Estimation of Confidence Intervals for Power Distribution Reliability Indices (SAIFI and SAIDI)

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***Abstract* — Power distribution reliability indices, system average interruption duration index (SAIDI) and system average interruption frequency index (SAIFI), depend on the number of service interruptions per year, the number of customers affected by each interruption, and power supply restoration time. All three factors are stochastic and can vary widely even when the network structure and the technical condition of the electrical equipment remain unchanged. This leads to random year-to-year fluctuations in SAIDI and SAIFI values. Determining the range of these stochastic variations is essential for comparing the indices and assessing their compliance with regulatory standards. Currently, formal methodologies for estimating confidence intervals for reliability indices remain underdeveloped both in Russia and internationally. This paper proposes an algorithm for calculating confidence intervals for SAIDI and SAIFI based on daily segmentation and numerical simulation. The proposed algorithm is validated using a case study of distribution systems in Moscow and the Moscow region.**

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***Index Terms* — Distribution system reliability, reliability indices, SAIDI, SAIFI, confidence interval estimation, stochastic modeling, power outage analysis.**

I. Introduction

Reliability of power distribution systems is measured around the world by SAIDI, SAIFI, or similar indices [1, 2]. These indices are recognized by the current Russian legislation in Order No. 1256 of the Ministry of Energy of the Russian Federation dated November 29, 2016 [3]. Standardized reliability values are determined on a case-by-case basis for each grid company based on actual historical data spanning several years, establishing a permissible deviation between actual and planned values. Reliability values are deemed to meet the planned targets if the actual values do not exceed the planned ones by more than 30% [4]. The coefficients of permissible deviations factor in the stochastic nature of reliability metrics and their random year-by-year fluctuations.

Despite existing regulations, there is still a need for mechanisms to justify both permissible values of reliability metrics and their variation ranges [5].

The quantitative assessment of random variations of reliability metrics remains a significant research challenge regarding their comparison and standardization. At present, there are no scientifically grounded solutions to this issue either in Russia or internationally. This study proposes an approach to estimating confidence intervals of SAIDI and SAIFI metrics that measure reliability performance of power distribution systems. We demonstrate our approach using a case study of power distribution systems operated by Rosseti Moscow Region PJSC.

TABLE 1. Yearly SAIDI and SAIFI Values, Moscow and the Moscow Region

Year	Moscow region		Moscow	
	SAIDI, min/year	SAIFI, interruptions per year	SAIDI, min/year	SAIFI, interruptions per year
2020	22.281	0.3155	1.5746	0.0280
2021	22.578	0.2847	1.0646	0.0229
2022	13.162	0.1879	1.9035	0.0404
2023	12.771	0.1834	1.5746	0.0280

II. RELIABILITY METRICS OF POWER DISTRIBUTION SYSTEMS

Order No. 1256 of the Ministry of Energy of the Russian Federation dated November 29, 2016 [3] defined SAIDI and SAIFI metrics as follows.

The system average interruption duration index (SAIDI) is

$$\text{SAIDI} = \frac{\sum_{j=1}^{J} T_j N_j}{N_t}, \quad (1)$$

where T_j is the duration of the j-th interruption of electricity supply to points of delivery resulting from a system disturbance; N_j is the number of points of delivery affected by the j-th interruption of electricity supply due to a system disturbance; N_t is the maximum yearly number of points of delivery served by the grid company; J is the yearly number of electricity supply interruptions affecting points of delivery.

The system average interruption frequency index (SAIFI) is

$$\text{SAIFI} = \frac{\sum_{j=1}^{J} N_j}{N_t}. \quad (2)$$

The values of reliability indices depend on the number of power system disturbances per year that cause interruptions of electricity supply to customers, the number of customers affected by each event, and the speed of supply restoration. All three factors are stochastic and can vary widely even when the network structure and the technical condition of grid equipment remain unchanged. This leads to random year-to-year fluctuations in SAIDI and SAIFI values. Table 1 summarizes reliability indices for Moscow and the Moscow region for years 2020 to 2023 [6–9]. These data are used for further analysis. For convenience, SAIDI values are given in minutes per year.

Conventional statistical methods cannot be applied to yearly values of reliability indices as they require large-size samples. The sample size can be meaningfully increased by replacing the yearly SAIDI and SAIFI with the daily $\text{SAIDI}_{\text{day}}$, $\text{SAIFI}_{\text{day}}$. Then a sample of 365 values (or 366, for leap years) will correspond to each year. This approach is adopted in IEEE Std 1366-2012 “Guide for Electric Power Distribution Reliability Indices” [10] to detect Major Event Days (MED). The standard assumes that daily SAIDI values are approximately log-normally distributed.

III. SAIDI AND SAIFI CONFIDENCE INTERVAL ESTIMATION ALGORITHM: A CASE STUDY OF MOSCOW AND THE MOSCOW REGION

If a random variable is log-normally distributed, its natural logarithm is normally distributed. Figure 1 presents yearly natural logarithm distributions of the $\text{SAIDI}_{\text{day}}$ index for the Moscow region. The histogram shows the actual

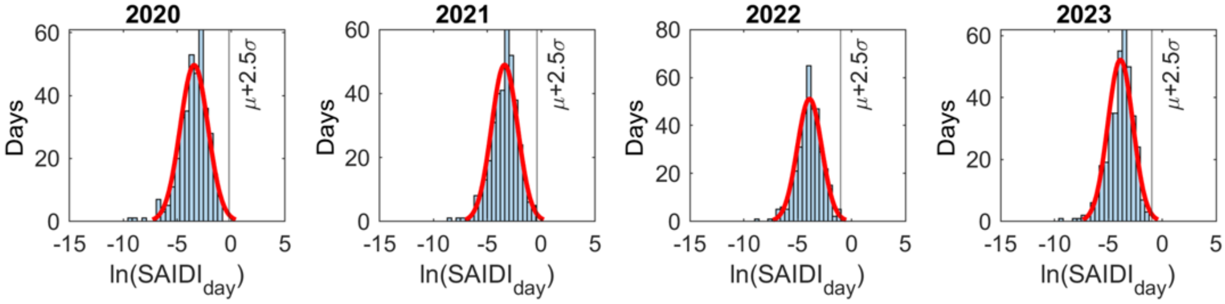

Fig. 1. Yearly distributions of the natural logarithm of $\text{SAIDI}_{\text{day}}$, the Moscow region.

TABLE 2. Omission of Major Event Days, the Moscow Region

Year	Max($SAIDI_{day}$), min/year	$SAIDI_{MED}$, min/year	Days omitted
2020	0.4267	0.8086	0
2021	0.5469	0.6960	0
2022	0.3844	0.3509	1
2023	0.2892	0.3788	0

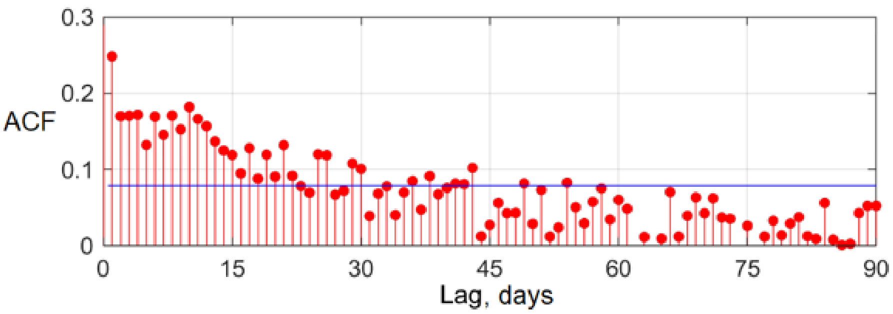

Fig. 2. The autocorrelation function of ln($SAIDI_{day}$) values, Moscow.

(empirical) distribution, the red line indicates its normal approximation.

Figure 1 indicates that the $SAIDI_{day}$ logarithm distribution is close to normal while not being strictly normal. This approximation is utilized to remove outliers. To this end, we calculate the mean (μ) and standard deviation (σ) for $SAIDI_{day}$ logarithms. In compliance with IEEE Std 1366-2012 [9], we classify as outliers those ln($SAIDI_{day}$) values that deviate from the mean by 2.5 σ or more. Then the minimum $SAIDI_{day}$ values for MED are defined by

$$SAIDI_{MED} = e^{\mu + 2,5\sigma}. \quad (3)$$

Table 2 shows maximum yearly $SAIDI_{day}$ values, $SAIDI_{MED}$ values, and the number of days omitted from further analysis.

The resulting samples of $SAIDI_{day}$ values with omitted outliers are then used to estimate confidence intervals of yearly SAIDI values.

Assuming that $SAIDI_{day}$ values are independent random variables, we define the distribution of yearly SAIDI values as a sum of 365 (or 366, for leap years) randomly sampled $SAIDI_{day}$ values

$$SAIDI = \sum_{i=1}^{T} SAIDI_{day\,i}. \quad (4)$$

Since there is no analytical closed-form expression for the distribution function of log-normal random variables, we rely on numerical methods. The $SAIDI_{day}$ distribution is not strictly log-normal, therefore bootstrapping approach is used where random $SAIDI_{day\,i}$ values are sampled with replacement from the input filtered dataset [11]. We generate 10 000 pseudo-samples with a size of 365 (or 366, for leap years) to form the distributions of yearly SAIDI values. The number of pseudo-samples used for bootstrapping is standard. When the accuracy is insufficient, the number of samples is increased. For each sample, we calculate the sum and use the obtained values

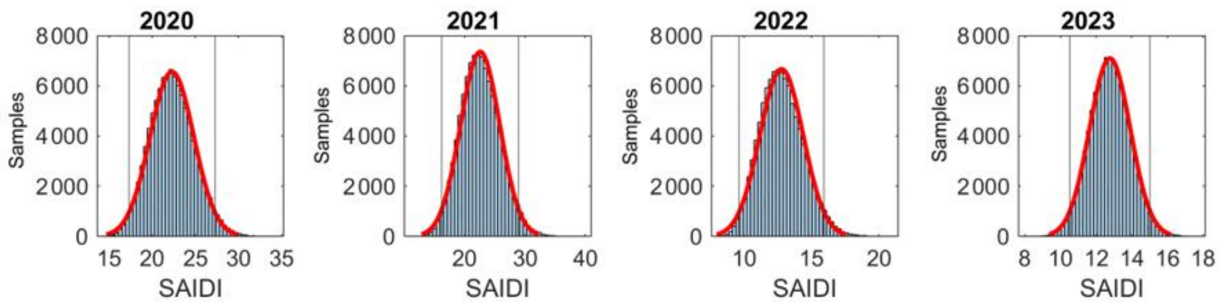

Fig. 3. Yearly SAIDI distributions, the Moscow region.

TABLE 3. Key Parameters of SAIDI Distributions, the Moscow Region

Year	SAIDI, min/year	Generated SAIDI distributions			
		M, min/year	σ, min/year	C_v	$C_{95\%}$, %
2020	22.281	22.276	2.509	0.113	22.1
2021	22.578	22.554	3.244	0.144	28.2
2022	13.162	13.171	1.601	0.122	23.8
2023	12.771	12.766	1.124	0.088	17.3

TABLE 4. SAIDI Comparison, the Moscow Region

Years	$\|M_1\text{-}M_2\|$	z-test	p-significance level	Statistically significant difference
2021–2020	0.278	0.0677	0.9460	no
2022–2021	9.383	2.5942	0.0095	yes
2023–2022	0.404	0.2068	0.8362	no

to generate the distribution, calculate the mean, and estimate confidence intervals.

Time series values often exhibit temporal dependencies; therefore, an autocorrelation data analysis is essential before the bootstrapping procedure [12]. To make the data more uniform, we analyze ln($SAIDI_{day}$) values. The resulting autocorrelation function shown in Fig. 2 demonstrates significant autocorrelation values for lags extending to approximately 30 days.

When input data show autocorrelation, block bootstrapping is typically employed to generate pseudo-samples. To this end, a block of consecutive values is randomly selected from input data. The block size corresponds to the lag exhibiting significant autocorrelation levels. In this particular case, the block size of 30 days is chosen.

Figure 3 shows the resulting distributions of yearly SAIDI values. The histogram indicates the generated distribution, the red line is the approximation by the normal distribution. It is clear that the distribution of yearly SAIDI values is close to normal, therefore the boundaries of the 95% confidence intervals are determined by the standard formula

$$\text{SAIDI}^{\pm} = M(\text{SAIDI}) \pm 1.96\sigma(\text{SAIDI}), \qquad (5)$$

where M is the mean; σ is the standard deviation.

In Fig. 3, the boundaries of the 95% confidence interval are shown by vertical lines.

Table 3 summarizes key parameters of the distributions for the generated sample, including the mean (M); the standard deviation (σ); and the coefficient of variation (C_v) defined as the ratio of the standard deviation to the mean. Additionally, it presents the coefficient of the permissible deviation ($C_{95\%}$), calculated by the expression

$$K_{95\%} = \frac{\text{SAIDI}^{+} - M(\text{SAIDI})}{M(\text{SAIDI})} \cdot 100\%\,. \qquad (6)$$

The difference between actual SAIDI values and the mean of the generated samples does not exceed 0.1%,

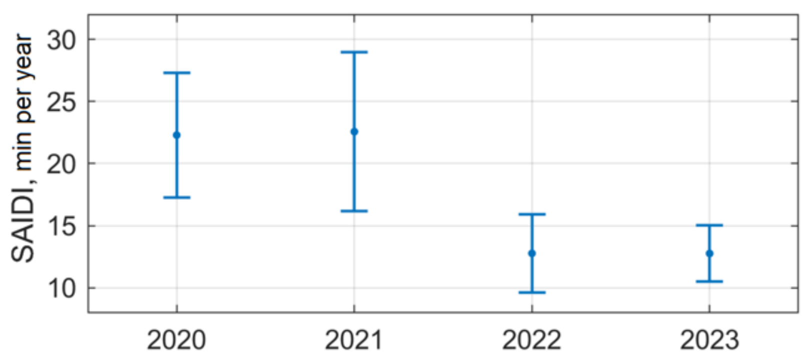

Fig. 4. 95% confidence intervals of SAIDI, the Moscow region.

TABLE 5. Key Distribution Parameters of SAIFI, the Moscow Region

Year	SAIFI, 1/year	Generated SAIFI distributions			
		M, 1/year	σ, 1/year	C_v	$C_{95\%}$, %
2020	0.3155	0.3157	0.0346	0.1094	21.4
2021	0.2847	0.2846	0.0324	0.1139	22.3
2022	0.1879	0.1880	0.0203	0.1080	21.2
2023	0.1834	0.1833	0.0107	0.0583	11.4

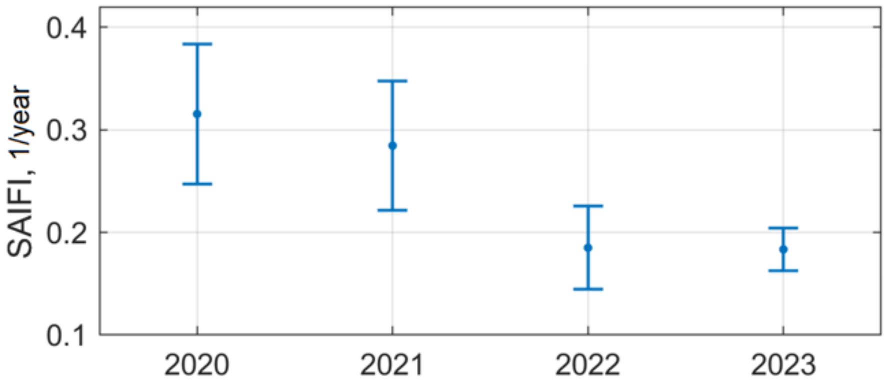

Fig. 5. 95% confidence intervals of SAIFI, the Moscow region.

which proves that the number of pseudo-samples is sufficient.

In the case where the distribution shape is close to normal and distribution parameters are known, *z*-test is used to compare two random variables. The test statistic is defined as

$$z = \frac{M(\text{SAIDI}_1) - M(\text{SAIDI}_2)}{\sqrt{\sigma(\text{SAIDI}_1)^2 + \sigma(\text{SAIDI}_2)^2}}. \quad (7)$$

Given the significance level $p = 0.05$, the values of SAIDI_1 and SAIDI_2 are deemed statistically different if the absolute value of *z* is not less than 1.96. Since the mean of the generated sample coincides with the actual SAIDI values, the condition of the significant difference in indices can be rewritten as follows:

$$\left|\text{SAIDI}_1 - \text{SAIDI}_2\right| \geq 1.96\sqrt{\sigma(\text{SAIDI}_1)^2 + \sigma(\text{SAIDI}_2)^2}. \quad (8)$$

Table 4 summarizes the comparison of SAIDI values to those from the previous year. A statistically significant difference is observed only between years 2021 and 2022.

Figure 4 shows SAIDI values for the Moscow region with 95% confidence intervals.

Confidence interval of SAIFI is estimated similarly, utilizing the bootstrap block size and the resampled data obtained in the previous step. Table 5 summarizes key distribution parameters, while Fig. 5 shows SAIFI values for the Moscow region with 95% confidence intervals.

Below we summarize the algorithm of SAIDI confidence interval estimation as a sequence of steps:

1. Determine $\text{SAIDI}_{\text{day}}$, $\text{SAIFI}_{\text{day}}$, and their natural logarithms for each day of the year.
2. Calculate $\text{SAIDI}_{\text{MED}}$, remove major event days from $\text{SAIDI}_{\text{day}}$ and $\text{SAIFI}_{\text{day}}$ samples.
3. Generate the autocorrelation function of $\text{SAIDI}_{\text{day}}$ natural logarithms and identify the bootstrap block size for the remaining sample.
4. Use the block bootstrap technique to generate 10 000 pseudo-samples from $\text{SAIDI}_{\text{day}}$ and $\text{SAIFI}_{\text{day}}$ values, each with a size of 365 (or 366, for leap years) values.
5. Calculate the sum (the generated yearly SAIDI or SAIFI values) for all pseudo-samples.
6. Calculate the mean and standard deviation of SAIDI and SAIFI. If the means are significantly different from the original SAIDI and SAIFI values, increase the number of pseudo-samples and go to Step 4.
7. Calculate SAIDI and SAIFI confidence intervals as $M \pm 1.96\sigma$.

IV. RESULTS OF SAIDI AND SAIFI CONFIDENCE INTERVAL ESTIMATION FOR THE CASE OF MOSCOW

We estimate confidence intervals of reliability metrics of a metropolitan area through a case study of Moscow. Figure 6 shows yearly distributions of the natural logarithm of non-zero $\text{SAIDI}_{\text{day}}$ values. The distributions

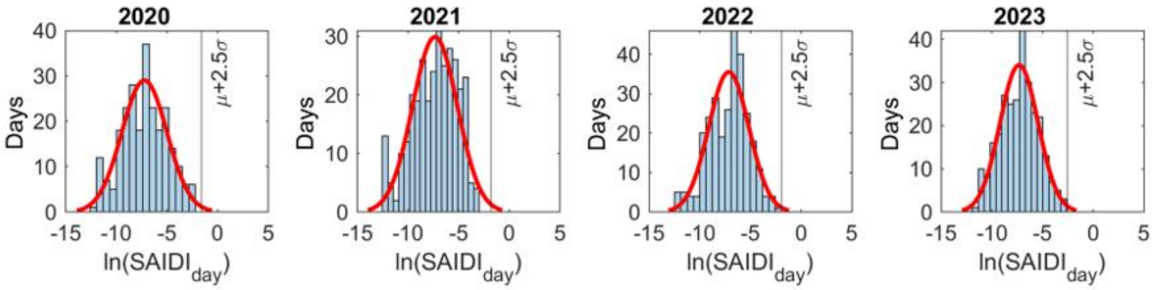

Fig. 6. Yearly distributions of the natural logarithm of SAIDI$_{day}$, Moscow.

TABLE 6. Omission of Major Event Days, Moscow

Year	Max(SAIDI$_{day}$), min/day	SAIDI$_{MED}$, min/day	Days omitted
2020	0.2047	0.2036	1
2021	0.0443	0.1651	0
2022	0.3117	0.1435	3
2023	0.1188	0.0788	1

are less uniform than in the case of the suburban area, but are also close to normal. Table 6 presents maximum yearly SAIDI$_{day}$ values, SAIDI$_{MED}$, and the number of days omitted from further analysis.

Figure 7 illustrates the autocorrelation function of ln(SAIDI$_{day}$). It is clear that there is no significant autocorrelation and SAIDI$_{day}$ values are independent, therefore bootstrapping without blocks is applied to generate pseudo-samples.

Table 7 and 8 summarize key parameters of SAIDI and SAIFI distributions. Figures 8 and 9 show 95% confidence intervals of SAIDI and SAIFI for Moscow. The coefficient of permissible deviation ($C_{95\%}$) of SAIDI in the case of several years slightly exceeds the standard limit of 30%, which suggests that the coefficient could take on values beyond the permissible range due to random variations.

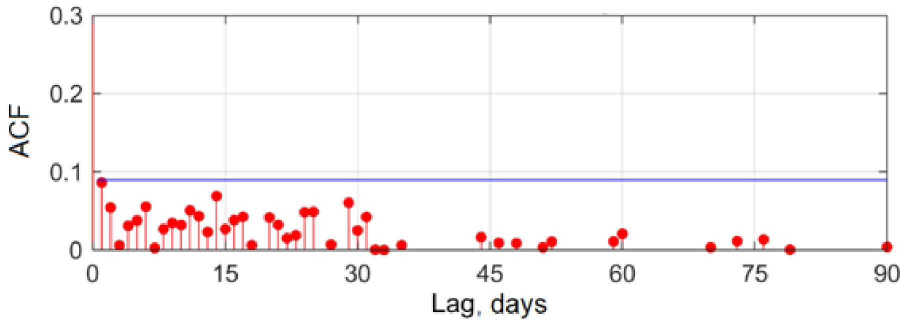

Fig. 7. The autocorrelation function of ln(SAIDI$_{day}$) values, Moscow.

TABLE 7. Key Parameters of the SAIDI Distribution, Moscow

Year	SAIDI with omissions, min/year	Generated SAIDI distributions			
		M, min/year	σ, min/year	C_v	$C_{95\%}$, %
2020	1.370	1.370	0.231	0.169	33.1
2021	1.065	1.062	0.109	0.102	20.1
2022	1.307	1.128	0.201	0.178	34.9
2023	0.830	0.829	0.117	0.141	27.7

TABLE 8. Key Parameters of the SAIFI Distribution, Moscow

Year	SAIFI, 1/year	Generated SAIFI distributions			
		M, 1/year	σ, 1/year	C_v	$C_{95\%}$, %
2020	0.0232	0.0232	0.0034	0.1453	28.5
2021	0.0229	0.0228	0.0023	0.0988	19.4
2022	0.0237	0.0237	0.0036	0.1539	30.2
2023	0.0180	0.0180	0.0020	0.1137	22.3

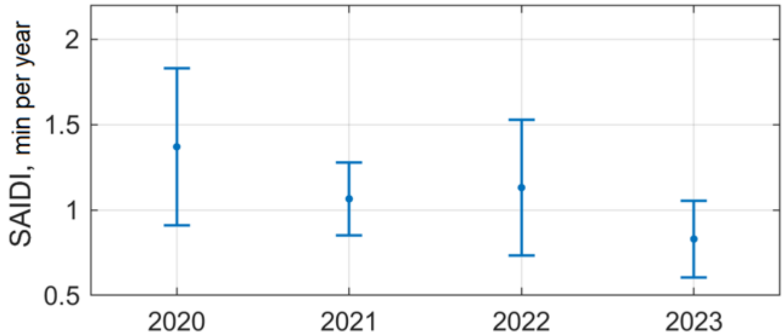

Fig. 8. 95% confidence intervals of SAIDI, Moscow.

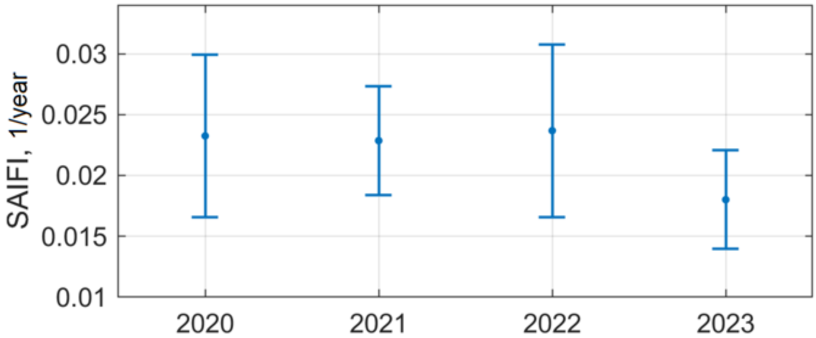

Fig. 9. 95% confidence intervals of SAIFI, Moscow.

V. CONCLUSION

Estimation of confidence intervals for the reliability indices of power distribution systems (SAIDI and SAIFI) is essential for comparing them, distinguishing systematic changes from random ones, and verifying compliance of actual values with the standards. At present, the confidence intervals for SAIDI and SAIFI are not estimated in Russia or internationally.

This study contributes a formal algorithm for the estimation of confidence intervals for reliability indices SAIDI and SAIFI. The approach is based on partitioning data into 1-day units and generating pseudo-samples through bootstrapping. The case study of Moscow and the Moscow region confirms that the 30% permissible deviation stipulated by current regulations is highly appropriate.

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