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Quantitative assessment of the operational reliability of overhead power lines

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ABSTRACT

The relevance of developing a methodology for assessing the operational reliability of overhead power lines of electrical power systems is due to the increase in the number and length of power lines, the service life of which exceeds the standard value. The lack of a methodology is due to unusual requirements for calculating reliability indicators. It is necessary to calculate a quantitative assessment of reliability based on statistical data only for operational data, i.e., small enough time interval. All data preceding this interval cannot be used as characterizing an object in the "past". A calendar month is taken as the operational interval, in particular, because the economic operational efficiency is traditionally calculated on this interval. Let us recall that today, operational efficiency is understood as a combination of three properties: efficiency, reliability and safety. Such a transformation of the concept of efficiency is also determined by the consequences of the aging of EPS facilities. The recommended new methods for calculating average monthly estimates of reliability indicators, comparing these estimates, recognizing the expediency of classifying statistical data, allow making decisions that ensure reliable, safe and efficient operation of overhead power lines. Difficulties in developing a methodology for assessing operational reliability were overcome by taking into account the multidimensional nature of statistical data, using a fiducial approach when assessing the feasibility of information classification, conducting simulation of representative samples.

Symbols and abbreviations used in the paper:

OPL – overhead power lines
EPS – electric power systems
PGF – power grid facilities
ARC – automatic reclosing
MaR – maintenance and repair
VF – varieties of features (factors)

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1. Introduction

Evaluation of the OPL performance until recently was limited to an assessment of economic efficiency. Difficulties began to appear due to the increase in the number and length of OPLs, the service life of which began to exceed the standard value, and the guarant EPS of reliable and safe operation set during their design expired. These OPLs sooner or later began to show a process of non-linear growth in the wear of individual elements, an increase in the specific number of automatic shutdowns, together with an increase in the likelihood of an unsuccessful ARC and an increase in the duration of wear recovery. These are known facts because the collection and processing of OPL state change statistics is systematic and very useful as operational experience. Periodic random tests of the main elements of OPL were equally valuable. The OPL reliability indicators calculated from the failure data were used in the design of power supply systems for new industrial facilities in order to ensure compliance with the requirements for power supply reliability and service safety. The expiration of the standard service life and a clear increase in the number of automatic emergency shutdowns, in the number and duration of emergency repairs lead to a significant decrease in the reliability of operation and the efficiency and safety correlated with it.

From the theory of reliability, and from everyday life, it is known that aging, on average, begins not from the moment of commissioning, but from the moment of the expiration of the standard service life and manifests itself in a nonlinear decrease (increase) in the maximum permissible values of the parameters of individual properties. For instance, the insulation level begins to decrease nonlinearly, or the contact resistance increases nonlinearly, or the elasticity of the metal decreases. This indicates only one thing –OPLs with a service life exceeding the standard values cannot be treated in the same way as an OPL operating within the standard service life.

The change in treatment of aging OPLs means, first of all, the need for operational assessment the performance efficiency reflecting not only cost-effectiveness, but also reliability and safety.

At the first stage, “operational” means at least a monthly analysis of statistical data with a quantitative assessment of the efficiency, reliability and safety of OPL (by analogy with Form 3-TECH energo).

But those who dealt with the collection and analysis of data on state changes in the OPL understand well that while it is necessary, it is impossible. And there are many reasons for this. Firstly, although we say that OPL failures occur much more often than, for instance, for transformers or switches, but not so often that it would be possible to calculate the average monthly estimates of the reliability indicators of a particular OPL. Secondly, the use of estimates of reliability indicators given in numerous reference books, monographs and articles is out of the question, since they are not capable of monitoring OPL reliability. These averaged indicators were and are calculated, as a rule, on the basis of the statistical data of operation for a number of years of observation. At the same time, these OPL information sources always indicate their dependence on passport data (e.g., voltage class, year of commissioning, length, etc.) and external factors (e.g., meteorological factors, degree of insulation pollution, etc.). In other words, the information about failures is multidimensional, and the traditional use of the mathematical apparatus for analyzing one-dimensional data for their analysis is associated with a high risk of an erroneous decision. Further, evaluation of indicators of operational reliability of work is not an end in itself. They are necessary for comparison and ranking in the formation of recommendations for the organization of operation and MaR. In particular, answers are needed to questions about the significance of certain factors (features) and their varieties.

In other words, this is the issue of the expediency of statistical data classification according to given VF [1]. Moreover, this expediency should take into account both errors of the first and second kind.

But the ability to compare multidimensional assessments of reliability indicators is still far from sufficient. After all, it will be necessary to present a set of reliability indicators as one integral indicator, bearing in mind that they have different units of measurement, different scales, different directions, etc. [2]. It should be noted the problem of data security and accuracy [3], great cumbersomeness and laboriousness, the need to switch to computer technologies that provide the EPS and PGF management with not only information, but also methodological support in solving many problems related to the operation and MaR [4].

This paper will consider methods for assessing and comparing operational reliability indicators of operation of 110 kV and above OPL of EPS and on their PGF.

2. Traditional methods of assessing the main indicators of OPL reliability

Traditionally, the specific number of automatic emergency shutdowns of OPL (λ^*) was carried out annually for each voltage class according to the formula:

$$\lambda^*_{i,j} = 100\sum_{k=1}^{n_{i,j}} m_{k,i,j} \Big/ \sum_{k=1}^{n_{i,j}} L_{k,i,j}$$

where $n_{i,j}$ is the number of considered OPL of the i-th voltage class in the j-th year; $m_{i,j}$ is number of automatic emergency shutdowns of the k-th OPL of the i-th voltage class in the j-th year; $L_{k,i,j}$ is the length of the k-th OPL.

Automatic emergency shutdowns (failures) of OPL can be intermittent and persistent. The former is, of course, preferable. This is why OPLs are equipped with ARC devices, which can be single, double, or even triple. But even after an unsuccessful ARC, the operational regulations recommend another manual reclosing of OPL, which sometimes turns out to be successful [1]. The effectiveness of ARC is a subject for separate study. But it should be noted that for switches whose service life exceeds the standard value, such loads can be dangerous. The specific number of persistent failures $\omega^*_{1,j}$ is determined by a formula similar to the estimate $\lambda^*_{1,j}$, with the difference that the number of persistent failures of each OPL ($m^p_{k.i.j}$) is substituted instead of $\lambda^*_{1,j}$. The average duration of the OPL downtime in emergency repair $M^*_{i,j}(\tau_a)$ is calculated by the formula:

$$M^*_{i,j}(\tau_a) = \left[\sum_{k=1}^{n_{i,j}} \sum_{v=1}^{m_{k,i,j}} \tau_{a,i,j,k,v}\right] \Big/ \sum_{k=1}^{n_{i,j}} m^p_{k,i,j}$$

Traditional methods of assessing and analyzing OPL reliability indicators have one feature in common – they are averaged over all features and their varieties, with the exception of the "voltage class" feature.

Analysis of the latest publications devoted to the problem of increasing the reliability of 110 kV and above OPL showed that the recommended methodology for assessing reliability indicators has somewhat changed. Research is aimed at improving the reliability of the main elements of the OPL, reducing the influence of disturbing factors. In other words, the significance of VF is analyzed.

For instance, in [5] one of the most important areas of scientific research is formulated. It is noted that the more factors that are not amenable to quantitative analysis, the greater the risk of an erroneous decision and the occurrence of unacceptable consequences. In [6], the authors note the need to develop a methodology for assessing the indicators of operational reliability OPL since the recommended indicators in reference books and books are too averaged and do not take into account the difference in climatic conditions of the regions and the time of year. And the small number of failure statistics is cited as one of the main difficulties.

It is proposed that the parameter of the flow of failures ω (the specific number of automatic stable emergency shutdowns) be determined individually for each element $(\omega_{e,i})$ of OPL with $i = \overline{1,n}$, where n is the number of elements and taking into account the partial weight coefficients $(K_{e,i})$, i.e., according to the formula:

$$\omega = \sum_{i=1}^{n} K_{e,i} \cdot \omega_{e,i}$$

In [7], an analysis of reliability indicators and causes of failures of 220–1150 kV OPL is carried out on the basis of data for the period 1999–2016. This information allowed us to identify the least reliable OPL elements of one of the EPS regions.

In [8], based on long-term data, the influence of climatic factors on the reliability of 35-500 kV OPL in EPS of Kazakhstan is analyzed.

The list of these important publications of recent years can go on. But all of them clearly confirm the lack of a methodology for assessing the monthly average indicators of OPL operational reliability based on operational statistics.

3. Methods for assessing and comparing the operational reliability of OPL

Before considering methods for solving a number of typical practical problems, it is necessary to discuss the specifics of collecting and processing statistical data on OPL, their emergency and scheduled shutdowns:

1. Table 1 is compiled for information about the OPLs under consideration. Its order usually corresponds to the classification according to the voltage class from the highest value to the lowest value. The ordinal numbers are conditional, but they are obligatory for recording the VF. Then follow columns that provide information on passport data and operating conditions, including the name of the OPL, the name of the PGF, voltage class (kV), length (km), year of commissioning, type of supports, climatic conditions, etc. This information is updated as necessary;
2. Table 2 of information on emergency and planned OPL outages is compiled monthly, indicating: conditional sequence number and name of the OPL, as well as characteristic outages, date, type, duration of recovery and cause of failure.

If we agree that the automatic emergency shutdowns of OPL occur randomly, then the estimates of reliability indicators calculated from this data will also be random. And the risk of an erroneous decision when mechanically comparing these indicators is significant. Assessment of the average monthly (operational) values of the specific number of automatic emergency shutdowns OPL is not an end in itself. Based on them, specific operational tasks are solved and solutions are formed that provide an increase in the efficiency of the EPS.

These include:

- how the operational reliability of OPL in EPS has changed in the past month from the previous month;
- on which PGF of EPS OPL operational reliability is worse than for OPL in EPS as a whole;
- specifically which OPLs cause the decrease in the efficiency of the EPS and its PGF.

Having stipulated the initial data and some types of systematically solved operational problems, we proceed to the methods of solving them.

3.1. Assessment and comparison of operational reliability indicators of OPL in EPS

First of all, we agree that the monthly average estimates of the specific number of failures, as estimates over a sufficiently short time interval, are numerically equal to the probability of failure, provided that OPLs are represented by unit intervals of length, the number of which N_i is equal to either the length of the OPL or the number of supports installed on the OPL. The performed statistical analysis showed that the risk of an erroneous decision depends on the method of assessing the probability of failure. In this regard, the authors have retained the traditional definition by the number of unit intervals. In addition, since during emergency or scheduled repair, OPL failures are practically unlikely, the number of single OPL sections should be reduced by an amount equal to the steady state availability factor $K^*_{s,s,i,j}$:

$$\delta t^*_{i,j} = {(\tau_{a,i,j} + \tau_{\text{п},i,j})}\Big/{t_i} = 1 - K^*_{s,s,i,j} \ ,$$

where t_i is the duration of the i-th calendar month in hours, and $\tau_{e,i,j}$ and $\tau_{s,i,j}$ are the durations of emergency and scheduled repairs of the j-th OPL in the i-th month.

In accordance with the above, the monthly average estimate (*) of the probability of failure OPL (Q *) in EPS can be a quantity according to the formula:

$$Q^*_{a,i} \cong \lambda^*_{a,i} = {\sum_{j=1}^{n^L_\Sigma} m_{a,i,j}}\Big/{\sum_{j=1}^{n^L_\Sigma} K^*_{s,s,i,j} \cdot L_j} = {m^\Sigma_{a,i}}\Big/{N_L}$$

where n^L_Σ is the number of OPL; $m_{a,i,j}$ is the number of failures of the j-th OPL in the i-th month; $m^\Sigma_{a,i}$ is the total number of OPL failures; L_j is the length j-th OPL; N_L is the total number of total number of single sections of OPL.

To calculate Q^*_i, it is necessary from Table 2 to determine the total number of OPL failures $\left(m^\Sigma_{a,i}\right)$ and the relative duration of downtime $\left(\delta t_{i,j}\right)$ of each OPL. Further, according to table 1, the length of each OPL L_j is determined, and according to the value of $\delta t_{i,j}$, the corrected number of single sections of OPL (N^L_i) is determined. Knowing $n^\Sigma_{a,i}$ and N^L_i, we define $Q^*_{a,i}$.

The average monthly assessment of the probability of a persistent failure $Q^*_{p,i}$ is carried out similarly to the assessment of $Q^*_{a,i}$, with the difference that according to the data in the "type of shutdown" column of Table 2, only persistent failures are automatically selected. The ratio $Q^*_{p,i}$ and $Q^*_{a,i}$ characterizes the EPS-average probability of a persistent failure, and, consequently, the general technical condition of OPL in EPS.

As noted earlier, assessing monthly average OPL failure rates is not an end in itself. It is necessary to establish the significance of the observed change in this estimate. Let us consider the sequence of solving this problem.

The accuracy of assessing the probability of failure $Q^*_{a,i}$ in accordance with [9] is characterized by the width of the confidence interval, the one-sided boundary values of which for the notation we have adopted $\left(\underline{Q_{a,j}}; \overline{Q_{a,J}}\right)$ and significance level α, can be calculated by the formula:

$$\underline{Q_{a,i}} = \frac{\chi\left[100(1-\alpha)\%, 2m^\Sigma_{a,i}\right]}{2N_{i,j} - m^\Sigma_{a,i} + 1 + 0{,}5\chi\left[100(1-\alpha)\%, 2m^\Sigma_{a,i}\right]}$$

$$\overline{Q_{a,i}} = \frac{\chi\left[100\alpha\%, 2(m^\Sigma_{a,i}+1)\right]}{2N_{i,j} - m^\Sigma_{a,i} + 0{,}5\chi\left[100\alpha\%, 2(m^\Sigma_{a,i}+1)\right]}$$

It is known that the confidence interval *covers* the true value of the probability of failure Q with a significance level α. I.e., the value of Q in the interval may be absent. That is why more attractive and physically clear for comparing two estimates of the probability of failure should be considered their fiducial approach, in which the comparison of these estimates is carried out on the basis of fiducial intervals [10]. Recall that the fiducial approach is based on the distribution of possible implementations of the probability of failure $[F^{**}(Q^*)]$.

Fiducial intervals calculated by simulation of the statistical distribution function $[F^{**}(Q^*)]$ are irreplaceable in conditions when the type of the distribution law of random variables is unknown, i.e., confidence intervals cannot be calculated. This primarily refers to the distributions of complex reliability indicators. In cases where the distribution law of complex reliability indicators is known, the quantitative estimates of the boundary values of the confidence and fiducial intervals coincide. And in order to emphasize the peculiarity of the fiducial approach, we present a statement that is unusual for representative samples: with a decrease in the number of implementations, the accuracy of estimates with the fiducial approach can increase [11]. I.e., if the width of the confidence interval under these conditions increases, then the width of the fiducial intervals may decrease.

In accordance with established practice, comparison of estimates (in our case, these are the monthly average values of the OPL failure probability for the calculated i-th month $Q^*_{a,i}$ and the preceding $(i-1)$-th month $Q^*_{a,(i-1)}$) is carried out according to some criterion (rule, algorithm). As a result of the comparison, one of the two conclusions is made:

- ❖ the observed discrepancy between $Q^*_{a,i}$ and $Q^*_{a,(i-1)}$ is due to the random nature of these estimates. Denote this conclusion as H1;
- ❖ the observed discrepancy is significant. This conclusion will be denoted as H2.

The algorithm for comparing $Q^*_{a,i}$ and $Q^*_{a,(i-1)}$ has the form:

$$\left.\begin{array}{lcl} \text{if } Q^*_{a,i} > Q^*_{a,(i-1)} & \rightarrow & \text{otherwise if } Q^*_{a,i} < Q^*_{a,(i-1)} \\ \text{then if } Q^*_{a,(i-1)} < \underline{Q_{a,i}}\text{, then H}\rightarrow\text{H2} & & \text{then if } Q^*_{a,(i-1)} > \overline{Q_{a,i}}\text{, then H}\rightarrow\text{H2} \\ \text{otherwise if } Q^*_{a,i} < \overline{Q^{**}_{a,(i-1)}}\text{, then H}\rightarrow\text{H1} & & \text{otherwise if } Q^*_{a,i} > \underline{Q^{**}_{a,(i-1)}}\text{, then H}\rightarrow\text{H1} \\ \text{otherwise H}\rightarrow\text{H2} & & \text{otherwise H}\rightarrow\text{H2} \end{array}\right\}$$

where:

$$\overline{Q_{a,i}} = \frac{\chi\left[100\alpha\%, 2m^{\Sigma,*}_{a,(i-1)}\right]}{2N_{i,j} - m^{\Sigma,*}_{a,(i-1)} + 0{,}5\chi\left[100\alpha\%, 2(m^{\Sigma}_{a,(i-1)} + 1)\right]}$$

$$\underline{Q_{a,i}} = \frac{\chi\left[100(1-\alpha)\%, 2m^{\Sigma,*}_{a,(i-1)}\right]}{2N_{i,j} - m^{\Sigma,*}_{a,(i-1)} + 1 + 0{,}5\chi\left[100(1-\alpha)\%, 2m^{\Sigma,*}_{a,(i-1)}\right]}$$

$$m^{\Sigma,*}_{a,(i-1)} = m^{\Sigma}_{a,(i-1)} \cdot N_{L,i} \big/ N_{L,(i-1)}$$

3.2. Assessment and comparison of monthly average values of reliability indicators of OPL of PGF in EPS

Among the possible criteria for information classification about the reliability of OPL, the most interesting are PGF in EPS. Given the difference between OPL of PGFs and their operating conditions, this interest is determined by [12]:

- ❖ the orientation on the optimal distribution of material resources that are allocated by the EPS to improve the reliability of the PGF;
- ❖ the need to clarify the number of personnel responsible for ensuring the reliability and safety of OPL;
- ❖ the clarification of the contingent for advanced training in the restoration of hazardous defects;
- ❖ the formation of an emergency stock of OPL elements, spare parts and materials.

Some difficulties in the analysis are created by long-length OPLs, passing along two or even three EPSs. This difficulty can be overcome by identifying all these lines as controlled by the EPS.

The calculation algorithm is reduced to the following sequence of transformations:

3.2.1. Classifications of the data in Table 1 by i-mus $i = 1, N_\text{P}$ PGF in EPS. These data are entered into table 1P, the form of which coincides with the form of Eable 1. The presence of the PGF name column allows you to control the accuracy of the classification;

3.2.2. The classification of the data in Table 2 is carried out in a similar way;

3.2.3. Further, for each PGF, monthly average values are determined:

- ❖ probability of automatic emergency shutdowns of OPL:$Q^*_{\text{P},i}$, with $i = 1, N_\text{P}$, where N_P is the number of PGFs increased by unit;
- ❖ probabilities of persistent failures of the i-th OPL of PGF: $Q^{*,p}_{\text{P},i}$, c $i = 1, N_\text{P}$;
- ❖ probabilities of unsuccessful ARC: $\delta Q^*_{\text{P},i} = {Q^{*,p}_{\text{P},i}} / {Q^*_{\text{P},i}}$;

3.2.4. Ranked in decreasing order of implementation, monthly average values for each of the indicators, are compared with the boundary values of the fiducial interval of these indicators for the totality of all OPL in EPS.

3.2.5. Thus, for each indicator, three groups of possible implementations are identified. The first group contains PGFs, the failure rates of which are higher than those for the EPS in general for a reason. The second group contains PGFs whose reliability indicators randomly differ from those of OPL in EPS as a whole. The third group includes the PGF of the OPL failure probability, which are lower than the OPL EPS in general for a reason.

3.2.6. If the number of PGFs of the first group exceeds unit, then the need to classify them is no less important from the point of view of the MaR organization. For this reason, according to the statistics of the first group:

- ❖ the estimate of the average monthly probability of failure of these PGFs is determined;
- ❖ the boundary values of the fiducial interval of possible implementations of failure probability are calculated;
- ❖ the totality of PGFs of the first group, similarly to the above, is classified into three subgroups.

These two stages of classification are usually sufficient. The classification process is complete if the number of monthly average estimates of failure probability for OPL of PGF does not exceed unit.

3.2.7. The above analysis results are formalized for methodological support of the EPS management in the organization of operation and MaR.

3.2. Assessment and comparison of monthly average values of the failure probability for groups of OPL of PGF in EPS

It is, of course, tempting to identify PGF in EPS, on which the average monthly estimates of the OPL failure probability exceed those for OPL in EPS in general, of course, but it is not sufficient, since it is important to know the OPL that cause this ratio and notify the management and personnel of PGF. It would seem that for this it is sufficient to estimate the monthly average values of the failure probability of each OPL with their subsequent ranking. In short, it is necessary to classify all OPLs of the network enterprise according to all the specified characteristics and their varieties. Since the operational interval is small enough, repeated failures of the same OPL are unlikely. Hence, the OPLs under consideration can be divided into two groups. The first, largest, one will contain OPLs that have never failed and a small OPL group, the number of failures of which is equal to unit.

Therefore, estimates of the failure probability of these OPLs are of little use for comparisons. But such a "mechanical" classification of OPL of PGF is also not justified due to the difference in the significance of all features and their varieties. In other words, it is wrong to classify OPL without monitoring its appropriateness. But classification is not always feasible. In particular, OPL of PGF can be of only one voltage class or their service life has not yet exceeded the standard value. Consequently, the list of features that characterize the OPL diversity must be specified in advance. The refinement algorithm is reduced to monitoring the content of the corresponding columns of Table 1P.

Thus, the initial data for recognizing "weak links" in the list of OPL of PGF are:

❖ the estimate of the failure probability of OPL of PGF $Q^*_{\text{a,P}}$ with the indication of the upper bound of the fiducial interval $\overline{Q_{a,\text{P}}}$

❖ the estimate of the persistent failure probability of OPL of PGF $Q^{*,p}_{a,\text{P}}$ with the indication of the upper bound of the fiducial interval $\overline{Q^p_{a,\text{P}}}$.

Further, for each type of each estimated feature, monthly average estimates $Q^*_{a,\text{L}}$ and $Q^{*,p}_{a,\text{L}}$ of OPL failure probability are calculated.

The largest value of the failure probability among the estimates for VF is compared, respectively, with $\overline{Q_{a,\text{P}}}$ and $\overline{Q^p_{a,\text{P}}}$. If $[Q^*_{a,\text{L}}] > \overline{Q_{a,\text{P}}}$, and $[Q^{*,p}_{a,\text{L}}]_{max} > Q^{*,p}_{a,\text{L}}$, then with the probability $(1-\alpha)$ the estimates $Q^*_{a,\text{P}}$ and $[Q^*_{a,\text{L}}]$, as well as $Q^{*,p}_{a,\text{P}}$ and $[Q^{*,p}_{a,\text{L}}]_{max}$ differ for a reason, and the VF under consideration is significant.

As a result of these calculations, the list of significant VF is formed. For instance, it is known that the most frequent are automatic emergency shutdowns of 110 kV OPLs on wooden supports with service life exceeding 45 years. *The results of a statistic analysis will show that the most frequent are automatic emergency shutdowns of 110 kV OPLs, OPLs on wooden supports and OPLs with service life exceeding 45 years.*

At the next stage, the totality of OPLs that forms these three groups is analyzed. It will be called estimated. The formation of the totality by combining these three groups of OPL will lead to an unjustified increase in the number of OPLs under consideration due to their repetition. The lack of repetition of OPL is ensured by controlling their sequence number. The second stage of analysis determines:

❖ monthly average values of the probability of all failures and only persistent ones for the estimated totality of OPL ($Q^*_{a,\text{P}i,\text{L}j}$ and $Q^{*,p}_{a,\text{P}i,\text{L}j}$);

❖ upper bounds of the fiducial interval for $Q^*_{a,\text{P}i,\text{L}j}$ and $Q^{*,p}_{a,\text{P}i,\text{L}j}$. Denote them by $\overline{Q^*_{a,\text{P}i,\text{L}j}}$ and $\underline{Q^{*,p}_{a,\text{P}i,\text{L}j}}$.

❖ monthly average values of the probability of failure $[Q^*_{a,\text{P}}]_{max}$ and $[Q^{*,p}_{a,\text{P}}]_{max}$, exceeding $\overline{Q^*_{a,\text{P}i,\text{L}j}}$ and $\underline{Q^{*,p}_{a,\text{P}i,\text{L}j}}$, respectively.

Thus, for each PGF, we can indicate not only the nature of the change in operational reliability compared to the previous month, but also the list of OPLs that cause a decline in the performance efficiency of PGF. Monthly automated methodological support allows taking appropriate measures in a timely manner, increasing the reliability of OPL of PGF in the entire EPS in general.

4. Conclusion

OPLs with a service life exceeding the specified value cannot be treated in the same way as OPLs operating within the specified service life. The difference, first of all, lies in the need to increase the level of control over the reliability of their operation and, in particular, to assess the operational reliability indicators.

4.1. A method and an algorithm have been developed for the operational assessment and comparison of the reliability of the totality of OPLs in an EPS. A distinctive feature of the calculation method is taking into account the degree of technical use of the OPL. Four indicators are recommended: the probability of an automatic emergency shutdown (failure) of OPL, the probability of a persistent OPL failure, the relative number of persistent failures (the probability of manifestation), and the steady state availability factor of OPL. It is proposed to compare the estimates of these OPL indicators in two adjacent operational time intervals based on the boundary values of the fiducial interval of their possible implementations;

4.2. Methods and algorithms have been developed for comparing and ranking the monthly average values of operational indicators of OPL of PGF in EPS. Practical significance lies in the identification of PGFs that reduce the reliability of the EPS;

4.3. Methods and algorithms have been developed for analyzing the reliability of OPLs of specific PGFs based on a set of specified features and their varieties. As a result of the calculations, OPLs are identified, the increase in the reliability of which leads to a significant increase in the reliability of the PGF in EPS at the lowest cost;

4.4. The developed specialized forms containing information and recommendations to improve the reliability of OPL operation provide monthly information and methodological support to the EPS management and each PGF in EPS.

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