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CHARACTERISTICS OF REFUSALS IN LOW-VOLTAGE DISTRIBUTION SYSTEMS

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Abstract. This paper focuses on the determination of the characteristics of refusals in low voltage electrical distribution systems. In order to solve this problem, the phenomena of occurrence of refusals in low-voltage electrical distribution systems, conditioned by different influencing factors, processed and mathematically modelled. The main results of the research consist in establishing the static characteristics of the refusals, the mathematical models that determine the occurrence of the cause phenomena and the parameters that characterize the distributions of the refusals, depending on the occurrence per system, depending on the occurrence per season, depending of interruptions duration and the number of affected consumers. The significance of the results obtained consists in solving a number of problems faced by the operating services of electrical distribution systems, concerning the assurance of reliability of operation, providing the possibility of forecasting and preventing the occurrence of the phenomena of occurrence of refusals, which enable the justified planning of prophylactic measures and ensuring the reliability level.

Keywords: *electrical distribution systems, refusal characteristics, influence factors, mathematical models.*

Abstract. Articolul se concentrează pe determinarea caracteristicilor refuzurilor în sistemele electrice de distribuție de joasă tensiune. Pentru a rezolva această problemă, au fost prelucrate și modelate matematic fenomenele de apariție a refuzurilor în sistemele de distribuție a energiei electrice de joasă tensiune, condiționate de diferiți factori de influență. Principalele rezultate ale cercetării constau în stabilirea caracteristicilor statice ale refuzurilor, a modelelor matematice care determină apariția fenomenelor cauze și a parametrilor care caracterizează distribuțiile refuzurilor, în funcție de apariția pe sistem, în funcție de apariția pe anotimp, în funcție de durata întreruperilor și de numărul de consumatori afectați. Semnificația rezultatelor obținute constă în rezolvarea unei serii de probleme cu care se confruntă serviciile de operare a sistemelor electrice de distribuție,

privind asigurarea fiabilității funcționării, oferirea posibilității de prognozare și prevenire a apariției fenomenelor de apariție a refuzurilor, ceea ce permite planificarea justificată a măsurilor preventive și asigurarea nivelului de fiabilitate.

Cuvinte cheie: *sisteme electrice de distribuție, caracteristici de refuz, factori de influență, modele matematice.*

1. Introduction

At this stage, an important number of refusals are occurring in low-voltage electricity distribution systems from the Republic of Moldova, which are severely affecting consumers and causing substantial economic damage [1, 2]. Establishing the factors causing these refusals and determining the reasons for their occurrence, allows the development of a mechanism to prevent and ensure continuity of supply to consumers, with a reduction in economic damage [3, 4].

The static characteristics of refusals, the causes of their occurrence and their impact on the reliability of distribution systems, are not currently studied to the level stipulated by current documents on reliability indicators [5, 6].

Although multiple researches have been done by researchers in the field so far, but the data in the literature on the theoretical and practical basis of the reliability of low voltage distribution systems are quite modest and require further study, especially the static characteristics of refusals, the causes of their apparition and their effect on reliability, as they are not currently known at the level stipulated by the current documents on the reliability of these systems [7-11].

Reliability of low-voltage distribution systems can only be ensured based on an in-depth knowledge of the phenomena accompanying this process, which permit technically and economically planning of the measures and activities of power system operation services to ensure the standard reliability indicators [12, 13].

Accordingly, the focus of the research is on the characteristics of refusals in low voltage electricity distribution systems caused by various random factors for the 5-year period (2016-2021) [1, 2].

The general objective of the work is to develop mathematical models which determine the laws for distributing refusals in these systems, conditioned by different influencing factors [14, 15].

The results obtained and the mathematical models developed allow forecasting refusals with 95% reliability and their parameters, which provides the possibility of justified planning of measures to prevent cause factors and the mechanisms development to ensure the reliability of low-voltage distribution systems, reducing operating costs and economic damage caused by these refusals [16].

2. Materials and Methods

To solve the problems formulated for research have been: graph theory; probability theory; methods of statistical analysis and experimental data processing; linear and nonlinear equations theory; mathematical modeling; calculation techniques with the software „Easy Fit 5.5”, „Stat Graphics”, „Curve Expert” [15, 16].

The following steps were taken to carry out the research:

- Recording of refusals in low-voltage electricity distribution systems (10 systems and 57 subsystems) for a period of 5 years (2016-2021).

- Classification of refusals according to their occurrence and influencing factors.
- Development of the analysis and systematization concept of refusals according to season and geographical location of systems.
- Determination of laws and the parameters which characterize the distributions of faults for all influencing factors.
- Developing the mathematical models that identify the laws of faults occurrence.
- Argumentation of the procedure for forecasting random refusals in distribution systems and the parameters that characterize these refusals.

3. Results

The study found that the reliability of low-voltage distribution systems, directly affected by a number of random factors that determine the continuity of the electricity supply to consumers. Considerations relating to the aspect of ensuring the continuity and quality of power supply for consumers also identified, by determining the reasons for the occurrence of refusals caused by random factors and establishing the mechanism for reducing the level of influence of these factors. It is established that the level of reliability of electrical distribution systems can only be assured on the basis of an understanding of all phenomena accompanying the operating processes of these systems and through technical and economic justified planning of necessary measures to ensure the standard reliability indicators. It was found necessary to develop the procedure for forecasting the intensity of faults conditioned by different factors and to estimate the weight of the impact of random influencing factors on reliability indicators, with consideration for the number of interruptions, their duration and the number of consumers affected, which allows justified planning of technico-economic activities in order to ensure reliability of low voltage distribution systems. It was found necessary to develop the procedure for forecasting the intensity of refusals conditioned by various factors and to estimate the weight of the impact of random influencing factors on reliability indicators, with consideration for the number of interruptions, their duration and the number of consumers affected, which allows a justified planning for technico-economic activities to ensure the reliability of low voltage distribution systems.

Methodology for reliability analysis of distribution systems using graph theory and diacoptics has been proposed, which allow analytical reliability calculations to be performed for systems with any structure, according to which complex systems have been examined on subsystems, sections, graphs and nodes.

The solution for outage classification and processing is presented, which allows to characterize specific refusals depending on each influencing factor (for each system according to season) and the concept for assessing and forecasting the reliability level of distribution systems, which systemize the consecutiveness of operations done in the process of reliability assessment. Processing the characteristic information on interruptions in the systems reviewed, using a standard procedure of analysis and calculation, the unique concept of a generalized methodological approach for the assessment of reliability indicators was proposed. Using the specific unit of line length notion, which allows to determine and compare the actual level of reliability for all power lines, disregarding of their total length.

The methodological and theoretical-scientific support for assessing the reliability of electrical distribution systems was provided by graph and matrix theory; probability theory; methods of statistical experimental data analysis and processing of faults in distribution systems; linear and non-linear of equations theory; math modelling.

Using the classification method and the developed concept of refusal processing, the frequency of occurrence of defects resulting from each random factor was determined for each system by season.

In Table 1 are presents the processed results of random faults that took place seasonally in the investigated systems by different groups of factors, reported on a specific unit of line length.

Table 1

The faults generated by different groups of factors

Groups of factors	Seasonal number of faults per specific unit of line length				
Name	Winter	Spring	Summer	Autumn	Annual
Animal and bird action	0.17	0.13	0.33	0.35	0.98
Climatic conditions	6.33	5.77	3.88	5.17	21.15
Equipment defects	5.28	4.52	4.42	4.77	18.99
Acts of vandalism	0.34	0.39	0.49	0.36	1.58
Unidentified factors	5.94	4.56	5.00	5.61	21.11
Damage caused by vegetation	0.83	0.36	0.65	0.55	2.39
The action of mechanisms	0.08	0.26	0.28	0.15	0.77
Operational errors	0.03	0.01	0.03	0.02	0.09
TOTAL	**19**	**16**	**15**	**17**	**67**

All this has made it possible to make simple the calculation and to establish rejection distributions for all the factors, according to the frequency of occurrence per system and season, which allows to determine structures and measures to improve reliability in power distribution systems. In the process of assessing the reliability of the investigated systems the following was done: using the proposed methodology, primary information on refusals that occurred in low voltage distribution systems (10 systems and 57 subsystems) for the 5-year operating period (years 2016-2021) was processed; based on the developed classification concept, all random refusals were selected, which allowed structuring and classifying the information sets according to 8 groups influencing factors by geographical location and season; the concept of homogenizations of primary information was proposed, which ensures the possibility of comparing the intensity of refusals conditioned by different influencing factors for any distribution system, regardless of the summary length of the lines, allowing the determination of numerical values of reliability indicators based on a standard analysis and calculation procedure.

It has been established only to predict influence of random factors on the reliability of power systems, it is necessary to determine the laws of refusals distribution generated by factors of these distributions.

Based on findings, for the following indices where examined experimental and theoretical distributions: frequency of occurrence of faults by system and season, duration of faults and number of consumers which was disconnected.

Table 2 shows examples of mathematical models and their parameters, which establish the distribution laws of faults as a function of duration, for the groups of factors examined.

Table 2

Mathematical models determining the distribution laws of refusals

Groups of factors	Type Function	The mathematical model	Mathematical model parameters			
			a	b	c	d
Animal and bird action	Weibull	$y = a - be^{-cx^d}$	1612.01	1682.03	0.24	-0.57
Damage caused by vegetation	Log-Logistic 3-Param.	$y = a/[1 + (x/b)^c]$	3803.98	463.97	3.29	-
The action of mechanisms	Weibull	$y = a - be^{-cx^d}$	274.98	270.99	4.51	-2.39
Climatic conditions	Lognormal 3- Param.	$y = e^{a+b/x+cln\,(x)}$	11.57	-3.40	-2.27	-
Unidentified factors	Weibull	$y = a - be^{-cx^d}$	1166.98	1169.01	2.19	-1.79
Equipment defects	Lognormal 3- Param.	$y = e^{a+b/x+cln\,(x)}$	11.69	-4.01	-2.21	-
Acts of vandalism	Weibull	$y = a - be^{-cx^d}$	538.95	535.99	3.48	-2.11
Operational errors	Exponential	$y = ae^{b/x}$	1.61	4.52	-	-

The mathematical models developed confirm that the 8 groups influencing factors, in terms of the duration of interruptions caused, behave differently. It can be seen that 4 of them (vandalism acts, action of animals, action of various mechanisms, unidentified factors) are characterized by a Weibull distribution, 2 factors (faults in equipment, weather condition) have a Lognormal distribution (3-parameters), one group of factors (operating errors) has an Exponential distribution and one group of factors (damage caused by vegetation) has an Log-Logistic distribution (3-parameters).

At the same time, at each stage of the research carried out, the theoretical models made in this study were compared with the obtained experimental results. Thus, for each group of factors, comparing the experimental distributions and the elaborated theoretical models, which determine the distributions of the refusals and the static characteristics, based on the application of the similarity criteria, it was found that the degree of overlap is about 95 %.

So, for example, arbitrarily selecting a group of factors among those examined, as an example, in figure 1, is graphically presented the experimental distribution of refusals according to duration, caused by climatic conditions, and in figure 2, the theoretical model elaborated is graphically presented, which determines the law of distribution of refusals according to duration, for this group of factors - climatic conditions, and the compatibility for this model, the similarity criteria indicate an insignificant deviation of about 5 %.

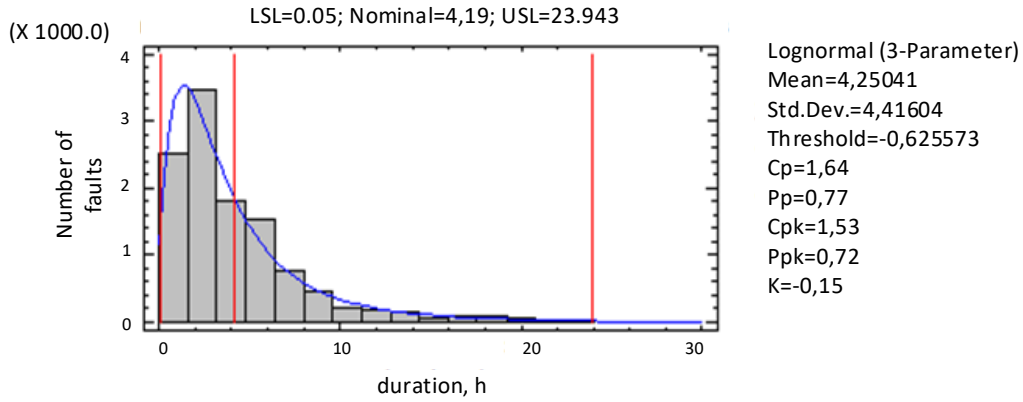

Figure 1. Graphic presentation of the experimental distribution of refusals according to duration, caused by climatic conditions.

It was found that, according to the number of affected consumers, 6 groups of factors were described using Weibull distribution law (vandalism acts, action of animals and birds, action of different mechanisms, damage caused by vegetation, equipment faults, operating errors), one of them (weather conditions) was described using Lognormal model (3-Parameters) and (unidentified factors) with the Log-Logistic model (3-Parameters).

On the basis of the mathematical models developed, the main parameters of the replications, which characterize the interruptions caused by the 8 groups of influencing factors examined, were established according to the duration of disconnections and number of consumers which were affected (total number of refusals caused, the average number of disconnections per season, average duration of disconnections, average number of disconnected consumers, root mean square deviation, coefficient of variation, minimal and maximal duration of disconnections, minimal and maximal number of disconnected consumers, crosstalk, marginal values of the confidence interval, skewness and excess coefficients).

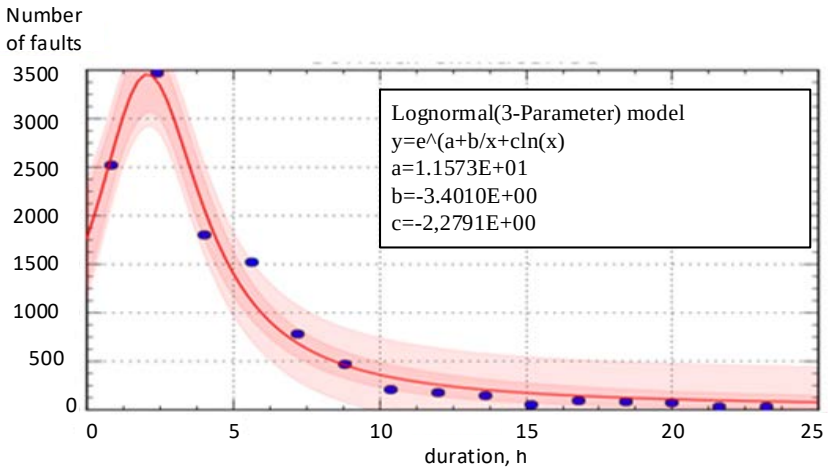

Figure 2. Graphic presentation of the developed mathematical model, which determines the distribution of refusals according to duration, caused by climatic conditions.

4. Discussion

Based on the above, the necessary criteria and parameter values were determined to characterize the influence of random factors on the reliability of power distribution systems and to forecast with 95 % reliability the following indices: expected number of interruptions on the system, depending on geographical location and season; duration of these interruptions; number of consumers likely to affect [1, 3].

Analyzing the distribution of random refusals and the parameters examined over the given time interval, it can be seen that the significant number of refusals that occurred due to unforeseen random factors influenced the level of reliability of these systems over the entire time period examined (2016-2021).

Because of the analysis of the reliability indicators, during the period investigated in the examined systems, there were 915463 refusals, which affected the process of energy supply and influenced the indicators of continuity and quality. Because of this, their impact on system reliability and quality only mitigated by forecasting these events in order to develop the mechanism for justified planning of operational works [4-6].

As a result, according to the developed method the reliability prediction of the investigated systems performed, taking into account the influence of random factors. The influence of the factors forecast based on the following parameters: expected number of refusals per system (per year per specific unit length); expected number of refusals per season; expected duration of refusals; expected number of consumers affected. These parameters establish the degree of operational reliability of the equipment installed in the power distribution systems and the results obtained from their forecasting allow technically and economically justified planning of activities to ensure the quality and continuity of the power supply for consumers, in compliance with the standard reliability indicators.

5. Conclusions

The mathematical modelling allowed establishing the theoretical distributions characterizing refusals according to duration and number of consumers affected, with the highlighting of four types of theoretical models such as Weibull, Lognormal, Log-Logistic and Exponential and covering all the characteristic experimental distributions for the 8 groups of influence factors included in the list of classification of interruptions.

The processing of the experimental data groupings offers the possibility to determine the values of all coefficients in the theoretical distributions established for describing the statistical behavior of the groups of random factors and to obtain the concrete relationships for calculating the distributions and the number of conditional breaks of all influencing factors accepted as significant in this research.

Thus, mathematical models determining the laws of occurrence of random interruptions developed, which allow forecasting with 95% reliability of all indices characterizing the level of operational reliability of low-voltage distribution systems, and this provides the possibility of specifying measures to prevent refusals, reducing operating costs and economic damage.

Conflicts of Interest: The authors declare no conflict of interest.

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