	0.772	0.843	0.891

Fig. 6 shows the graphs of change of functions of probability of failure-free operation and occurrence of failure in time with respect to each connection SHRs and PRs.

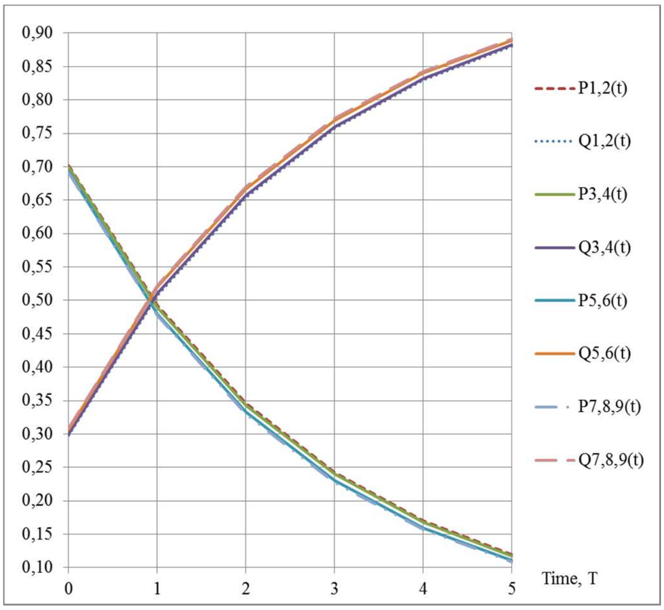

Fig 6. Graphs of change of functions of probability of failure-free operation and occurrence of failure in time with respect to each bay of SHRs and PRs

Based on the research results (Table IV, Fig. 6), it was found that the functions of probability of failure-free operation and failure occurrence in time obey the exponential law of parameter distribution. This method is recommended for evaluating the reliability of the circuit with respect to each connection.

IV. LOGICAL-PROBABILISTIC METHOD

For the design scheme (Fig. 1), we determine the frequency of outages of the first and second busbar sections by building a tree of failures with respect to the power supply sources SHRs and PRs and with respect to each feeder separately (using the example of the first and fifth feeders).

The notation of the elements used in Figure 7 and in the formulas is presented in Table V.

TABLE V. SYMBOLS

Abbreviation	**Abbreviation designation**
T	Transformer 10/0,4 kV
QF	Circuit breaker
L	Cable line 0,4 kV
QS	Switch
MS	Magnetic starter
C	Contactor

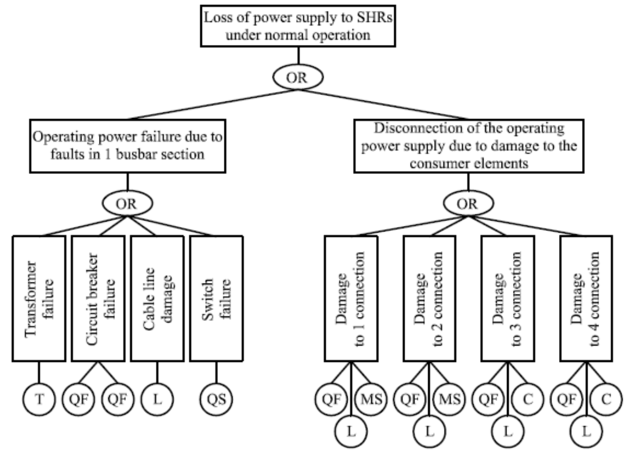

Fig 7. Failure tree for estimating the frequency of power loss to SHRs

Failure function in case of loss of power supply to SHRs (Fig. 7) will be written in the following form:

$$X(SHRs)=[T+QF+QF+L+QS]+\begin{bmatrix}(QF+L+MS)+(QF+L+MS)+\\+(QF+L+C)+(QF+L+C)\end{bmatrix}=$$
$$=T+2\cdot QF+L+QS+2\cdot(QF+L+MS)+2\cdot(QF+L+C)=$$
$$=T+6\cdot QF+5\cdot L+QS+2\cdot MS+2\cdot C=$$
$$=0.015+6\cdot 0.051+5\cdot 0.026+0.038+2\cdot 0.095+2\cdot 0.098=0.973$$

Failure function in case of loss of power supply of PRs will be written in the form of:

$$X(PRs)=[T+QF+QF+QF+L]+\begin{bmatrix}(QF+L+MS)+(QF+L+MS)+\\+(QF+L+C)+(QF+L+C)+(QF+L+C)\end{bmatrix}=$$
$$=T+3\cdot QF+L+2\cdot(QF+L+MS)+3\cdot(QF+L+C)=$$
$$=T+8\cdot QF+6\cdot L+2\cdot MS+3\cdot C=$$
$$=0.015+8\cdot 0.051+6\cdot 0.026+2\cdot 0.095+3\cdot 0.098=1.063$$

Failure function in case of power failure of the first bay SHRs:

$$X(1)=[T+QF+QF+L+QS]+[(QF+L+MS)+QF+QF+QF]=$$
$$=T+2\cdot QF+L+QS+QF+L+MS+3\cdot QF=$$
$$=T+6\cdot QF+2\cdot L+QS+MS=$$
$$=0.015+6\cdot 0.051+2\cdot 0.026+0.038+0.095=0.506$$

Failure function in case of power failure of the fifth bay PRs:

$$X(5)=\left[T+QF+QF+QF+L\right]+\left[(QF+L+MS)+QF+QF+QF+QF\right]=$$
$$=T+3\cdot QF+L+QF+L+MS)+4\cdot QF=$$
$$=T+8\cdot QF+2\cdot L+MS=$$
$$=0.015+8\cdot 0.051+2\cdot 0.026+0.095=0.57$$

V. Conclusion

As a result of researches it is established that the investigated methods can be used for estimation of reliability of the scheme of low-voltage network. The method of calculation with respect to the SHRs and PRs is recommended for specifying the frequency and timing of maintenance and repair of electrical equipment in the system of in-plant power supply.

The method of calculation with respect to the connections SHRs and PRs can be used to analyze the reliability of the network circuit sections. The results of calculations of circuit reliability parameters using the logical-probabilistic method (failure tree) can be used to estimate the frequency of power loss of both the SHRs and PRs, as well as each connection separately.

References

[1] E.Yu. Abdullazyanov, E.I. Gracheva, E.E. Ibatullin, P.M. Petrova, T.V. Sinyukova, “Analysis of the main indicators of industrial production of facilities of average capacity,” KAZAN STATE POWER ENGINEERING UNIVERSITY BULLETIN. 15; 2(58), pp. 93-108, 2023.

[2] I.Z. Bagautdinov, “Reliability calculation,” Theory and practice of modern science. №4 (22), 2017. (In Russ.).

[3] A.V. Vinogradov, R.A. Perkov, “Analysis of electrical equipment damageability of electrical networks and justification of measures to improve the reliability of power supply to consumers,” Vestnik of NSTEI. №12 (55), 2015.

[4] E.I. Gracheva, O.V. Naumov, Z.M. Shakurova, “INFORMATION PARAMETRICAL CHARACTERISTICS OF RELIABILITY OF LOW-VOLTAGE COMMUTATION APPARATES OF INDUSTRIAL COMPLEXES,” KAZAN STATE POWER ENGINEERING UNIVERSITY BULLETIN. №3 (39), 2018. (In Russ.).

[5] E.I. Gracheva, R.R. Sadykov, R.R. Husnutdinov, R.E. Abdullazianov, “Investigation of reliability parameters of low-voltage switching devices according to operational data of industrial enterprises,” Izvestiya Vuzov. Problems of power engineering. №1-2, 2019. (In Russ.).

[6] E.I. Gracheva, R.R. Sadykov, R.R. Husnutdinov, A.N. Alimova, “RELIABILITY AND COMPONENT OF LOW-VOLTAGE DISPLAYING DEVICES OF INTERNAL ELECTRICAL SUPPLY,” KAZAN STATE POWER ENGINEERING UNIVERSITY BULLETIN. №1 (41), 2019. (In Russ.).

[7] V.I. Zatsepina, S.S. Astanin, “Reliability analysis of the electrical power supply system with taking into account the fail-safety of the relay protection,” Vestnik of TSTU. №4, 2020. (In Russ.).

[8] Catalog of electrical products KEAZ: website. – URL: https://keaz.ru/catalog (date of reference: 10.08.2023)

[9] Catalog of electrical products IEK: site. – URL: https://www.iek.ru/products/catalog/ (access date: 10.08.2023)

[10] Schneider Electric product catalog: website. – URL: https://www.se.com/ww/en/ (date of address: 10.08.2023)

[11] ABB Product Catalog: website. – URL: https://global.abb/group/en (date of address: 10.08.2023)

[12] Legrand product catalog: website. – URL: https://legrand.ru/services/library/ (date of address: 10.08.2023)

[13] E.A. Konyukhova, E.A. Kireeva, “Reliability of power supply of industrial enterprises,” Biblioteka elektrotechnika. Issue 12(36). Moscow: NTF "Energoprogress", "Energetik", pp. 93, 2001.

[14] E.A. Konyukhova, “RESEARCH AND ANALYSIS OF THE RELIABILITY OF SCHEMES WHEN COMPARING OPTIONS OF INDUSTRIAL ELECTRICAL SUPPLY SYSTEMS WITH DOUBLE-TRANSFORMATOR SUBSTATIONS,” KAZAN STATE POWER ENGINEERING UNIVERSITY BULLETIN. №4 (40), 2018.

[15] R.M. Petrova, E.Yu. Abdullazyanov, E.I. Grachieva, S. Valtchev, Yousef Ibragim, “Study of probability characteristics of reliability of electrical equipment in internal power supply systems,” KAZAN STATE POWER ENGINEERING UNIVERSITY BULLETIN. 15; 1(57):93-105, 2023.

[16] R.R. Sadykov, “Reliability assessment of low-voltage shop networks of industrial power supply,” Izvestiya vuzov. Problems of power engineering. №5-6, 2017.

[17] A.R. Safin, T.I. Petrov, A.M. Kopylov, “METHOD OF DESIGN AND TOPOLOGICAL OPTIMIZATION OF ROTORS OF SYNCHRONOUS MOTORS WITH PERMANENT MAGNETS,” Bulletin of KSEU. No. 2 (46). pp. 45-53, 2020. (In Russ.).

[18] Yu.A. Secretarev, A.A. Gorshunov, D.A. Menyaykin, “Modeling of the technical state of the equipment of the power supply systems of the mono-consumers taking into account the circuit reliability,” Vesti of the higher educational institutions of the Chernozem region. T. 18, № 3 (69). – pp. 3-14, 2022. DOI: 10.53015/18159958_2022_18_3_3.

[19] A.N. Shpiganovich, A.A Shpiganovich, E.P. Zatsepin, “To the analysis of the failure-free operation of the electrical systems of the industrial enterprises,” Izvestiya TulSU. Technical Sciences. №12, 2018.

[20] T.I. Petrov, A.R Safin, "Modification of the synchronous motor model for topological optimization," E3S Web of Conferences, 178, paper #01016, 2020. (In Russ.).

[21] E. Gracheva, R. M. Petrova, S. Valtchev and T. Sinyukova. 2023. "Study of Probability Characteristics of the Reliability of Electrical Equipment in Internal Power Supply Systems," 2023 5th Global Power, Energy and Communication Conference (GPECOM), Nevsehir, Turkiye, pp. 460-465, doi: 10.1109/GPECOM58364.2023.10175821.

[22] S. P. Ivanova, D. A. Pestryaev, T. V. Myasnikova and O. V. Sveklova. 2022. "Reliability assessment of switching process control equipment," 2022 4th International Youth Conference on Radio Electronics, Electrical and Power Engineering (REEPE), Moscow, Russian Federation, pp. 1-6, doi: 10.1109/REEPE53907.2022.9731393.

[23] A. A. Gasparyan and G. V. Komarova. 2018. "Reliability assessment of a technical equipment complex of a monitoring system of parameters for electrical equipment taking into account reserve elements," 2018 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus), Moscow and St. Petersburg, Russia, pp. 632-635, doi: 10.1109/EIConRus.2018.8317176.

[24] A. Shpiganovich, A. Shpiganovich and A. Boychevskiy. 2021. "Assessment of Reliability of Individual Units Electrical Equipment by Characteristics Power Supply Systems," 2021 3rd International Conference on Control Systems, Mathematical Modeling, Automation and Energy Efficiency (SUMMA), Lipetsk, Russian Federation, pp. 1088-1090, doi: 10.1109/SUMMA53307.2021.9632126.

[25] X. Shenggang, L. Jin, L. Jiale and C. Rushan. 2019. "Research on Reliability and Working Life Assessment Method of Mechanical and Electrical Products in Weapon Equipment," 2019 4th International Conference on System Reliability and Safety (ICSRS), Rome, Italy, pp. 364-368, doi: 10.1109/ICSRS48664.2019.8987718.

[26] Y. Soluyanov, A. Fedotov, A. Akhmetshin, V. Khalturin, “Monitoring of electrical consumption, including self-isolation during the COVID-19 pandemic,” in 2020 Ural Smart Energy Conference, 2020, art. no. 9281179, pp. 80-83, doi: 10.1109/USEC50097.2020.9281179.

[27] R. F. Gibadullin, G. A. Baimukhametova and M. Y. Perukhin, "Service-Oriented Distributed Energy Data Management Using Big Data Technologies," 2019 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), Sochi, Russia, 2019, pp. 1-7, doi: 10.1109/ICIEAM.2019.8743064.