Informatics and Control Problems 42 Issue 1 (2022)
journal homepage: www.icp.az

Quantitative analysis of the operational reliability of overhead power lines

E.M. Farhadzadeh*, A.Z. Muradaliyev, S.A. Abdullayeva

Azerbaijan Scientific-Research and Design-Prospecting Institute of Energetic, Baku, Azerbaijan

ARTICLE INFO

Article history:
Received 27.10.2021
Received in revised form 11.11.2021
Accepted 24.11.2021
Available online 25.05.2022

Keywords:
Analysis
Operational reliability
Overhead power lines
Automated system
Classification
Features
Varieties

ABSTRACT

The relevance of ensuring the efficiency of equipment, devices and installations (facilities) of electric power systems increases every year, becoming the most important problem of maintaining energy security. The decrease in work efficiency is due to a number of factors, but, above of all, due to an increase in the relative number of objects whose service life exceeds the standard value. An illustration of the methodology for quantifying, comparing and ranking the monthly average values of the operational reliability indicators of 110 kV and higher overhead power lines is given in order to identify and restore the wear of the least reliable lines.

1. Introduction

Currently, the service life of more than half of overhead power lines (hereinafter OPL) of electric power systems (hereinafter EPS) exceeds the standard value, which leads to a decrease in their efficiency [1]. To limit the consequences of this change, risk-oriented approaches are being developed for the organization of their maintenance and repair (hereinafter MaR) [2-4]. Their essence boils down to the theory of production assets management by ensuring a balance between operating costs and the risk of damage.

It is known that [5]:

- there is no methodology for calculating the technical condition (hereinafter TC) index. There is no monitoring of TC of OPL, the methods used to assess the risk of damage are subjective;
- there are no operational recommendations to improve the OPL performance.

TC of OPL determines the reliability and safety of their work. Therefore, it is relevant to assess the operational reliability indicators by analogy with the individual reliability of power units [6]. The seeming simplicity of this solution is deceptive, and, first of all, because there are no statistics of continuous monitoring TC of the OPL, and it is impossible to estimate the reliability indicators of specific OPLs based on the statistics of failure within one month due to their small number. When comparing and ranking indicators of operational reliability, the use of the mathematical apparatus for analyzing homogeneous statistical data is unacceptable, because the data are multivariate and scarce [7].

*Corresponding author.
E-mail addresses: elmeht@rambler.ru (E.M. Farhadzadeh), aydin_murad@yahoo.com (A.Z. Muradaliyev), samira.afqan@yandex.ru (S.A. Abdullayeva).

www.icp.az/2022/1-07.pdf https://doi.org/10.54381/icp.2022.1.07

We also recall that:

- the efficiency of operation of EPS facilities today is understood as a *joint accounting of efficiency, reliability of operation and safety of service*;
- such an expanded concept of efficiency is due to an increase in the number of facilities requiring *operational* inspection not only for efficiency, but also for reliability and safety;
- operational survey is understood as a *quantitative assessment of performance efficiency*;
- if, for design purposes, a methodology for quantitative assessment of reliability indicators is developed and is widely used in practice to compare the design options of facilities being designed, then there is *no* methodology for calculating operational reliability indicators for solving operational problems. The science intensity, cumbersomeness and laboriousness of calculating operational reliability indicators requires *a transition to automated systems* of assessment, comparison and ranking, with monthly submission of guidelines for increasing TC to the management of EPS facilities and electrical enterprises. Implementation of automated systems for analyzing the TC of EPS facilities allows a major power grid enterprise to save tens of millions of rubles [5];
- unfortunately, there is no methodology for quantitative assessment of service safety indicators not only when solving operational problems, but also when designing EPS facilities [5];
- the identity of the methodological approach to the assessment, comparison and ranking of EPS facilities does not affect the discrepancy of the calculation algorithms due to the fundamental features of operation of these facilities.

2. Initial data and indicators of operational reliability OPL of EPS

The original OPL data is represented by constant and variable parts. The constant part is compiled on the basis of the OPL nominal data and includes: line name, PGF name, nominal voltage, year of commissioning, bearing material, line length, number of circuits. The variable part is compiled on the basis of operational logs and includes the following information about the OPL state change: OPL name, nominal voltage, date (month, day, hour) of shutdown and start, type of shutdown (emergency, on emergency or planned request). This information is entered into special database tables (we will designate them, respectively, as tables A and B) and are used to assess the operational reliability indicators of OPL of EPS. These averaged indicators theoretically allow us to compare the operational reliability of a number of EPS and are necessary to monitor the nature of the change in the OPL reliability in the accounting month compared to the reliability in the previous month.

For illustrative purposes, Table 1 shows the results of the assessment of indicators characterizing the initial data of OPL of EPS in one of the accounting months and their operational reliability.

Table 1

Illustration of initial data and estimates of the operational reliability indicators of 110 kV and higher OPL of EPS

Indicators	Symbols	Unit of measurement	Quant. estimate	Calculation formula
Initial data os OPL				
Number of OPL	$n_{с,л}$	pcs	273	
Total length	$L_{с,л}$	km	7918.5	$L_c = \Sigma L_i$
Number of aut. shutdowns	$n_{с,а}$	pcs	58	
- same but with success. ARC	$n_{с,р}$	pcs	50	
Number of shutdowns on aut. request	$n_{с,а,з,}$	pcs	94	

Duration of aut. downtime	$T_{\text{c,a}}$	h	407	$T_{\text{c,a}}=T_{\text{a}}+\tau_{\text{a.з.}}$
Number of CT OPL	$n^{\text{ст}}_{\text{с,л}}$	pcs	164	
Total length of CT	$L^{\text{ст}}_{\text{с}}$	km	4853	$L^{\text{ст}}_{\text{с}}=\Sigma L^{\text{ст}}_{\text{i}}$
Total service life of CT	$\Delta T^{\text{ст}}_{\text{с}}$	year	3718	$\Delta T^{\text{ст}}_{\text{с}}=\Sigma \Delta T^{\text{ст}}_{\text{i}}$
Operational reliability indicators				
Specific number of aut. sh.	$\lambda^*_{\text{с,а}}$	sh/year	12.9	$\lambda^*_{\text{с,а}}=12\cdot 10^2 n_{\text{с,а}} / L_{\text{с,л}}$
Specific number of aut. sh. with success. ARC	$\lambda^*_{\text{с,р}}$	sh/year	7.6	$\lambda^*_{\text{с,р}}=12\cdot 10^2 n_{\text{с,р}} / L_{\text{с,л}}$
Specific number of sh. on aut. request	$\omega^*_{\text{с,а.з.}}$	sh/year	14.2	$\omega^*_{\text{с,а.з}}=12\cdot 10^2 n_{\text{с,а.з}} / L_{\text{с,л}}$
Av. duration of downtime in maintenance on aut. request	$M^*(\tau_{\text{а.з.}})$	h	4.3	$M^*(\tau_{\text{а.з.}})=\sum_{i=1}^{n_{\text{с,а.з}}} \tau_{\text{а.з,i}} / n_{\text{с,а.з}}$
Av. duration of downtime in aut. maintenance	$M^*(\tau_{\text{а.р.}})$	h	3.3	$M^*(\tau_{\text{а.р.}})=\sum_{i=1}^{n_{\text{а.р}}} \tau_{\text{а.р,i}} / n_{\text{а.р}}$
Rel. duration of downtime in aut. maintenance	$K^*_{\text{а.р.}}$	%	0.71	$K^*_{\text{а.р.}}=10^4 T_{\text{с,а}} / (T_{\text{М}}\cdot L_{\text{с,р}})$
Average length of OPL	$M^*_{\text{с}}(L)$	km	29	$L_{\text{с,ср}}=L_{\text{с,л}}/n_{\text{с,л}}$
Rel. number of CT OPL	$\delta n^{\text{ст}}_{\text{с,л}}$	%	60.1	$\delta n^{\text{ст}}_{\text{с,л}}=10^2 n^{\text{ст}}_{\text{с,л}} / n_{\text{с,л}}$
Rel. length of CT OPL	$\delta L^{\text{ст}}_{\text{с,л}}$	%	61.3	$\delta L^{\text{ст}}_{\text{с,л}}=10^2 L^{\text{ст}}_{\text{с,л}} / L_{\text{с,л}}$
Average service life of CT OPL	$M^*_{\text{с}}(\Delta T^{\text{ст}})$	year	22.7	$M^*_{\text{с}}(\Delta T^{\text{ст}})=\Delta T^{\text{ст}}_{\text{с}} / n^{\text{ст}}_{\text{с,л}}$
Average length of CT OPL	$M^*_{\text{с}}(L^{\text{ст}})$	km	23.6	$M^*_{\text{с}}(\Delta T^{\text{ст}})=L^{\text{ст}}_{\text{с}} / n^{\text{ст}}_{\text{с,л}}$

Note: $T_{\text{a}} \ll T_{\text{a.з.}}$; $T_{\text{м}}$ – duration of the accounting month, CT – designation of OPL, service life of which exceeds the standard value

To compare these indicators with the reliability indicators given in reference books and literature on the reliability of EPS facilities, the monthly average estimates of the reliability indicators of OPL were multiplied by the number of months in a year (12) and reduced to a conventional 100 km long line.

As expected, the specified monthly average values of operational reliability indicators may differ significantly from the average annual values due to the uneven distribution of the intensity of the impact of perturbing factors (e.g., thunderstorm activity) throughout the year. Nevertheless, the reduced average monthly value of the estimate of the operational reliability indicator significantly exceeding the average annual value indicates insufficient protection of OPL from the main influencing factor in the accounting month.

3. Initial data and operational reliability indicators OPL of PGF of EPS

The possibility of comparing the operational reliability of the OPL of PGF of EPS is one of the most pressing issues for EPS and, above all, because it allows optimizing the total operating costs of EPS. The methodology for assessing operational reliability indicators of OPL of PGF of EPS is similar to the methodology for assessing operational reliability indicators OPL EPS in general. The essential difference is that the information about the nominal data and changes in the technical condition of the OPL must be classified according to the attribute "PGF name". Here, similar to the data in Table A, tables AN are compiled, where N is the conventional ordinal number of PGF of EPS, which are also practically unchanged, but unlike Table A, they do not contain the column "PGF name". The automated generation of AN tables is not difficult.

Of course, when classifying nominal data by PGF manually, the grouping process is laborious and cumbersome. But it is carried out only once. Formation of BN tables turns out to be much more difficult, since in table B, and of course in the operational logs, there is no information about the name of the PGF, to which the OPL belongs, the state of which has changed. Searching for the nominal data of a particular OPL among the hundreds of OPLs in question is tedious, and the risk of a wrong solution turns out to be unacceptably high. An automated search can, of course, solve this problem without error. But even in this case, the amount of time spent turns out to be unacceptably large.

We propose:

- transforming the accepted sequence of OPL placement (as a rule, by voltage class) into a sequence of OPL names in alphabetical order, indicating the PGF name of each OPL (an analogue of this is a telephone directory);
- determining the group of OPLs, the first letter of the name of which coincides with the first letter of the name of the OPL being identified;
- among the relatively small number of OPLs of this group (several dozen OPLs maximum), it is quite simple to identify the desired PGF to which this OPL belongs.

Table 2

Results of the calculation of initial data and estimates of the operational reliability indicators

Indicator	Unit of meas.	PGF N							
		1	2	3	4	5	6	7	8
Initial data									
$n_{п,л}$	pcs	49	22	28	7	29	34	69	18
$L_{п}$	km	1600	561	850	220	1026	604	1253	1802
$n_{п,а}$	pcs	31	0	4	1	14	6	23	18
$n_{п,а.р.}$	pcs	25	0	3	1	7	3	9	3
$n_{п,а,з,}$	pcs	20	2	7	0	15	13	23	14
$T_{п,а}$	h	97.4	2.5	21.5	0	97.5	60	83.7	44.4
$n^{ст}_{п,л}$	pcs	38	16	20	7	13	18	41	11
$L^{ст}_{п,л}$	km	1214	392	633	220	403	470	610	911
$\Delta T^{ст}_{п}$	year	653	256	403	109	291	442	1340	224
Operational reliability indicators									
$\lambda^{*}_{ï,à}$	sh/year	**23.3**	0	5.6	5.5	16.4	8.2	17.6	4.0
$\lambda^{*}_{п,р}$	sh/year	**18.8**	0	4.5	5.5	8.2	6.0	8.6	2.0
$\omega^{*}_{п,а.з.}$	sh/year	15	4.2	9.9	0	17.6	**25.8**	22	9.3
$M^{*}(\tau_{а.з.})$	h	4.9	1.5	3	0	**6.5**	4.6	3.6	3.8
$K^{*}_{п}$	%	0.85	0.061	0.35	0	1.32	**1.38**	0.93	0.34
$M^{*}_{с}(L)$	km	327	25.8	30.4	31.4	**35.4**	17.8	12.2	100.1
$\delta n^{ст}_{п,л}$	%	77.6	72.7	71.4	**100**	44.8	52.9	59.4	61.1
$\delta L^{ст}_{п,л}$	%	45.9	69.1	74.5	**100**	39.3	77.8	48.7	50.6
$M^{*}_{п}(\Delta T^{ст})$	year	17.2	16.0	20.2	15.6	22.4	24.6	**32.7**	20.4
$M^{*}_{п}(L^{ст})$	km	31.9	24.5	31.7	31.4	31	26.1	14.9	***82.8***

Table 2 shows the results of calculations of operational reliability indicators of OPL of PGF of EPS. This data allows:

1. Comparing and ranking PGFs. For instance, according to the indicator $\lambda^{*}_{\text{ï,à}}$, the ranking of PGF in order of increasing reliability is: PGF1, PGF7, PGF5, PGF6, PGF3, PGF4, PGF8, and PGF2. If we take into account that for EPS as a whole, the value of $\lambda^{*}_{\text{c,à}}$ is equal to 12.9 sh/year (see Table 1), then we can conclude that the least reliable are the OPL in PGF1, PGF7 and PGF5.
2. Note that the *ranking results depend on the operational reliability indicator*. For instance, for the indicator $\omega^{*}_{\text{п,а.з.}}$ the least reliable are the OPL in PGF6, and for the indicator $\text{M}^{*}_{\text{п}}(\Delta\text{T}^{\text{ст}}_{\text{п}})$ - in PGF7. To overcome this ambiguity of the solution, it is necessary either to select for comparison one of the ten operational reliability indicators or to calculate an integral indicator that takes into account the significance of each of the 10 indicators. The second method is more reliable, but it also requires solving a number of problems, such as assessing the degree of relationship between the operational reliability indicators, overcoming the difference in their dimensionality and scale, preserving the physical essence. [8].
3. Increasing the reliability of comparison and ranking of operational reliability indicators requires taking into account their random nature. In the first approximation, the list of PGFs is classified into three groups. The indicators of the first group of OPLs of PGF randomly differ from the same indicator for the OPL of EPS as a whole, the second group – non-randomly less than the indicator for OPL of EPS, and the third group – non-randomly higher than the indicator for OPL of EPS.

4. Analysis of OPL of PGF with the lowest operational reliability

Before carrying out this analysis, let us answer one non-standard question: how much the operational reliability of OPL of EPS can be increased if the reliability of OPL of EPS1 can be increased at least to the level of operational reliability of OPL of EPS in the accounting month. According to Table 1 $\lambda^{*}_{c,a} = \frac{12\cdot 10^{2} n_{c,a}}{L_{c,л}} = 12\cdot 10^{2}\cdot\frac{85}{7918=12.15}\ sh/year$, and according to Table 2 for PGF1 $\lambda^{*}_{п,a} = \frac{12\cdot 10^{2}\cdot n_{п,a}}{L_{п,л}} = 12\cdot 10^{2}\,\frac{31}{1600} = 23.3\ sh/year.$

It is easy to see that the approximate equality $\lambda^{*}_{\text{c,à}}$ and $\lambda^{*}_{\text{ï,à}}$ can be achieved by reducing the value of $\lambda^{*}_{\text{п,а}}$ by about half. At the same time, the specific number of automatic shutdowns of OPL of EPS will decrease by $10^{2}\cdot 15/85=17.6\%$. Such a dramatic change is certainly tempting.

The purpose of the OPL PGF1 analysis is to identify the varieties of features for which the specific number of automatic shutdowns of OPL of identify will most exceed the estimate of $\lambda^{*}_{\text{ï,à}}$, for OPL of PGF1.

For illustrative purposes, Table 3 shows the calculation results for the specific number of automatic shutdowns when classifying OPL of PGF1 by voltage class, service life, bearing material and OPL length. Analysis of this data shows:

- the dependence of the specific number of automatic shutdowns of OPL on the voltage class, known from reference books, remains unchanged according to long-term data – with an increase in the rated voltage, the specific number of automatic shutdowns of OPL decreases;

- the dependence of the specific number of automatic shutdowns of OPL on the service life is clearly confirmed. It is somewhat overestimated in the initial period of operation and increases significantly when the service life is exceeded ΔT=53 years.
- at the initial stage, the classification of OPLs according to the material of the bearings [metal or mixed (metal, reinforced concrete or wood)] turned out to be impractical, since their significance is approximately the same;
- most often automatically shut down are the OPLs whose length is in the interval (31÷60) km.

Table 3

An illustration of the significance of the varieties of features that characterize operational reliability of OPL of PGF1

Name of variety of features		Indicators		
		n_a, pcs	$L_л$, km	λ^*, sh/year
PGF1		31	1600	23.3
Voltage class, kV	330	2	268	9.0
	220	5	284	21.1
	110	24	1048	27.5
Service life, year	≤ 17	6	228	31.6
	18-35	-	7.2	-
	36-52	4	654.8	7.5
	≥ 53	21	710	35.5
Bearing material	Metal	10	513.3	23.4
	Mixed	21	1086.7	23.2
Length of the line, km	≤ 30	4	330.2	14.5
	30-60	20	613.3	39.2
	60-90	6	542.5	13.3
	≥ 90	1	114	10.5

Table 4

Identification of the most significant variety of features for OPL of PGF1 with L=30-60 km.

Name of variety of features		Indicators		
		n_a, pcs	$L_л$, km	λ^*, sh/year
PGF1, $L_л$=30-60 km		20	613.3	39.2
Voltage class, kV	330	-	-	
	220	2	78.7	30.4
	110	18	534.6	40.4
Service life, year	≤ 17	4	94.9	50.6
	18-35	-	-	-
	36-52	2	202	119
	≥ 53	14	316.4	53.1
Bearing material	Metal	5	252.7	19.7
	Mixed	15	360.6	41.5

Table 5

Results of the third stage of classification OPL of PGF 1

Name of variety of features		Indicators		
		n_a, pcs	$L_л$, km	λ^*, sh/year
PGF1, $L_л$=30-60 km; $\Delta T_{сл}$>53 years		14	316.4	53.1
Voltage class	220	-	-	-
	110	14	316.4	53.1
Bearing material	Metal	5	173.3	34.6
	Mixed	9	143.1	75.5

To identify the features of OPLs with a length of 31 to 60 km, Table 4 shows the results of their classification according to the characteristics: voltage class, service life and bearing material. The calculation results allow us to conclude that:

- the significance of the varieties of the "voltage class" attribute has changed little. Only the excess of the specific number of automatic shutdowns of 110 kV OPL over 220 kV OPL became clearer;
- the dependence of the specific number of automatic shutdowns of OPL on the service life has also remained unchanged;
- but the higher reliability of OPL on metal supports, known from the operational experience, has been confirmed – the specific number of automatic shutdowns is almost twice less;
- the largest specific number of automatic shutdowns is observed in OPLs whose service life is 1.5 times higher than the standard value. Since the length of these lines is 316.4 km, and the number of OPLs is 7, let us clarify the significance of these OPLs by classifying them according to the remaining two features, stress class and bearing material. The calculation results are shown in Table 5.

  Analysis of this data shows that
- the greatest significance of the varieties of features established at the second stage of the classification – OPL with $\Delta T>53$ years relates entirely to OPL with $U_н=110$ kV.
- a significant increase in the reliability of operation of OPLs on metal bearings compared to OPL on mixed bearings is manifested at the third stage.

Let us sum up the results obtained. It has been established that:

- 110 kV OPL on mixed bearings with a length of 30 to 60 km, the service life of which exceeds one and a half of the nominal service life, are subject to increase in the reliability of operation in PGF1;
- it is easy to see that it is for these varieties of features that the intuitive selection of OPLs subject to TC certification and overhaul is carried out;
- the recommended method allows establishing the list of OPLs to be restored in PGF automatically based on operational statistics. It refers to risk-based approaches since it significantly reduces the risk of erroneous solutions;
- with all the obvious cumbersomeness and laboriousness, the apparent simplicity of the OPL operational reliability analysis is deceiving, primarily because when comparing and ranking estimates of operational reliability indicators, their random nature was not taken into account, and thus the recommendations were not specified. The possibility of a random discrepancy is objective and indicates the inexpediency of classification, and the use of the recommended methods and algorithms requires an unconditional transition to automated systems for analyzing operational reliability.

5. Conclusion

1. The developed methods and algorithms for assessing, comparing and ranking the indicators of operational (monthly average) operational efficiency (economy, reliability and safety), practical testing of individual stages of their application according to operational statistics indicate real possibilities for *improving the management of production assets*;

2. This result is due to a significant increase in the number of facilities whose service life has exceeded the standard values;

3. On the example of OPL with a voltage of 110 kV and higher:

– calculation formulas and quantitative estimates of monthly average values of operational reliability indicators characterizing their TC have been given. These estimates can be compared with similar estimates calculated for the month preceding the accounting month;
– the monthly average values of operational reliability indicators of OPL for PGF of EPS have been calculated and compared. These estimates allowed for the first time ranking the operational TC of OPL of EPS, identifying enterprises with the least operational reliability;
– since this enterprise may include dozens of OPLs, not all of which do not meet the requirements of operational reliability, the method for identifying the OPLs that require immediate (prompt) recovery has been illustrated.

The use of the developed algorithms in automated systems for assessment, comparison and ranking of production assets eliminates the risk of erroneous solutions of an intuitive approach when organizing operation, maintenance and repair.

References

[1] Н.И. Воропай, Г.Ф. Ковалев и др., Концепция обеспечения надежности в электроэнергетике, Москва, ООО ИД «Энергия», 2013, 304 p. [In Russian: N.I. Voropay, G.F. Kovalev et al., The concept of ensuring reliability in the electric power engineering, Moscow, LLC PH Energia].

[2] СТО-34.01-24-003-2017, Система управления производственными активами ЕНЭС, (2017), ФСК. [In Russian: STO-34.01-24-003-2017, UNEG production assets management system, FSK].

[3] СТО-34.01-24-002-2018, Организация технического обслуживания и ремонта объектов электроэнергетики ЕНЭС, (2018), ФСК [In Russian: STO-34.01-24-002-2018, Organization of maintenance and repair of power engineering facilities of the UNEG, FSK].

[4] СТО-34.01-35-001-2020, Методическое указание по проведению технического освидетельствования оборудования подстанций, линий электропередачи, «Россети», (2020) 20 p. [In Russian: STO-34.01-35-001-2020, Guidelines for the engineering certification of the equipment of substations, power lines, Rosset].

[5] Г.А. Громова, Л.А. Исмаилова, Управление производственными активами электросетевой компании в концепции жизненного цикла, Вестник Алтайской академии экономики и права. 1 No.1 (2019) pp.37-44. [In Russian: G.A. Gromova, L.A. Ismailova, Management of production assets of a power grid company in the life cycle concept, Vestnik Altayskoy akademii ekonomiki i prava. 1].

[6] Э.М. Фархадзаде, А.З. Мурадалиев, Ю.З. Фарзалиев, С.А. Абдуллаева, Сравнение и ранжирование паротурбинных установок энергоблоков ТЭС по эффективности работы, Теплоэнергетика. No.10 (2018) pp.41-49. [In Russian: E.M. Farhadzadeh, A.Z. Muradaliyev, Y.Z. Farzaliyev, S.A. Abdullayeva, Comparison and ranking of steam turbine units of TPP power units by operating efficiency, Teploenergetika]. http://www.doi.org/10.1134/SOO40363618100028

[7] Э.М. Фархадзаде, А.З. Мурадалиев, Т.К. Рафиева, А.А. Рустамова, Повышение эффективности работы энергоблоков тепловых электростанций, «Электрические станции». No.8 (2019) pp.14-17. [In Russian: E.M. Farhadzadeh, A.Z. Muradaliyev, T.K. Rafiyeva, A.A. Rustamova, Improving the efficiency of power units of thermal power plants, Elektricheskiye stantsii]. http://www.doi.org/10. 34831/EP.2019.1054.44206

[8] Э.М. Фархадзаде, А.З. Мурадалиев, Т.К. Рафиева, С.А. Абдуллаева, Метод и алгоритм расчета показателей надежности по многомерным данным, Минск, Энергетика. No.1 (2017) pp.16-29. [In Russian: E.M. Farhadzadeh, A.Z. Muradaliyev, T.K. Rafiyeva, S.A. Abdullayeva, Method and algorithm for calculating reliability indicators from multivariate data, Minsk, Energetika]. http://www.doi.org/10.21122/1029-7448-2017-60-1-16-29