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Analysis Of The Error In Calculating The Mode In The Problem Of Eliminating Accidents In Distribution Electric Networks.

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ABSTRACT

The article analyzes the errors in the results of calculating the modes of electrical distribution networks on computers caused by inaccurate input of initial data. This analysis shows the advisability of developing a program to prepare recommendations for the implementation of switching to eliminate accidents in distribution electrical networks.
Keywords: *errors, initial data, elimination of accidents*

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INTRODUCTION

One of the main indicators of reliability of electricity supply to rural consumers in case of accidents is the time of restoration of electricity supply. Often, to quickly restore power supply, there is a need to perform switching operations in which the network configuration changes. In order to make a decision on the expediency of developing a program for preparing recommendations on how to perform switching operations to eliminate accidents in rural electrical networks, including those caused by natural effects, it is important to investigate the error values when determining controlled parameters of the regime from erroneous input data.

When modeling the modes of electrical networks on a computer and performing calculations, one should not forget about errors. Errors in mathematical modeling include errors due to inaccurate input data, errors in the mathematical description (mathematical model), calculation and rounding methods, as well as the error in the implementation of mode control [1]. The methodology, results of development and research of analytical and calculation methods for determining various types of errors in mathematical modeling in the control of power system regimes are described in detail in [1]. For distribution networks (DN), a number of studies have also been performed [2].

The results of the computational study of the uncertainties of the DN for steady-state simulation (SS) parameters are presented in [2]. SS parameters such as voltage at the feeder nodes, line current, total power losses in the lines, power loss in the transformers, power losses in the transformer steel were investigated. However, when changing the open DN circuits, the main task is to maintain the necessary bandwidth and sufficient voltage in them.

The feeder capacity of the feeder can be estimated from the maximum line load factor:

$$I_F = max\left\{\frac{I_{L\,i}}{I_{L\,nom\,i}}\right\}, \tag{1}$$

where $I_{L\,i}$ – load current in *i* line; $I_{L\,allow}$ – the longest allowed current for heating the *i* line.

The required voltage level is estimated by the maximum value of the voltage deviation up or down from the nominal voltage, expressed as a percentage:

$$\Delta U_F = 100 \cdot max\left\{\frac{\left(U_i - U_{NOM}\right)}{U_{NOM}}\right\}. \tag{2}$$

The investigations were carried out according to the procedure given in [1, 3]. The initial information for the calculation of SS DN 6-10 kW has its own characteristics. The vector of initial information for calculating SS DN can be represented as:

$$D = \begin{bmatrix} Z \\ S \\ J \end{bmatrix}, \tag{3}$$

where Z – parameter vector of replacement circuit elements; S – parameter vector of the head region mode; J – vector of loads of distribution transformers (DT).

The parameter vector of the head area mode is the most reliable information about the load of the distribution network and the errors in their determination depend on the errors of the measuring instruments [3]. Parameters of the head area mode include the voltage in the power center U_{PC}, feedhead current I_{FC} and power factor of the head section of the feeder $\cos\varphi_{FC}$.

The information on real loads of TS, as a rule, is absent, therefore the vector, besides nominal powers DT, contains the additional information, for example, factor of loading DT $K_{LOAD\,\mathrm{DT}}$. The load factor DT has a significant error and a low confidence coefficient [4], because its magnitude is determined by the operating personnel for empirical reasons.

The calculation of SS DN begins with the determination of the loads DT in accordance with the current of the head section I_{FC} and load factors DT $K_{\mathrm{LOAD\,DT}}$, when correcting data with the lowest confidence coefficient. In addition, there is an additional error due to an unknown power factor $\cos\varphi_i$ on each DT.

As a result of the error analysis, when determining the parameters of the DN mode in accordance with [3], it is assumed that the change in the load of the transformer is within limits, and the change $\cos\varphi_i$ – $0,6 \div 0,95$. In addition, in accordance with [3], the error in specifying the parameters of the head section is taken within the limits of I_{FC} $-\pm 5\%$, for U_{PC} $-\pm 5\%$, for $\cos\varphi_{\mathrm{FC}}$ – $\pm 10\%$. Errors in the assignment of the vector, parameters, and topology of the elements of the replacement scheme were not included in this study. These data are refined before the calculations, and can directly come from the topological geoinformation system integrated with the program calculation mode [5].

Errors from the inaccurate specification of the source data vector play an important role in comparison with other types of errors. In [1, 3] the expressions substantiating the separate investigation of each term of the resulting error are given. Let's consider a technique of an estimation of an error from an inexact task of a vector of the initial data.

Setting the initial data with an error that is usually random, leads to a corresponding error in the calculation results, for which evaluation it is preferable to use probability-statistical methods [1-3]. Based on the results of calculations, the statistical characteristics of the monitored parameter are determined: the probability distribution law, the mathematical expectation, the standard deviation. The most known method for these purposes is the method of statistical tests.

MATERIALS AND METHODS

The method of statistical tests consists in the following steps:

1. Using a random number generator, in accordance with the known distribution law for a given interval, a set of values is generated for each random parameter of the input data for calculations.

2. A series of calculations of the steady-state DN for each random set of parameters of the initial data are performed and controlled quantities are found.

3. Statistical processing of the obtained controlled quantities is performed.

STATISTICA package was used to generate random numbers and statistical processing of results. Changing the parameters of the feeder head mode I_{FC}, U_{PC}, $\cos\varphi_{\mathrm{FC}}$ described by the normal law of probability distribution, the probability density of which is written as

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} \cdot \exp\left[-0,5\left(\frac{x}{\sigma}\right)^2\right]. \quad (4)$$

The properties of mathematical expectation (ME) and standard deviation (SD). Since the discrete readings were made x_i, then the calculation of the integral determining the mathematical expectation was replaced by calculating the arithmetic mean:

$$X = \sum_{i=1}^{n} \frac{X_i}{n}, \tag{5}$$

where n – number of tests.

On the basis of a comparison of the various techniques used in practice to estimate the magnitude of the spread of random errors with respect to the center (the width of the distribution), it was decided to use the standard deviation of the random variable, the estimate of which is defined as

$$\sigma = \sqrt{\sum_{i=1}^{n} \frac{(x_i - X_C)}{(n-1)}}, \tag{6}$$

where X_C – coordinate of the distribution center.

To describe random changes in the load factor DT $K_{\text{LOAD }PT}$ The uniform probability distribution law was used, the probability density of which is determined by the expression:

$$\begin{cases} p(x) = \dfrac{1}{(X_2 - X_1)} = const \quad npu\ X_1 < x < X_2; \\ p(x) = 0 \qquad\qquad npu\ x < X_1\ u\ X_2 > x. \end{cases}, \tag{7}$$

To calculate the SS, a software package was used to determine information about the DT loads in accordance with the current of the head section I_{FC} and load factor DT $K_{\text{LOAD DT}}$.

The purpose of the research was to analyze the influence of the error in the task I_{FC}, U_{PC}, $\cos\varphi_{\text{FC}}$, $K_{\text{LOAD DT}}$ when calculating the SS feeder DN by the value of the investigated parameters-the maximum load factor of the feeder lines I_F and the maximum voltage deviations up and down from the nominal in consumers ΔU_{FB} and ΔU_{FH}.

RESULTS AND DISCUSSION

The design schemes are represented by three 10 kW feeder circuits that differ in the number of transformer substations (TS) and lines. The design studies consisted of three parts, the results are presented in Tables 1 and 2.

Table 1: Results of part 1 of the study

Initial data		Feeder № 1 (5 lines HL, 3 TS)			Feeder № 2 (7 lines HL, 11 TS)			Feeder № 3 (57 lines HL, 41 TS)		
Number of tests		200	200	200	200	200	200	200	200	200
I_{FC} plan, A		60	30	12	50	25	10	200	100	40
U_{PC} plan, kW		10,5	10,5	10,5	10,5	10,5	10,5	10,5	10,5	10,5
$\cos\varphi_{\text{FC}}$ plan		0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75
$K_{LOAD\ DT}$		0,2-1,4	0,2-1,4	0,2-1,4	0,2-1,4	0,2-1,4	0,2-1,4	0,2-1,4	0,2-1,4	0,2-1,4
I_{FC}	ME, A	59,89	29,97	11,93	49,79	25,01	10,016	199,69	100,25	40,03
	SD, A	2,871	1,493	0,619	2,558	1,268	0,521	10,22	4,935	1,980
	SD, % from ME	4,79	4,98	5,19	5,14	5,07	5,20	5,12	4,92	4,9
U_{PC}	ME, kW	10,521	10,507	10,504	10,507	10,529	10,468	10,521	10,417	10,489
	SD, kW	0,501	0,549	0,539	0,549	0,548	0,488	0,531	0,540	0,504
	SD, % from ME	4,76	5,23	5,13	5,23	5,20	4,66	5,05	5,18	4,81
$\cos\varphi_{\text{FC}}$	ME	0,750	0,748	0,747	0,757	0,761	0,743	0,752	0,743	0,750

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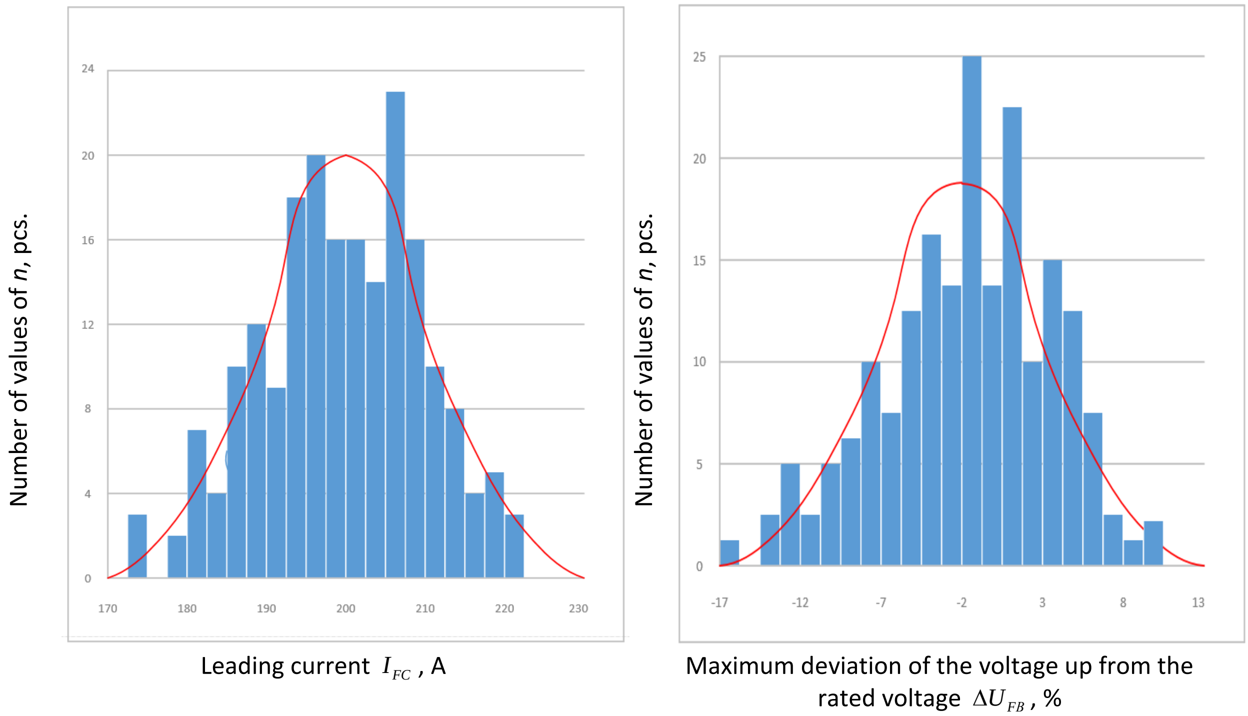
	SD,	0,077	0,066	0,069	0,081	0,074	0,078	0,078	0,077	0,0725
	SD, % from ME	10,1	8,82	9,24	10,70	9,72	10,50	10,37	10,36	9,67
Calculation results										
I_F	ME, o.e.	0,2260	0,1131	0,0450	0,2846	0,1429	0,0572	0,9509	0,4774	0,1906
	SD, o.e.	0,0108	5,63E-3	2,34E-3	0,0146	7,25E-3	2,97E-3	0,0487	0,0235	9,43E-3
	SD, % from ME	4,48	4,98	5,20	5,13	5,07	5,19	5,12	4,92	4,95
ΔU_{FB}	ME, %	1,610	3,230	4,285	-0,066	2,682	3,617	-1,270	0,879	3,566
	SD, %	5,014	5,494	5,387	5,507	5,457	4,890	5,339	5,392	5,037
ΔU_{FH}	ME, %	-0,804	2,063	3,857	-4,886	0,310	2,658	-20,586	-7,809	0,325
	SD, %	5,086	5,508	5,385	5,560	5,445	4,895	5,649	5,380	5,036

Table 2: Results of parts 2 and 3 of the study

Initial data		Feeder №3 (57 lines HL, 41 TS)		Feeder №3 (57 lines HL, 41 TS)		
Number of tests		200	500	200	200	200
I_{FC} plan, A		200	200	200	200	200
U_{PC} plan,kW		10,5	10,5	10,5	10,5	10,5
$\cos\varphi_{FC}$ plan		0,75	0,75	0,75	0,75	0,75
$K_{LOAD\ DT}$		0,2-1,4	0,2-1,4	0,2-1,4	0,2-1,4	0,2-1,4
I_{FC}	ME, A	199,69	200,095	199,69	199,365	199,69
	SD, A	10,22	9,858	10,22	5,162	10,22
	SD, % from ME	5,12	4,93	5,12	2,59	5,12
U_{PC}	ME, kW	10,521	10,533	10,521	10,521	10,509
	SD, kW	0,531	0,543	0,531	0,531	0,246
	SD, % from ME	5,05	5,16	5,05	5,05	2,34
$\cos\varphi_{FC}$	ME	0,752	0,751	0,752	0,752	0,752
	SD,	0,078	0,072	0,078	0,078	0,078
	SD, % from ME	10,37	9,59	10,37	10,37	10,37
Calculation results						
I_F	ME, o.e.	0,9509	0,9528	0,9509	0,9494	0,9509
	SD, o.e.	0,0487	0,0469	0,0487	0,0246	0,0487
	SD, % from ME	5,12	4,92	5,12	2,59	5,12
ΔU_{FB}	ME, %	-1,270	-1,178	-1,270	-1,259	-1,394
	SD, %	5,339	5,425	5,339	5,319	2,476
ΔU_{FH}	ME, %	-20,586	-20,537	-20,586	-20,587	-20,708
	SD, %	5,649	5,720	5,649	5,526	2,871

In the first part, the influence of I_{FC} for ME and SD controlled values at a test number of 200. Figure 1 shows the frequency histograms of the distribution of values for the current in the head section I_{FC} and the maximum deviation of the voltage up from the nominal ΔU_{FB} and their statistical characteristics (Table 3) for Feeder No. 3 (57 lines, 41 TS) at $I_{FC} = 200 \pm 10$ A, $U_{PC} = 10,5 \pm 0,525$ kW, $\cos\varphi_{FC} = 0,75 \pm 0,075$, $K_{\text{LOAD DT}} = 0,2 \div 1,4$. Analysis of the results showed that a decrease in the load of the head section leads to a decrease ME I_F, increase ME ΔU_{FB} and ΔU_{FH}, and also has practically no serious effect on SD deviation of the monitored parameters.



a) *b*)

Figure 1: Frequency histograms of the distribution of values: a) current of the head section I_{FC} ; b) the maximum deviation of the voltage up from the nominal ΔU_{FB}

Table 3: Statistical characteristics of the distribution of values

Statistical characteristics	Leading current I_{FC} , A	Maximum deviation of the voltage up from the rated voltage ΔU_{FB} , %
Sample size	200	200
Average	199,688	-1,26994
Median	199,961	-1,20367
Mode	199,932	-1,20661
Variance	104,485	28,5053
Standard deviation	10,2218	5,33903
Minimum	172,665	-16,1895
Maximum	222,483	11,6488
Range	49,8181	27,8383
Lower quartile	192,76	-4,5542
Upper quartile	207,022	2,73693
Interquartile range	14,262	7,29113
Skewness	0,180121	-0,232329
Standardized skewness	1,03993	-1,34135
Kurtosis	0,351582	-0,23626

The second part of the calculations investigated the effect of an increase in the number of tests from 200 to 500 on ME and SD controlled values with the largest feeder load No. 3. Analysis of the results shows that the differences do not exceed 0.2%.

In the third part of the calculations, we investigated the effect of increasing the reliability of the initial data (with $\pm 5\,\%$ before $\pm 2,5\,\%$ separately for I_{FC}, and then for U_{PC}) due to the use of modern systems for collecting information on the ME and SD controlled quantities with the greatest load of the feeder № 3.

From the analysis of the results it follows that the increase in reliability I_{FC} leads to a corresponding decrease in SD I_F and does not have a noticeable effect on SD ΔU_{FB} and ΔU_{FH}. And increasing the reliability U_{PC} leads to a corresponding decrease in SD ΔU_{FB} and ΔU_{FH} and has absolutely no effect on I_F.

An analysis of all the results shows that the mean square deviations of the controlled quantities (I_F, ΔU_{FB}, ΔU_{FH}), expressed in percentage, differ from the standard deviations of the corresponding initial data (I_{FC}, U_{PC}) slightly, the largest difference is 0.6% for ΔU_{FH}.

CONCLUSIONS

1. To evaluate the error in determining the maximum load factors of feeder lines and the maximum voltage deviations in consumers due to erroneous input data, it is effective to apply algorithms based on the method of statistical tests.
2. According to the calculations performed by SS DN, the average quadratic deviations of the controlled parameters, expressed as a percentage, differ from the standard deviations of the corresponding initial data by 0.6% as much as possible.
3. The use of modern information retrieval systems that increase the reliability of the initial data leads to the same decrease in the error in determining the corresponding controlled parameters.
4. The results of the study give grounds to consider it expedient to develop a program for the preparation of recommendations on the implementation of switching to eliminate accidents in rural electrical networks, including those caused by natural effects.

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