UDC 621.311 DOI: https://doi.org/10.15407/publishing2026.73.012

METHOD FOR DECOMPOSITION OF SAIDI INDEX BY OUTAGE DURATION STRUCTURE TO JUSTIFY RELIABILITY IMPROVEMENT PRIORITIES IN DISTRIBUTION NETWORKS

O.V. Gai 1*, G.A. Gai 2, I.V. Blinov 1*****
1 – Institute of Electrodynamics, NAS of Ukraine,
Beresteyskyi Ave., 56, Kyiv, 03057, Ukraine e-mail: blinovihor@gmail.com , gaalxold@gmail.com
2 – National University of Life Resources and Environmental Sciences of Ukraine,
03041, 15 Heroiv Oborony St., Kyiv, Ukraine e- mail: gtatana704@gmail.com

The paper proposes a method for decomposing the SAIDI indicator by the structure of emergency interruptions, based on an analysis of retrospective data on technological failures in distribution electrical networks. The method is based on a statistical analysis of the duration of power supply restoration, with two characteristic modes: "short" emergency interruptions caused by the search for the location of the damage and operational switching, and "long" interruptions, which additionally include repair and restoration work. The boundary between the modes is formally determined by the maximum consistency of the empirical distribution with the normal law, as measured by the Kolmogorov-Smirnov criterion. It is shown that for short emergency interruptions, an approximation by a normal distribution is appropriate. In contrast, for long interruptions, an adequate description is provided by distributions with a "long tail" (lognormal or Pareto). Based on the proposed decomposition, a quantitative assessment of each zone's contribution to the SAIDI indicator was performed, revealing that long emergency outages, despite a smaller share of events, account for the dominant contribution to the integral outage duration. The proposed method allows us to justify the priorities for increasing the reliability of distribution networks without resorting to optimisation tasks, focusing on the impact of localising emergency areas and reducing the duration of repair and restoration work. The results obtained can be used as an engineering tool to support decision-making when forming reliability improvement programs under conditions of limited availability of detailed operational information. Bibl. 14, Figs. 4, table.

Keywords: SAIDI, reliability of power supply, distribution electrical networks, retrospective data, statistical modelling, Kolmogorov-Smirnov criterion, Pareto distribution, lognormal distribution, ranking of measures.

Introduction. The reliability of electricity supply is one of the key characteristics of the quality of service provided by distribution system operators (DSOs). It is assessed, in particular, by the average interruption duration index SAIDI, which is used in regulatory reporting, when forming investment programs and when monitoring compliance with regulatory indicators of the quality of electricity supply [1]. In the context of the transformation of the electricity sector, the increasing complexity of network operating modes, increasing requirements for controllability, automation and digitalisation of distribution electricity networks, the task of a well-founded choice of technical and organisational measures aimed at reducing integral indicators of unreliability is becoming more urgent [2, 3].

Practical statistics on emergency outages in distribution networks exhibit significant heterogeneity in both the causes of occurrence and the duration of power supply restoration. In particular, a significant proportion of events has a relatively short duration. It is mainly associated with the search for the damage location and the performance of operational switching. In contrast, a smaller group of events with a long recovery time, due to the need for repair and restoration work, accounts for the main part of the SAIDI indicator value. Such heterogeneity means that the effectiveness of various reliability improvement measures depends significantly on the stage of the power supply restoration process at which they operate [4–6].

Modern approaches to improving the reliability of distribution systems include the use of sectioning devices, remotely controlled switching devices, fault indicators, automation and dispatching elements, as well as the integration of distributed energy sources, storage systems and microgrids [7–14]. A significant part of the research focuses on optimising the placement or number of individual types of technical means to increase reliability, often using detailed topological network

---

ORCID ID: * https://orcid.org/0000-0001-5460-7260 , ** https://orcid.org/0000-0001-5707-2927 ,
*** https://orcid.org/0000-0001-8010-5301

models or combinatorial optimisation problems [9–12]. At the same time, in the practice of planning DSO activities, integral indicators (SAIDI, SAIFI) prevail, which lack a direct link to specific network elements but do determine economic consequences and investment constraints.

Such division of the power supply restoration process into separate technological stages – damage localisation, prompt power restoration of undamaged areas and repair – is consistent with both classical models of power supply reliability and modern approaches to optimising the structure of distribution networks and their control means [4, 5, 11, 12]. At the same time, in most known works, the influence of the time structure of emergency events on the formation of integral reliability indicators is considered indirectly or within the framework of simplified average estimates, which complicates the quantitative comparison of the effectiveness of alternative technical solutions under conditions of limited investment resources.

In the context of the growing share of automated elements, microgrids and intelligent control systems, the combination of statistical analysis of actual technological failures with models for assessing the effectiveness of various reliability improvement measures, which have functionally different effects on different stages of the emergency response process, is of particular relevance [6, 7, 11, 12, 14]. This makes it appropriate to decompose the statistics of emergency shutdowns by restoration duration and to build models that allow quantitatively assessing the contribution of "short" and "long" interruptions to the formation of the SAIDI indicator and, accordingly, to justify the priorities for implementing reliability improvement measures.

In connection with the above, the task of analytical research of the structure of emergency interruptions in the power supply of distribution electric networks, based on the distribution of emergency events by the duration of power supply restoration and assessing the contribution of short and long interruptions to the formation of the SAIDI indicator, is relevant. This approach provides the opportunity to justify the priorities of the impact on individual elements and technological stages of the power supply restoration process when planning reliability improvement measures, while maintaining compatibility with the practice of using integral indicators in the regulatory reporting of the DSO.

The purpose of the study is to analyse the structure of emergency interruptions in the power supply of distribution power networks and assess the contribution of short and long emergency outages to the formation of the SAIDI indicator to justify the priorities of impact on individual elements and technological stages of the power supply restoration process when planning reliability improvement measures.

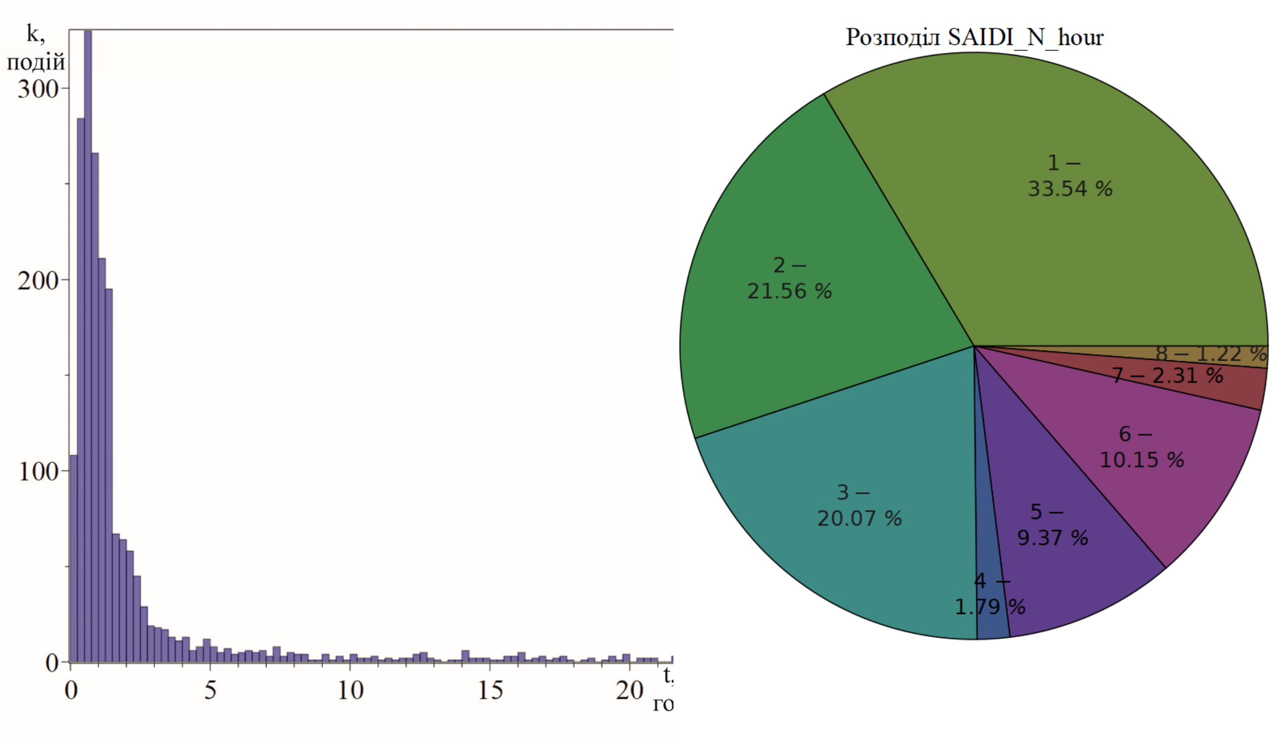
The task of the study is to analyse retrospective statistics of emergency outages in distribution power networks, decompose emergency outages by the duration of power supply restoration, and assess the contribution of short and long outages to the formation of the SAIDI indicator to justify the priorities of the impact on the elements and technological stages of the power supply restoration process while increasing the reliability of networks.

Materials and methods. The empirical basis of the study was retrospective statistical data on technological failures in urban electric distribution networks over a multi-year observation period. To align the sample with typical operational assumptions and limit the impact of emissions, the duration of elimination of individual emergency events was limited to a maximum of 22 hours, consistent with the practice of operating distribution networks and regulatory requirements for the quality of the electricity supply.

For analysis, emergency events were grouped into generalised classes of distribution network elements (element 1, element 2, …, element N), without detailing their designs or nominal parameters. Such classes included, in particular, events related to cable and overhead lines of different voltage classes, as well as other network elements for which emergency outages were recorded in the statistical data.

A separate group was formed for events for which the original data lacked an unambiguous identification of the primary element that caused the disturbance. Such aggregation allowed us to perform a structural analysis of emergency outages without reference to a specific topology or network configuration, while maintaining the representativeness of the integral statistical characteristics, and to produce a pie chart of the distribution of failures by generalised groups of elements (Fig. 1 *b*).

Based on the histogram of power supply restoration time (Fig. 1 *a*), a hypothesis has been put forward that the restoration process exhibits two characteristic modes. The first mode corresponds to “short” emergency breaks, whose duration is mainly determined by the time required to locate the damage and perform operational switching. The second mode corresponds to “long” emergency breaks, which, in addition to the above operations, include repair and restoration work.



a *b*

Fig. 1. Histogram of power supply restoration time distribution and pie chart of failure distribution by generalised groups of elements

The boundary between short and long outages $\boldsymbol{m}$ was determined based on a statistical consistency criterion, maximising the likelihood of assuming a normal distribution of the recovery time in the first zone. For this purpose, the Kolmogorov–Smirnov test (KS -test) was used in combination with empirical distribution function (ECDF) analysis. The value $\boldsymbol{m}$ was taken as the one at which the deviation between the empirical and theoretical distribution functions for the first zone was minimal.

To describe the statistical properties of short outages, a normal distribution of recovery times was adopted as the basic model. For long outages, due to the asymmetry of the sample and the presence of a “long tail”, heavy-tailed distributions were used, in particular the Pareto and lognormal distributions. The parameters of the corresponding distributions were estimated by the maximum likelihood method using aggregated data for each generalised class of elements.

The assessment of the contribution of short and long emergency interruptions to the formation of the integral SAIDI indicator was conducted through a comparative analysis of their frequency of occurrence and average duration, which enabled the determination of the dominant recovery modes in terms of their impact on the overall value of the reliability indicator.

Mathematical model. Formed based on the assumption that the available retrospective statistics of emergency outages do not contain detailed information on the number of disconnected consumers for each event. In this regard, at the initial stage of the analysis, it is assumed that the number of disconnected consumers in the sample under consideration is constant. Under such an assumption, the contribution of an emergency event to the formation of the integral indicator SAIDI can be estimated in proportion to the duration of the corresponding interruption in power supply. The assumption of the constancy of the multiplier for the number of disconnected connections within the sample was used to estimate the contribution of events to SAIDI, proportional to the duration of the interruptions. Under conditions where the average value $\boldsymbol{n_i}$ does not demonstrate a systematically different structure between the groups of short and long interruptions, such an assumption does not change the qualitative conclusion regarding the dominance of long interruptions in the formation of SAIDI and the corresponding ranking of priorities of measures; it affects mainly the absolute estimates, rather than the relative shares of the contribution.

Accordingly, for the sample of $\boldsymbol{M}$ emergency events, the generalised estimate of the SAIDI indicator was determined as a value proportional to the total duration of interruptions:

$$SAIDI_{total} = \frac{\sum n_i t_i}{N} \approx \sum_{i=1}^{k} t_i \, , \tag{1}$$

where $\boldsymbol{t_i}$ is duration of the $\boldsymbol{i}$-th emergency break, hours; $\boldsymbol{n_i}$ is number of subscriber connections disconnected during the $\boldsymbol{i}$-th emergency break, pcs.; N is total number of subscriber connections, pcs.; $\boldsymbol{k}$ is total number of events, pcs.

That is

$$\mathbf{SAIDI} \propto \sum_{i=1}^{k} t_i \, . \tag{2}$$

If a finite set of elements is operated in the distribution network, for which emergency shutdowns with certain statistical characteristics were recorded during the observation period, then, for analysis, it is advisable to present this set in the form of a generalised system of groups of elements, each of which is characterised by homogeneous indicators of emergency. In this case, the overall network reliability indicators can be determined by aggregating the characteristics of individual groups of elements:

$$SAIDI_{total} = \sum_{j}^{\substack{summary \\ groups}} SAIDI_{total\, j} \approx \sum_{j}^{\substack{summary \\ groups}} \sum_{i=1}^{k} t_i \, . \tag{3}$$

Considering the results of statistical analysis, a two-zone model of power supply restoration time with a threshold value is introduced $\boldsymbol{m}$, which divides emergency events into two groups:

for interval $\boldsymbol{t \leq m}$ – “short” emergency breaks;

for interval $\boldsymbol{t > m}$ – “long” emergency breaks.

The value $\boldsymbol{m}$is a parameter determined for a specific sample (and/or subsample) and may vary depending on the organisation of field service, network configuration, and data quality; $\boldsymbol{m}$ it is used in the work as a formalised tool for separating the two recovery modes, rather than as a normatively fixed boundary.

The limit $\boldsymbol{m}$ was determined by maximising the consistency of the empirical distribution of durations in the first zone with the normal distribution law, using the Kolmogorov–Smirnov criterion.

To verify the correspondence of the empirical distribution of the duration of short emergency interruptions to the theoretical models, an empirical distribution function (ECDF) was formed:

$$F_k(x) = \frac{1}{k} \sum_{i=1}^{k} I(X_i \leq x), \tag{4}$$

where X_i are the elements of the sample, k its volume, $I(\cdot)$ is the indicator function.

Correspondence of the empirical distribution to a given theoretical distribution function $F(x)$ was evaluated by the Kolmogorov -Smirnov criterion, the statistics of which are defined as

$$D_k = \sup_x \mid F_k(x) - F(x) \mid . \tag{5}$$

The value of the boundary parameter m was determined by analysing the dependence of the consistency of the empirical distribution of the duration of emergency breaks of the first zone on the normal law on the position of the boundary between the zones. For this purpose, the Kolmogorov–Smirnov criterion was used in combination with the analysis of the empirical distribution function, enabling estimation of the probability of accepting the hypothesis of normality as m varied. The specified dependence is shown in Fig. 2 and is used to illustrate the procedure for choosing the boundary between short and long emergency breaks.

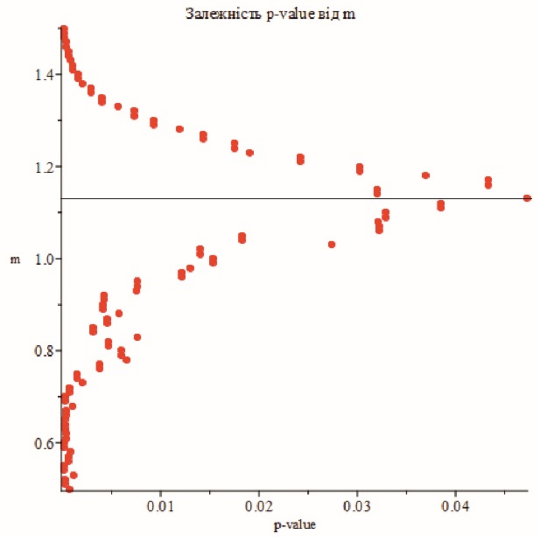
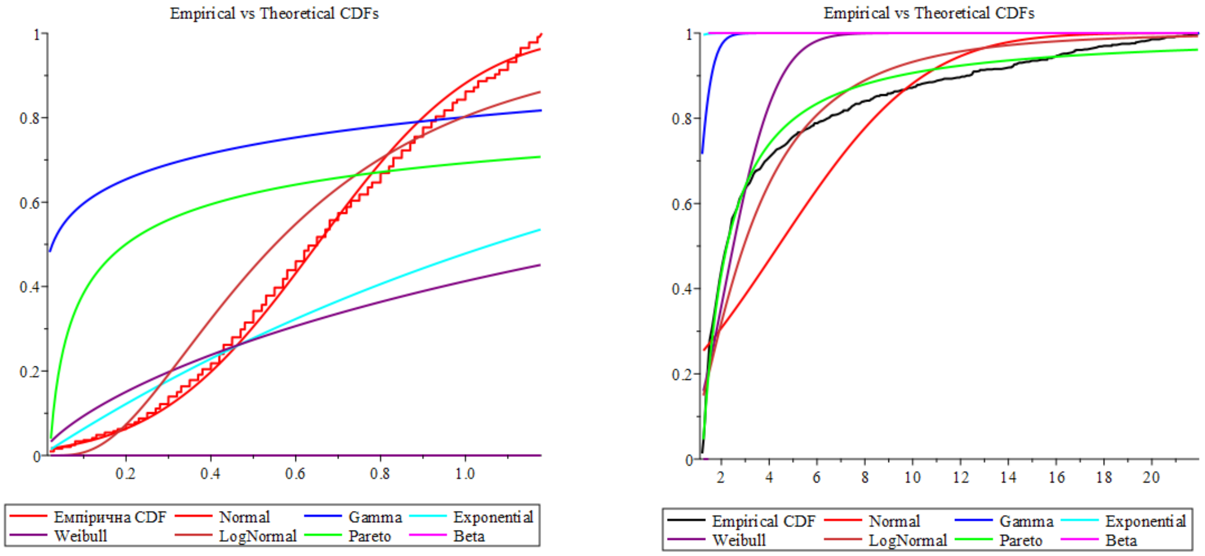


Fig. 2. Dependence of the probability of accepting the hypothesis of normal distribution for short emergency breaks from the limit parameter position m.

Formal assessment of the consistency between the empirical and theoretical distributions was performed using statistical criteria, particularly the Kolmogorov-Smirnov test, while Fig. 3 *a* and 3 *b* are provided for a visual comparison of the empirical distribution function with the corresponding theoretical models. According to the results of the comparative analysis of the correspondence of the empirical data of short emergency interruptions to theoretical models, in particular the normal, exponential, Weibull, gamma, lognormal, Pareto and beta -distributions, it was found that the normal distribution is characterized by a minimal deviation from the empirical distribution function within the first zone, which allows it to be used as a basic model for describing short emergency interruptions.



a *b*

Fig. 3. Comparison of the empirical distribution of the duration of short *a* and long *b* emergency interruptions with theoretical models when assessing statistical consistency

In this regard, for further analysis, a normal distribution with a probability density was adopted as the basic model for describing short emergency interruptions:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left(\frac{-(x-\mu)^2}{2\sigma^2}\right), \tag{6}$$

where μ is the mathematical expectation, σ is the standard deviation, estimated by sample dependencies.

After determining the threshold parameter m and forming a sample of short emergency interruptions, further analysis was focused on emergency events with a duration $t > m$corresponding to the long-term power supply restoration regime. This group of events is characterised by significant distribution asymmetry and the presence of significant duration values due to the performance of repair and restoration works, organisational and logistical factors.

To determine the theoretical statistical model most adequate to the empirical data on long emergency interruptions, a comparative analysis of the sample's compliance with the following distributions was performed: normal, exponential, Weibull, gamma, lognormal, Pareto, and beta. For each of these distributions, the degree of agreement with the empirical distribution function was assessed using generalised statistical criteria for the deviation between the empirical and theoretical distribution functions.

The results of the comparative analysis showed that the normal, exponential, Weibull, gamma, and beta distributions do not provide a proper description of the right-tailed part of the sample, since they significantly underestimate the probability of large values of the duration of emergency interruptions. At the same time, the lognormal distribution and the Pareto distribution best reproduce the empirical data, in particular the behaviour of the "long tail", which is decisive for the formation of the contribution of long interruptions to the integral indicator SAIDI. The use of the lognormal and Pareto models corresponds to the nature of repair and restoration processes, where the total duration is formed by the multiplicative (lognormal) or "heavy-tailed" (Pareto) nature of rare delays - logistical, organisational, and technological. A formal assessment of the consistency of the empirical and theoretical distributions was performed using statistical criteria, in particular the Kolmogorov - Smirnov criterion, while Fig. 3 *b is* provided for a visual comparison of the empirical distribution function with the corresponding theoretical models.

In this regard, the lognormal and Pareto distributions were adopted as baseline models for describing long outage events for further analysis. The Pareto distribution was defined by the probability density function:

$$f(x) = \frac{\alpha x_m^{\alpha}}{x^{\alpha+1}}, x \geq x_m, \tag{7}$$

where $x_m$is the minimum value of the random variable, α is the shape parameter.

The lognormal distribution was described by the density:

$$f(x) = \frac{1}{x\,\sigma_{\ln}\sqrt{2\pi}} \exp\ (\frac{-(\ln x - \mu_{\ln})^2}{2\sigma_{\ln}}), x > 0, \tag{8}$$

where $\mu_{\ln}$and $\sigma_{\ln}$ are the parameters of the normal distribution for the random variable $\ln x$.

To ensure the statistical validity of the results, an additional assessment of the sample size sufficiency was performed for each emergency interruption zone. Such analysis enables substantiation of the reliability of estimates of distribution parameters and, accordingly, the correctness of subsequent conclusions regarding the contribution of individual event groups to the SAIDI indicator.

For normal and lognormal distributions, the minimum required sample size was determined under the condition of a given permissible error ε:

$$n \geq \left(\frac{z_{\alpha/2}\,\sigma}{\varepsilon}\right)^2, \tag{9}$$

where $z_{\alpha/2}$is the quantile of the normal distribution, σ is the estimate of the standard deviation.

For power distributions (Pareto distributions), the shape parameter was estimated using the Hill estimator:

$$\hat{\alpha}^{-1} = \frac{1}{k}\sum_{i=1}^{k} \ln\left(\frac{X_{(i)}}{X_{(k+1)}}\right), \tag{10}$$

where $X_{(i)}$ are k the largest values of the sample ordered in descending order.

Stabilisation of the estimate $\hat{\alpha}$ when changing the number of maximum values taken into account k was used as a criterion for the sufficiency of statistical data to describe the "long tail" of the distribution.

The performed assessment allowed us to separate groups of accidents with representative statistics, for which the obtained parameter estimates are stable, from groups with limited data, for which further conclusions are considered preliminary and indicative.

Results and Discussion. The mathematical experiment consisted of applying the proposed method for decomposing the SAIDI indicator to an integral sample of emergency interruptions to quantitatively separate the contributions of short and long events and assess the SAIDI indicator's sensitivity to changes in each zone's parameters.

At the first stage, the boundary value between short and long emergency interruptions was determined as the parameter m, which corresponds to the maximum consistency of the sample of short interruptions with the normal distribution law according to the Kolmogorov–Smirnov criterion (Fig. 2). For the integral sample, the value $m = 1.101$ h was obtained. For short emergency interruptions ($t \leq m$), the correspondence to the normal distribution with parameters $\mu = 0.651$ h and $\sigma = 0.295$ h was established (Fig. 3 *a*), interpreted as the average time required to locate the damage and perform operational switching.

For long emergency interruptions ($t > m$), based on a comparative analysis of several theoretical models, the best agreement with empirical data was observed for the lognormal and Pareto distributions (Fig. 3 *b*). The use of distributions with a “long tail” is fundamentally important for an adequate description of rare but long-lasting events that disproportionately affect the integral value of SAIDI.

After defining the boundary m, and the statistical models for each zone, an assessment of the quantitative contribution of short and long emergency outages to the SAIDI index was conducted. Using available retrospective statistics, the share of events in each zone was determined by the relative number of emergency outages, while the contribution to SAIDI was estimated in proportion to the total duration of the corresponding events, using the ratio (1).

The results of such analysis for the integral sample are shown in Fig. 4 as a combined histogram of the frequency of emergency interruptions and a curve reflecting their weighted contribution to SAIDI. It was found that short emergency interruptions account for 57.87% of the total number of events but form only 17.27% of the total SAIDI value. In contrast, long emergency interruptions, which account for 42.13%, contribute 82.73% to the SAIDI indicator. Thus, despite their lower probability of occurrence, long emergency interruptions play a dominant role in shaping the integral unreliability of power supply.

The resulting decomposition allows us to move from qualitative analysis to a quantitative assessment of the impact on the SAIDI indicator. In particular, for each zone, the sensitivity of SAIDI to a decrease in the frequency and/or average duration of emergency interruptions can be determined. In practice, this means that a decrease in the probability of occurrence or the average time to eliminate long emergency interruptions results in a significantly greater decrease in SAIDI than an equivalent decrease in the parameters of short interruptions.

This situation is well illustrated in Fig. 4: although the number of long emergency outages is significantly lower, their contribution to the integral indicator is determined not by frequency but by the weight component associated with their long restoration duration. Accordingly, priorities for improving reliability should be set based on the structure of outages, rather than only on the total number of outages.

From the point of view of practical application, this means that measures aimed at reducing the duration of repair and -restoration work and localisation of the emergency area with partial restoration of power supply are more effective in terms of reducing SAIDI than measures that affect exclusively the reduction of the time to search for the damage site. The proposed SAIDI decomposition method thus creates a formalised basis for substantiating the priorities for increasing the reliability of distribution power networks, considering the real structure of emergency interruptions.

Fig. 4. Combined histogram of the frequency of emergency interruptions and their weighted contribution to SAIDI: short breaks ($t \leq m$) and long breaks ($t > m$)

To generalise the results and assess the stability of the proposed SAIDI decomposition method, an analysis of several independent subsamples of emergency outages, corresponding to different generalised classes of distribution network elements, was carried out. For each subsample, the threshold value of the first zone m, the parameters of statistical models for short and long emergency outages, the share of events of each zone and their contribution to the formation of the SAIDI indicator, as well as the sensitivity indicators of SAIDI to changes in the frequency of short and long emergencies, were determined separately. The results of such analysis are given in the table.

In the table, the indicators "reduce % of events to reduce SAIDI by 1%" were defined as the reciprocal of the share of the contribution of the corresponding group of interruptions to SAIDI at a fixed average duration within the group, i.e. as an indicator of the sensitivity of SAIDI to changes in the frequency of events in this group. This indicator is used for engineering comparison of the directions of influence without setting an optimisation problem.

The data in the table confirm the stability of the patterns obtained across different groups of elements. Despite significant differences in sampling depth and the threshold value m, as well as in the average recovery time for short emergency interruptions, the SAIDI indicator is dominated by long emergency interruptions in all considered cases. Thus, across most subsamples, the share of long emergencies does not exceed 50%, yet they contribute 60–98% to SAIDI.

The values of the sensitivity indicators given in rows 8–9 of the table are particularly indicative. A 1% reduction in the frequency of long accidents leads to a decrease in SAIDI several times faster than an equivalent reduction in the frequency of short accidents. This indicates a significantly higher effectiveness of measures aimed at reducing the duration or probability of long emergency interruptions.

Additionally, for some subsamples, specific failure rate indicators were estimated ω, which were defined as the average number of emergency events per unit of length or number of typical equipment per unit of time:

$$\omega = \frac{1}{T_{\text{observation}}} \cdot \frac{N_{\text{failures of standard equipment}}}{L_{\text{total length or number of standard units}}}, \tag{11}$$

where $T_{\text{observation}}$ is duration of the observation period, years; $N_{\text{failures of standard equipment}}$ is total number of recorded failures of the corresponding generalised class of elements during the observation period, pcs.; $L_{\text{total length or number of standard units}}$ is total length or number of elements of the corresponding class that were in operation during the observation period, km.

Characteristics	El. 1	El. 2	El. 3	El. 4	El. 5	El. 6	El. 7	El. 8
1) Sampling depth, pcs	958	194	173	26	252	264	62	41
2) The boundary of the first zone, h	1.3	1.8	1.1	2.14	1.15	1.00	0.80	0.80
3) Average time to eliminate "short" damage (Mean_D1), hours	0.683	0.904	0.647	0.912	0.627	0.569	0.515	0.399
4) Percentage of short-term accidents, %	73.25	39.66	25.91	22.54	57.29	50.61	71.18	73.34
5) Percentage of long accidents, %	26.75	60.34	74.09	77.46	42.71	49.39	28.82	26.66
6) Impact on SAIDI from short accidents, %	34.55	6.43	3.08	1.47	22.21	19.13	32.82	40.00
7) Impact on SAIDI from long accidents, %	65.45	93.57	96.92	98.53	77.79	80.87	67.18	60.00
8) Reduce % of short accidents to reduce SAIDI by 1%	2.12	6.17	8.41	15.33	2.58	2.65	2.17	1.83
9) Reduce % of long accidents to reduce SAIDI by 1%	0.41	0.64	0.76	0.79	0.55	0.61	0.43	0.44
10) Parameters of the normal distribution (μ; σ)	μ=0.683; σ=0.315	μ=0.904; σ=0.399	μ=0.647; σ=0.237	μ=0.912; σ=0.521	μ=0.627; σ=0.282	μ=0.569; σ=0.227	μ=0.515; σ=0.123	μ=0.399; σ=0.241
11) Distribution for long accidents (type; parameters)	Pareto; xm = 1.3; α=1.606	Lognorm.; μ=1.66; σ=0.807	Lognorm.; μ=1.415; σ=0.842	Lognorm.; μ=1.605; σ=0.705	Pareto; xm=1.15; α=1.289	Pareto; xm=1.0; α=1.431	Pareto; xm = 0.8; α=1.364	Pareto; xm=0.8; α=1.455
12) Average time to eliminate "long" damage, hours	2,698	7,286	5,866	6,381	3,093	2,339	1,984	1,835
13) Specific failure rate (ω), $\frac{\text{times}}{\text{km(pcs)}\cdot\text{year}}$	0.573	0.161	0.196	0.384	0.099	0.0038	n/a	n/a

This indicator was used to assess the consistency of the statistical characteristics across different subsamples and did not affect the overall logic of the SAIDI decomposition. The obtained values ω are within the typical range characteristic of the corresponding classes of distribution network elements, which confirms the representativeness of the statistical data used.

Conclusions. A method for decomposing the SAIDI indicator by the structure of emergency interruptions is proposed, based on the analysis of retrospective statistics on the duration of power supply restoration, and allows moving from an integral indicator to a quantitative assessment of the contribution of various emergency outage modes.

A two-zone model of power supply restoration time is substantiated, according to which short emergency interruptions are described by a normal distribution, and long ones by distributions with a "long tail" (lognormal or Pareto). The choice of the boundary between zones and the selection of statistical models are confirmed by a formal test of the consistency of the empirical data with the theoretical distributions.

The disproportionate influence of long emergency interruptions on the formation of the SAIDI indicator is quantitatively shown: despite their smaller share of total accidents, they account for the majority of the SAIDI's integral duration, a stable pattern across different subsamples of emergency data.

A method for assessing the sensitivity of the SAIDI index to changes in the frequency of short and long emergency interruptions is proposed, which allows comparing the effectiveness of the impact on different components of the power supply restoration process without going into optimisation problems. It is shown that reducing the probability or duration of long emergency interruptions has a significantly greater effect on SAIDI than an equivalent reduction in the frequency of short interruptions.

Based on the obtained decomposition, priorities for increasing the reliability of distribution networks are substantiated, according to which preference should be given to measures aimed at localising emergency areas and reducing the duration of repair and restoration work, rather than measures that affect only the time required to locate the damage site.

The proposed method is appropriate for analysis tasks based on integral indicators and retrospective outage statistics, provided a representative sample is available to estimate distribution parameters. Further improvement in accuracy is possible by supplementing the primary data with information on the number of de-energised connections in each event and by specifying the primary element of the disturbance.

It is shown that the use of specific failure rate indicators as a control parameter confirms the representativeness of the applied subsamples and the consistency of the statistical characteristics of different groups of emergency data. The proposed SAIDI decomposition method is the basis for developing a practical methodology and decision support tools for the formation of reliability improvement programs under conditions of limited availability of detailed operational information, in particular, substantiating investments in equipment replacement to increase the reliability of the operation of electrical networks, and also creates a basis for the formation of recommendations for collecting statistical information on damage in electrical networks, which is an important direction of further scientific and practical research to support the reliability and development of electrical networks.

The publication was prepared as part of the scientific work "Models and means of increasing the reliability of distribution electricity networks in the context of increasing renewable energy generation" (Monitor-5) (KPKVK 6541030).

1. Resolution of the National Energy and Utilities Regulatory Commission of Ukraine No. 374 dated 12.06.2018 "On approval of reporting forms on electricity supply quality indices and instructions for their completion" (Ukr)
2. Concept for the implementation of Smart Grids in Ukraine until 2035. Cabinet of Ministers of Ukraine, Order No. 908 -r dated 14.10.2022 (Ukr)
3. Energy Strategy of Ukraine until 2050. Cabinet of Ministers of Ukraine, Order No. 373 -r dated 04/21/2023 (Ukr)
4. Kozyrskyi VV, Gai OV Methods and models for reliability assessment of power supply systems. Kyiv: Gnozys , 2013. 563 p. (Ukr)
5. Allan RN Reliability Evaluation of Power Systems. Springer, 2013.
6. Kaplun V., Gai O., Stetsiuk P., Ivlichev A. Provision of optimal dispatching scenarios for regional power systems under uncontrollable power shortages. *Machinery & Energetics* . 2023, 14(2). DOI: https://doi.org/10.31548/machinery/2.2023.23
7. Blinov I., Zaitsev I., Parus Ye., Bereznychenko V. Fault indicators application for smart monitoring systems to improve reliability of electric power distribution. Power Systems Research and Operation. Studies in Systems, Decision and Control. Vol. 220. Springer, 2023. DOI: https://doi.org/10.1007/978 -3 -031 -17554 -1_11
8. Blinov I., Zaitsev I., Parus Ye., Bereznychenko V. Analysis of the effectiveness of fault indicators for overhead power line monitoring. *Proceedings of the 2022 IEEE 8th International Conference on Energy Smart Systems (ESS)* . Kyiv, 2022. Pp. 17–20. DOI: https://doi.org/10.1109/ESS57819.2022.9969272
9. Parus Ye.V. , Blinov IV, Bets O.Yu. Selection of locations and number of fault indicators in distribution lines as a combinatorial optimization problem. *Tekhnichna Elektrodynamika* . 2016, No. 5. Pp. 58–60. (Ukr) DOI: https://doi.org/10.15407/techned2016.05.058
10. Blinov IV, Parus Ye.V. , Rybina OB, Tankevych S.Ye. Optimal architecture and equipment of distribution line monitoring systems. *Praci Institute electrodynamics National academy science Ukraine* . 2018, Iss . 50. Pp. 16–22. (Ukr)
11. Popov V., Tkachenko V., Kostiuk VO, Yarmoliuk O., Frolov I. Optimal sectionalizing of distribution networks to meet reliability index regulations. *Proceedings of the 2022 IEEE 8th International Conference on Energy Smart Systems (ESS)* . 2022. pp. 95–100. DOI: https://doi.org/10.1109/ESS57819.2022.9969256
12. Volodymyr K., Oleksandr G., Oleksandr S., Savchenko V., Svitlana M. Optimization of sectionalization parameters of distribution electric networks. In: Handbook of Research on Smart Computing for Renewable Energy and Agro -Engineering., IGI Global, 2020, Pp. 78–105. DOI: https://doi.org/10.4018/978 -1 -7998 -1216 -6.ch004
13. Blinov I., Trach I., Parus Ye., Derevianko D., Khomenko V. Voltage regulation in distribution networks using distributed renewable energy sources. *Tekhnichna Elektrodynamika* . 2022, No. 2. Pp. 60–69. (Ukr) DOI: https://doi.org/10.15407/techned2022.02.060
14. Gai O., Novoseltsev O., Vorushylo A., Khomyak O., Gai H. Features of multi- -agent evaluation of microgrid systems efficiency in parallel operation with power systems under reliability criteria. *Machinery & Energetics* , 2024, Vol. 15, No. 3. Pp. 73–83. DOI: https://doi.org/10.31548/machinery/3.2024.73

МЕТОД ДЕКОМПОЗИЦІЇ ПОКАЗНИКА SAIDI ЗА СТРУКТУРОЮ АВАРІЙНИХ ПЕРЕРВ ДЛЯ ОБҐРУНТУВАННЯ ПРІОРИТЕТІВ ПІДВИЩЕННЯ НАДІЙНОСТІ РОЗПОДІЛЬНИХ МЕРЕЖ

О.В. Гай[2**]**,** канд. техн. наук, **Г.А. Гай**[2**]**,** канд. пед. наук, **І.В. Блінов**[1***]**,** чл.-кор. НАН України
1 – Інститут електродинаміки НАН України,
пр. Берестейський, 56, Київ, 03057, Україна e-mail: blinovihor@gmail.com, gaalxold@gmail.com
2 – Національний університет біоресурсів і природокористування України,
03041, вул. Героїв Оборони, 15, Київ, Україна e-mail: gtatana704@gmail.com

У роботі запропоновано метод декомпозиції показника SAIDI за структурою аварійних перерв на основі аналізу ретроспективних даних технологічних порушень у розподільних електричних мережах. Метод базується на статистичному аналізі тривалості відновлення електропостачання з виділенням двох характерних режимів: «коротких» аварійних перерв, зумовлених пошуком місця пошкодження та оперативними перемиканнями, і «довгих» перерв, що додатково включають ремонтно-відновлювальні роботи. Межу між режимами визначено формально на основі максимуму узгодженості емпіричного розподілу з нормальним законом за критерієм Колмогорова–Смирнова. Показано, що для коротких аварійних перерв доцільним є наближення нормальним розподілом, тоді як для довгих перерв адекватний опис забезпечують розподіли з «довгим хвостом» (логнормальний або Парето). На основі запропонованої декомпозиції виконано кількісну оцінку внеску кожної з зон у формуванні показника SAIDI та встановлено, що довгі аварійні перерви, незважаючи на меншу частку подій, формують домінуючий внесок в інтегральну тривалість перерв. Запропонований метод дозволяє обґрунтувати пріоритети підвищення надійності розподільних мереж без переходу до задач оптимізації, зосереджуючи увагу на впливі завдань локалізації аварійних ділянок і скорочення тривалості ремонтно-відновлювальних робіт. Отримані результати можуть бути використані як інженерний інструмент підтримки прийняття рішень при формуванні програм підвищення надійності за умов обмеженої доступності детальної експлуатаційної інформації. Бібл. 14, рис. 4, таблиця.

Ключові слова: SAIDI, надійність електропостачання, розподільні електричні мережі, ретроспективні дані, статистичне моделювання, критерій Колмогорова–Смирнова, розподіл Парето, логнормальний розподіл, ранжування заходів.

Надійшла: 14.04.2026
Прийнята: 27.04.2026

Submitted: 14.04.2026
Accepted: 27.04.2026