Interruptions of the Power Supply in Low Voltage Cable Networks

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Abstract— **The results, from a study of power supply interruptions in low voltage (LV) cable networks, are presented in the paper. Statistical processing of the data for interruptions of the power supply has been made and the type of distribution of the time of interruption, the average time of interruption, and the indicators for continuity are determined.**

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I. Introduction

The interruption of the electric power supply is one of the indicators for the quality of electrical energy and represents the interruption of the power supply to one or more consumers of electricity [1, 2].

The interruptions of the power supply to the consumers are: planned and unplanned (accidental). Unplanned interruptions are divided into short-term and long-term interruptions. An interruption with a duration less than or equal to 3 minutes is defined as a short-term interruption. In the case of sites with on-duty operational staff, short-term interruptions are those with a duration of less than or equal to 5 minutes. All other interruptions are long.

The norms for the number of interruptions in low voltage electric distribution networks, according to BDS EN 50160 are [1, 2]:

- for short-term interruptions - from a few dozens to several hundred a year;
- for long-term interruptions - from 10 to 50 per year, depending on the area.

The results, from a study of power supply interruptions in low voltage (LV) cable networks, are presented in the paper. Statistical processing of the data for interruptions of the power supply has been made and the type of distribution of the time of interruption, the average time of interruption, and the indicators for continuity are determined.

II. II. Classification of the Electric Power Supply Interruptions

The low voltage electric distribution network operated on the territory of Sofia Municipality consists of cable and overhead lines. In urban areas, where the number of customers and the power density are high, the cable network predominates (75%). In the suburban areas, the overhead network prevails. The total length of the LV cable network is 3650 km and the LV overhead network is 2770 km. The LV electricity distribution network is powered by 4474 transformer substations maintained by the electricity supply company and 1130 transformers substations which are privately owned. A classification of the transformer stations, depending on their type, is given in Table I.

TABLE I. Type of the Transformer Station

№	**Type**	**Count**	
		number	***%***
1	Underground (well, basement) station	558	12,5
2	Ground floor (built into a building) station	1210	27,0
3	Independent (masonry or panel) station	2247	50,2
4	Complete (metal-sheeted) station	200	4,5
5	Mast station	259	5,8

The total number of transformers is 6151 with a total installed capacity of 3653 MVA. The total installed power of the privately-owned transformers is 1331MVA. The average power of a single transformer is 550 kVA, in urban areas the transformers with a power of 630 kVA predominate.

The summarized data, on the power supply interruptions in the 0.4 kV low voltage cable distribution network operated on the territory of Sofia Municipality for a period of 6 months (July-December), are presented in Table II.

TABLE II. Interruptions of Power Supply in the Sofia Municipality

Number of interruptions, ***number***	642
Number of interrupted customers, ***number***	12 549
Duration of interruptions, ***minutes***	95 370
Unplanned interruptions, ***number***	634
Unplanned interruptions, ***%***	98,75
Duration of the unplanned interruptions, ***minutes***	94 037
Planned interruptions, ***number***	8
Unplanned interruptions, ***%***	1,25
Duration of the planned interruptions, ***minutes***	1 333
Short-term interruptions, ***number***	1
Short-term interruptions, ***%***	0,2
Duration of the short-term interruptions, ***minutes***	2
Long-term interruptions, ***number***	641
Long-term interruptions, ***%***	99,8
Duration of the long-term interruptions, ***minutes***	95 368

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The analysis of the data shows that the highest percentage is unplanned interruptions (98.75%), i.e. which ussualy are caused by unforeseen circumstances. Acording to the duration there are mainly long interruptions (lasting more than 3 minutes), which could be seen as a shortcoming in the process of electric power supply to consumers and the power supply company must work to reduce their percentage and improve the quality of electric power supply to the customers [7].

The study of power supply interruptions in low voltage cable networks shows that they are mainly due to overload, mechanical damage, poor connection and thefts. The number of interruptions and the number of customers affected during interruptions depending on the faults in low voltage cable lines are shown in Fig.1 and Fig.2 respectively.

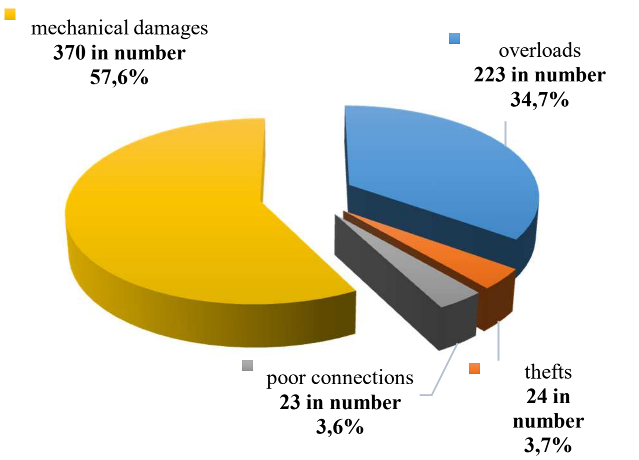

Fig. 1. Power supply interruptions due to faults to low voltage cable lines.

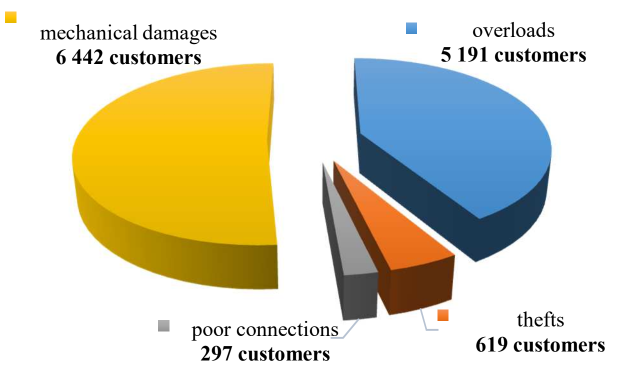

Fig. 2. Customers affected in the event of power supply interruptions due to faults to low voltage cable lines.

The largest percentage are interruptions are those caused by mechanical damage 57.6%, followed by interruptions caused by overloads 34.7%, thefts lead to 3.7% of interruptions, and poor connections are causing 3.6% from the total number of interruptions. The faults that have occurred in the low voltage cable lines due to mechanical damage and overload have affected the largest number of customers, but no less attention should be paid to the customers affected after thefts in the electric network.

All this shows that there is a need for repair and gradual renewal of the electric distribution network. In order to reduce thefts, greater control over the facilities owned by the electric powersupply company should be ensured and, accordingly, adequate penalties should arise in the event of such cases [6].

III. STATISTICAL PROCESSING OF DATA ON ELECTRIC POWER SUPPLY INTERRUPTIONS

Statistical processing of data on power supply interruptions for the period under review has been performed, with a sample size of 642 interruptions.

The mathematical expectation and the standard deviation of the power supply interruption time are:

$$T_0 = \frac{\sum_{i=1}^{n} t_i}{n} = \frac{95370}{642} = 149 \text{ minutes,} \tag{1}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (t_i - T_0)^2}{n-1}} = \sqrt{\frac{24869970}{641}} = 197 \text{ minutes,} \tag{2}$$

where t_i is the i-th time of power supply interruption.

To determine the law of distribution of the time of interruption of the power supply it is necessary to determine:

- maximum interruption time - $\max t_i = 2337$
- number of intervals - $m = 1 + 3{,}21 \lg n = 10$
- width of the interval - $\Delta t = \frac{\max t_i}{m} = 234$
- relative frequency of interruptions for each interval

$$p_k = \frac{\Delta N_i}{n}, \tag{3}$$

where ΔN_i is the number of interruptions for each interval $i = 1, 2, \ldots, m$

- statistical distribution density of the interruption time for each interval

$$f^*(t) = \frac{\Delta N_i}{n \Delta t}, \tag{4}$$

- statistical distribution function of interruption time for each interval

$$F^*(t) = \frac{\sum_{1}^{i} \Delta N_i}{n}. \tag{5}$$

Table III shows the obtained values of the statistical distribution density and the statistical distribution function of the time of interruption of the power supply for each interval.

The interruption time can be modeled with an exponential distribution with a parameter

$$\lambda = \frac{1}{T_0} = 0{,}0067 \text{ failures/half-year.} \quad (6)$$

TABLE III. STATISTICAL PROBABILITY DENSITY AND STATISTICAL DISTRIBUTION FUNCTION

№ of the interval	Interval limits	ΔN_i	p_k	$f^*(t)$	$F^*(t)$
	minutes	*number*	-	-	-
1	[2; 234)	568	0,8847	0,003781	0,8847
2	[234; 468)	58	0,0903	0,000386	0,9750
3	[468; 702)	6	0,0093	0,000040	0,9843
4	[702; 936)	2	0,0031	0,000013	0,9874
5	[936; 1170)	0	0,0000	0,000000	0,9874
6	[1170; 1404)	0	0,0000	0,000000	0,9874
7	[1404; 1638)	6	0,0093	0,000040	0,9967
8	[1638; 1872)	1	0,0015	0,000007	0,9982
9	[1872; 2106)	0	0,0000	0,000000	0,9982
10	[2106; 2337]	1	0,0015	0,000007	0,9997

Table IV shows the calculated values of the theoretical probability density and the theoretical distribution function of the interruption time according to the formulas

$$f(t) = \lambda e^{-\lambda t} = 0{,}0067 e^{-0{,}0067t} \quad (7)$$

$$F(t) = 1 - e^{-\lambda t} = 1 - e^{-0{,}0067t} \quad (8)$$

TABLE IV. THEORETICAL PROBABILITY DENSITY AND STATISTICAL DISTRIBUTION FUNCTION

№ of the interval	Interval limits	$f(t)$	$F(t)$
	minutes	-	-
1	[2; 234)	0,001397	0,7915
2	[234; 468)	0,000291	0,9655
3	[468; 702)	0,000061	0,9909
4	[702; 936)	0,000013	0,9981
5	[936; 1170)	0,000003	0,9996
6	[1170; 1404)	0,000001	0,9999
7	[1404; 1638)	0,000000	1,0000
8	[1638; 1872)	0,000000	1,0000
9	[1872; 2106)	0,000000	1,0000
10	[2106; 2337]	0,000000	1,0000

Fig. 3 shows the statistical and theoretical probability density of the interruption time, while Fig. 4 the statistical and theoretical probability distribution functions of power supply interruptions.

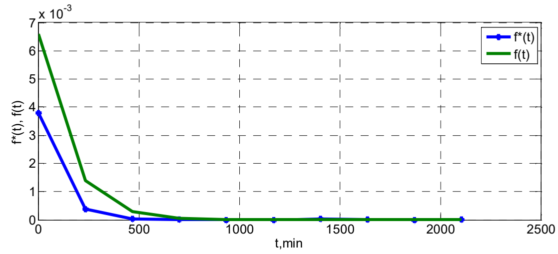

Fig. 3. Statistical and theoretical probability density function of the power interruption time.

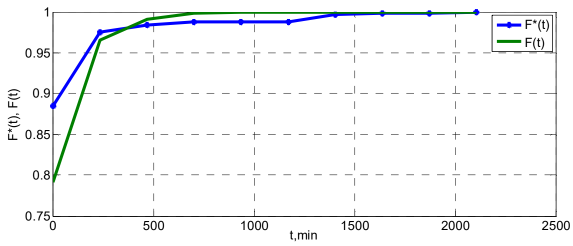

Fig. 4. Statistical and theoretical probability distribution of the power interruption time.

Pearson's criterion is used to test the hypothesis for the type of distribution of the random variable time of power outage in low voltage cable networks.

$$\chi^2 = \sum_{i=1}^{m} \frac{(\nu_i - \nu_{iT})^2}{\nu_{iT}} \quad (9)$$

where ν_{iT} is the theoretical absolute frequency in the i-th class; ν_T the emperical absolute frequency in the i-th class; m - number of classes.

The degrees of freedom are determined $k = m - r - 1$, where *r* is the number of parameters of the law is determined on the basis of experimental data.

χ^2 is a random variable and its distribution depends on the degrees of freedom k. In this case, it is equal to $\chi^2 = 7{,}416$.

From [3] the value of the quantity is determined $\chi^2_{T(k=8;\alpha=0{,}05)} = 15{,}5073$.

Therefore the hypothesis for an exponential distribution of the time of interruption of the power supply in low voltage cable networks is tested by Pearson's criterion [3] and is accepted as true because $sign(\chi^2 - \chi^2_T) = -8{,}091 < 0$.

The confidence interval of the average time of power outage in LV cable lines is $l_\beta = (136{,}21; 161{,}79)$ minutes, with $\varepsilon_\beta = 12{,}79$ minutes and is determined with confidence $\beta = 0{,}9$.

IV. POWER SUPPLY CONTINUITY INDICATORS

System Annual Interruption Frequency Index (SAIFI) determines the average number of interruptions per user for a period of one year and is determined by the formula [4, 5]

$$SAIFI = \frac{\sum_{i=1}^{l} n_i}{N}, \text{ number/year} \qquad (10)$$

where: n_i is the number of customers affected by the i-th interruption; N - total number of customers; l - number of the interruptions.

The System Average Interruption Duration Index (SAIDI) determines the average duration of interruptions that falls on a customer over a period of one year. Determined by the formula [4, 5]

$$SAIDI = \frac{\sum_{i=1}^{l} t_i\, n_i}{N}, \text{ minutes} \qquad (11)$$

Table V shows the results of the calculations for the two indicators for random interruptions in low voltage cable lines.

TABLE V. VALUES OF SAIDI AND SAIFI

Cable lines	N, ***number***	l, ***number***	$\sum_{i=1}^{l} n_i$, ***number***	$\sum_{i=1}^{l} t_i\, n_i$, ***number***	SAIFI, ***number/ half-year***	SAIDI, ***minutes***
LW	2 085 000	642	12 549	17 487 322	0,006	8,4

V. CONCLUSION

The study, statistical processing and analysis of the data on occurred interruptions of the power supply is made in order to determine measures for increasing the reliability of the power supply network and reduce the interruptions to the possible minimum.

Improving the quality and continuity of power supply can be achieved by:

- modernization of the power supply network and facilities;
- investments in innovations aimed at improving the efficiency of the power supply network;
- repair of the facilities;
- introduction of new technologies;
- increasing the control over the facilities, etc.

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