CRITERION OF THE SUPERVISION ACCURACY OF INDEXES RELIABILITY OF POWER-GENERATING UNITS A STATE DISTRICT POWER STATION.

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Abstract

The automized system is developed, allowing to determine and compare indexes of individual reliability of complex plants in view of a random in character of an initial conditions.

Despite of numerous probing, the quantitative assessment of indexes of reliability of plants EES on former draws notice of technicians. It speaks, first of all, variations in EES: a lifetime of an appreciable unit of plants EES (50÷60)% exceeds rated, that has led to essential body height of working costs. It in turn has inevitably led to variation of the strategy of maintenance. If earlier, in conditions of the regulated scheduled maintenance, indexes of reliability were used mainly for a solution of design problems, and was to evaluate enough some averaged value of indexes of reliability and reparability today the principal direction of probing of reliability of plants EES has a little varied. The strategy of realization of scheduled maintenances more and more is guided by real availability index of product of particular plants. More and more actual the possibility becomes to sample most (least) safe plants. Alongside with indexes of reliability and reparability, the assessment of indexes of longevity since these indexes characterize availability index of product of the equipment is actual. The methodology of problem solving of an assessment and comparison of indexes of reliability is developed insufficiently full, and in practice selection comes true "in the old manner", or at an intuitive level. To number of the fundamental methodical problems concern:

– how to evaluate reliability of particular plant (power-generating unit, a power line and so forth);
– how to calculate accuracy of assessments of indexes of reliability;
– as at matching to consider a random in character of assessments of indexes of reliability.
– In the present paper as plant EES power-generating units (PU) a state district power station are surveyed. Selection of plant not mated. PU a state district power station (SDPS):
– in many respects determine reliability and overall performance EES;
– concern to bunch of complex plants which are characterized by multidimensionality, diversity of types of properties of plant, lack of data on the functional intercoupling of indexes of reliability and the fundamental industrial indexes. The length of pipe ducts PU can be calculated in hundreds kilometers, hundreds units of the various equipment and systems, not speaking already about assemblies of the equipment and systems and their units;
– require an individual approach. The in-service experience displays, that each PU the state district power station has the «weak links», the average duration of working, emergency and standby estates, the periodicity and structure of a between-repairs cycle.

Problems of an assessment of indexes of reliability and reparability PU (named by us – IIR) are surveyed by indexes of individual reliability in [1], and assessments of indexes of longevity which are evaluated according to measurement of diagnostic parameters and inherently, are individual – in [2]. The assessment of accuracy IIR PU is surveyed by a method of simulation modeling in [3]. Accounts IIR are conducted under static data about estates PU a state district power station, assembled for series of years in the form of the empirical table in which columns match to flock of indications, and strings - to flock of estates. The table allows on purpose-built algorithms and programs [4] practically instantly to evaluate as averaged (on all PU) indexes of reliability and IIR for the preset combination of varieties of indications.

The empirical table represents a final population of static data (further a population) and the separate table lines describing estates particular PU, - sampling of a data set.

The of the same type averaged indexes of reliability PU and IIR as analogue quantities, will differ to some extent. Their accuracy will differ also. The natural problem on a significance of their divergence from here implies. It is known, that:

– sampling of random quantity Y (for example, duration of estates) can be representative and unrepresentable. Unrepresentable sampling in mathematical statistics is fathomed as sampling which $F_m^*(y)$ distribution was nonrandom differs from distribution general or of a final collection $F_M^*(y)$, where m and M – number of random quantities, accordingly samples and collection; * - means an assessment. Unrepresentatively samples are caused with difference of the averaged indexes of reliability and IIR;

– application analytical methods of mathematical statistics oriented on comparison of parameters of distributions two independent representative samples, methods of marshaling of plants on their significances and methods of an automatic group of plants also assume representatively samples from collection;

– comparison of the same type IIR is normal comes true between IIR surveyed PU. The number of such comparisons for one index of reliability is peer Nc=$(n_\delta$-1)!, where n_δ – number PU. For example, if n_δ=8, Nc=5040. More expediently, in our opinion to compare the of the same type averaged indexes of reliability and IIR PU. Thus Nc=8 and in hundreds times diminishes number of evaluations;

– the representative sampling can be received experimentally by means of random numbers. In actual conditions, in particular, at sampling data of empirical truth table PU, unconditional adoption of the supposition about representatively of sampling is unacceptable, that is quite physically explainable. If now to consider, that by means of the mathematical apparatus of check of statistical hypothesizes it is possible to deny only ours suppositions about representatively of sampling, but never it is impossible to proved justice, and versions of a possible divergence of compared indexes of reliability infinite flock, representatively of sampling appears improvable.

It is possible to simplify a task solution, having received correspondence of watched distribution $F_m^*(y)$ to real regularities of variation of random quantities of sampling. Thus, flock the sample of volume m is divided into three not intersected subsets (we shall designate them through Wo, W1 and W2). Sampling with specified probability is considered representative if (evaluated on experimental data) the statistician describing a divergence $F_M^*(y)$ and $F_m^*(y)$ (we shall designate it through S*), hits in subset Wo, no representatively – if S* hits in subset W_2 and if S* hits in subset W_1 it is considered, that the information has not enough for an adoption of a decision. Therefore, the problem is reduced to presence Wo, W1 and W2 for possible combinations m and M.

– each time when it is necessary to muster a divergence of distribution of random quantities, deal not with one, and with two hypotheses which it is accepted to name initial (H_0) and alternative (H_1) and, accordingly, with errors of two types. First from them - an error of first kind (we shall designate it through α), originates if hypothesis H_0 when actually she is correct is denied. The second type of errors named as an error of second kind (we shall designate it through β), originates if hypothesis H_1 when actually she is correct is denied. What hypothesis to receive for initial and what for alternative soundly is not reserved. Traditionally, for initial H_0 the hypothesis about a random divergence of compared allocations is received or of their parameters. However, it is not always correct, and at an automatic test can lead to essential errors. It speaks difference of means of simulated implementation of statisticians S.

– in actual conditions the true is unknown. Distribution $F_M^*(y)$ also $F_m^*(y)$ have a random in character. Natural aiming simultaneously to diminish α and β it is impossible, since with decrease α value β increases and on the contrary. The problem consists in making the strategy ensuring minimum risk of an erratic solution. The justified selection of statistical criterions constitutes rather a challenge of modern mathematical statistics [6]. Practical references are reduced to selection on those or to premises are maximal acceptable values α_c (more often 0.1 or 0.05) and further – to selection of the criterion ensuring the least value β. More precise references here are absent, as selection of criterion depends on the big number of the interrelated factors.

In [5] has been offered new non parametric criterion of the supervision of coefficient representativety of sampling (CRS) which short is reduced to following sequence of accounts:

1. The collection $\{y\}_M$ is placed in ascending order and «y» a variation series of a collection the assessment of probability is compared with each value.

$$F_M^*(y) = \frac{i}{M} \quad (i=1,M). \tag{1}$$

2. Analogously p.1 sampling $\{y\}_m$ is placed in ascending order and «y» a variation series of sampling the assessment of probability is compared with each value

$$F_m^*(y) = \frac{i}{m} \quad (i=1,m).$$

3. The divergence is determined

$$\Delta_{m,i}^* = \left|F_m^*(y) - F_M^*(y)\right| = \left|\frac{i}{m} - \frac{L_i}{M}\right| \quad (i=1,m) \tag{2}$$

where a L_i - serial number y_i in variation series of a collection of random quantities $\{y\}_M$

4. The statistician is evaluated

$$\Delta_m^* = \max\{\Delta_{m,i_i}\}_m. \tag{3}$$

5. If the actual greatest divergence Δ_m^* will appear not less critical value of a statistician $\Delta_m(\alpha)$ the hypothesis about representatively of sampling should be denied.

In [5] was also a task in view of an assessment of preferability of some modifications of criterion CRS in which basis is:

- peak value of a divergence (Δ_m),
- average statistical value of a divergence (Δ_{avr}),
- average quadratic value of a divergence (C_R).

As in the subsequent we should refer repeatedly to statisticians Δ_m, Δ_{AVR}, and C_R, we shall agree to designate them, as well as earlier, through S. Particular labels will be introduced only as required.

The simulation model has been developed, allowing to receive distributions $F^*(S/H_0) = 1-\alpha$ for arbitrary set values m and M.

With reference to the present paper, practical accounts have allowed to establish:

– the discrete character of distributions $F^*(\Delta_m/H_0)$, $F^*(\Delta_{cp}/H_0)$ and $F^*(C_R/H_0)$;

– number of the discrete value of arguments of distributions $F^*(S/H_0)$, the greatest for distributions $F^*(C_R/H_0)$;

– the discrete character of distributions $F^*(S/H_0)$, eliminates a possibility of account of critical value of statisticians (S_K) at the fixed value α_c. Value α_c is in some spacing which width the is more, than it is less m and M. Events when the lower limit of the spacing which is switching on a design value α_c, appears unfairly small are frequent, and the upper boundary value – is inadmissible greater;

– the time of the automized account of distributions $F^*(S/H_0)$ at arbitrary M, m and at hundreds iterations is calculated by seconds. In conditions when the analytical aspect of laws of distributions $F^*(S/H_0)$ is unknown, simulation modeling is the powerful instrument at statistical probing and is non-comparable to the restrained possibilities of the manual bill. The faultlessness of outcomes of account is easily controlled by a solution technique of "inverse problem".

– on particular instances it is displayed, that outcomes of application of various criteria CRS can differ is essential. Therefore, it is necessary to secrete criterion, which error of second kind the least. For this purpose, first of all, it is necessary to evaluate distribution $F^*(S/H_1)$

Simulation algorithm of distributions $F^*(S/H_1)=\beta$**.** Distributions $F^*(S/H_0)$ in conditions of a solved problem is necessary for:

- comparisons of criteria Δ_m, Δ_{AVR}, and C_R;
- assessments of value of argument S matching critical value of an error of second kind β_c, i.e. minimum from the possible discrete value S, satisfying to a condition $\beta \le \beta_c$;
- assessments of an error value of the second stem β for the greatest value of a divergence of distributions $F_M^*(X)$ and $F_m^*(X)$.

As it has noted been above if the representative sampling from a data set is simulated by means of random numbers with an even distribution in the interval [0,1] it is obvious, that the no representatively sampling can be received, if random numbers mismatch the uniform law in the interval [0,1]. For each law of distribution $F_m^*(y)$ there will be distribution $F(S/H_1)$. In turn, this parity bears that at an assessment $F^*(S/H_1)$ nonparametric criteria S are converted in parametric.

Analysis of statistical data of duration of estates PU displays, that in overwhelming majority of events minimum value of arguments of distributions $F_M^*(y)$ and $F_m^*(y)$ practically coincide. We shall designate a parity of spacing of variation of arguments $F_M^*(y)$ and $F_m^*(y)$ through δ, where 0<δ≤1. This parity, unconditionally, is a particular case. However he is simple enough, obvious, easily controlled on the intermediate evaluations.

The modeling algorithm in this case is similar to algorithm of an assessment of distributions $F^*(S/H_0)$. We shall analogously receive, that distributions $F_m(y)$ and $F_n(y)$ match to the uniform law, accordingly, in spacing [0; δ] and [0,1].

Modeling algorithm for surveyed statisticians is characterized by following sequence of evaluations:

1. Under the standard program RAND(y) it is simulated n random numbers y with an even distribution in the interval [0,1], mapping value of a distribution function $y=F_n(S)$. We shall designate a block of these numbers through $\{y_{1,i}\}_n$.
2. It is analogously simulated m random numbers «y» in the interval [0, δ], mapping value of a distribution function $y=F_m(S)$. The block of these numbers will be $\{y_{2,i}\}_m$.
3. The variation series of random numbers $\{y_i\}_M$ and $\{y_{2,i}\}_m$, where M=m+n is constituted.
4. Statistical distribution functions are evaluated $F_M^*(y_j)=j/M$ and $F_m^*(y_{2,i})=i/m$ with j=1,M and i=1,m
5. By formula (2) implementation of a divergence between equal value of arguments of statistical distribution functions are evaluated $F_m^*(y)$ and $F_M^*(y)$

$$\Delta_i = \left|F_m^*(y_{2,i}) - F_M^*(y_i)\right| \qquad \text{with i=1, m}$$

6. Implementation are determined

$$\Delta_m = \max\{\Delta_i\}_m, \qquad \Delta_{AVR} = \frac{1}{m}\sum_{i=1}^{m}\Delta_i \quad \text{and} \quad C_R = \sqrt{\frac{1}{m}\sum_{i=1}^{m}\Delta_i^2}$$

7. Having iterated evaluations p.p. 1÷6 N_I time, where N_I – number of iterations, we build a variation series of implementation of each statistician and by that it is calculated assessments $F^*(S/H_1)$.

The graphical case history of sequential account of a statistician Δ_m is reduced on fig.1. For δ=0.7, m=4 and M=10. Some outcomes of accounts of distributions $F^*(\Delta_m/H_1) = \beta^*(\Delta_m)$ of some δ are reduced on fig.2.

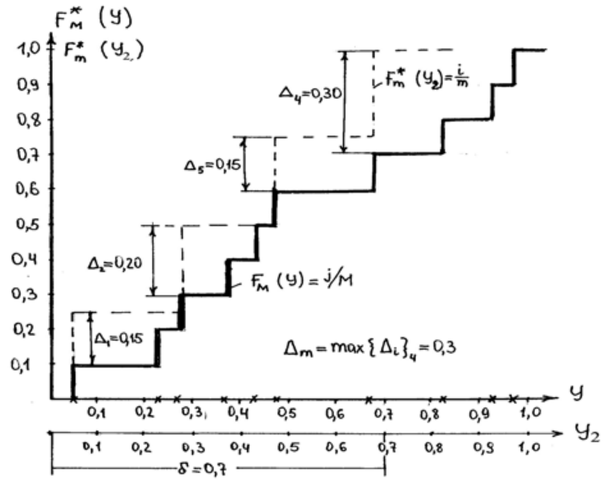

Fig 1. A graphical case history of an assessment of a statistician Δ_m at δ=0.7 m=4 and M=10

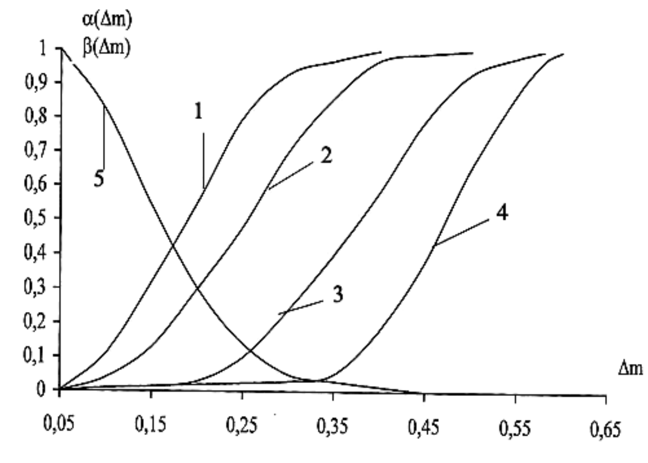

Fig.2, The graphical case history of error distributions of the first and second stem of criterion Δ_m at m=10 and n=40

1-$\delta = 0{,}3$; 2- $\delta = 0{,}5$; 3- $\delta = 0{,}7$; 4-$\delta = 0{,}85$; 5-$\delta = 0$

For matching, on fig.2 the assessment of a distribution function $\alpha^*(\Delta_m) = 1 - F^*(\Delta_m/H_0)$ is reduced at the same m and M, but for an event when sampling is representative $(\delta = 0)$. These distributions, first of all, confirm known character of their variation (with decrease α value increases β and on the contrary).

It is established, that: with body height δ the mean of value Δ_m increases; distributions $F^*(S/H_1)$ are discrete; the discrete value of arguments of allocations $F^*(S/H_0)$ and $F^*(S/H_1)$ for conforming statisticians not always coincide; the number of the discrete value of distributions C_R and Δ_{AVR} is essential to statisticians is more, than for a statistician Δ_m. On fig.3 experimental distributions $F^*(\Delta_m/H_1)$ for of some m and n are reduced.

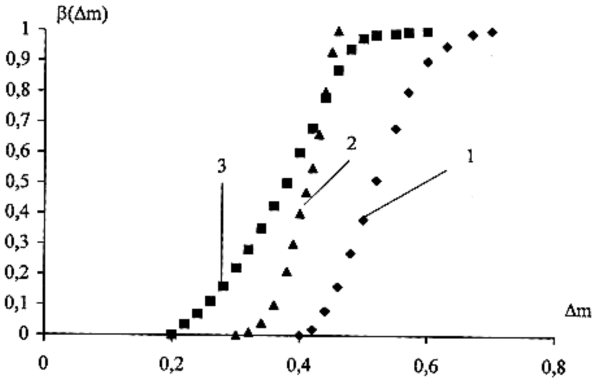

Fig.3. Distribution of the greatest spread of distributions F_m (x) and F_M (x) at $\delta = 0{,}5$
1 –m=10; n=200;   2 -m=10; n =20;   3 -m=50; n=200

As follows from fig.3, with magnifying of number of random quantities Δ_m of sampling (m) the mean $M^*(\Delta_m)$ and an average quadratic deflection $\sigma^*(\Delta_m)$ are diminished (we shall compare distributions 1 and 3 fig.3).

Distributions of random quantities a samples with equal m, taken of collections with a differing number of random quantities (for example M_1>>M_2), will have various $M^*(\Delta_m)$ and $\sigma^*(\Delta_m)$. The M=m+n it is more, and m it is less, the $M^*(\Delta_m)$ it is less, and $\sigma^*(\Delta_m)$ it is more. The magnifying $\sigma^*(\Delta_m)$ at magnifying of M is caused by increasing agency of a random in character of distribution $F_n^*(y)$. Therefore, build-down of spread $F_n^*(y)$ is one of main routes of build - down $\sigma^*(\Delta_m)$. The spread $F_m^*(y)$ depends not only on number of iterations, but also from correspondence of simulated pseudorandom numbers to the uniform law in the interval [0,1]. Analogous outcomes are received and at simulation modeling $F_m(y)$ on $F_m^*(y)$

Method of comparison of criteria. As it has noted been above to compare with criteria, it is necessary to compare with dependences $\beta(S) = f[\alpha(S)]$. Such comparison is most simply realized by a method of simulation modeling by:

- constructions of distribution $F^*(S/H_0)$ and determination $\alpha^*(S) = 1 - F^*(S/H_0)$:
- constructions of distribution $F^*(S/H_1) = \beta^*(S)$:
- constructions of dependence $\beta^*(S) = f^*[\alpha(S)]$.

Some singularities of comparison of criteria of testing of hypothesis about character of a divergence of distribution functions of sampling and a final collection have been surveyed by us in [7]. In the present section we shall try to update methodology of matching of these criteria and modes of build-down of agency of pseudorandom numbers on outcomes of account.

1. Matching of criteria can be carried out by a solution technique of "inverse problem" when character of sampling of a final collection is previously known, namely: sampling is representative

or no representative . It is established, that for representative sampling, than at the fixed arbitrary value of an error of first kind (α), an error of second kind (β) it is more, that reliability of criterion is more. If sampling is no representative, at the fixed arbitrary value α, than β it is less, that reliability of criterion is more.

So that to compare with reliability of surveyed criteria of a test of hypothesis it is necessary to build characteristics $\alpha(s) = f[\beta(s)]$ for representative (R) and no representative (NR) a samples and to compare at the fixed value $\alpha(s) = \alpha_0$ with a design value $\beta(s)$. If to designate criteria as S_1 and S_2 it will be formal condition of preference S_1 above S_2 to look like:

$$\left.\begin{aligned} \beta_R(S_1) = f_1[\alpha_0] < \beta_R(S_2) = f_1[\alpha_0] \\ \beta_{NR}(S_1) = f_1[\alpha_0] < \beta_{NR}(S_2) = f_2[\alpha_0] \end{aligned}\right\} \quad (4)$$

2. Singularities of statistical modeling. One of the fundamental difficulties at simulation analysis of distributions $\alpha^*(S)$ also $\beta^*(S)$ is build-down of agency of pseudo-random values program simulated a samples with an even distribution in the interval [0,1], on outcome of account. Fluctuations of numerical values $\alpha^*(S)$ also $\beta^*(S)$ cause the certain probability of an erratic solution which, in particular, the is more, than it is less number of implementation of sampling (m) and depends on number of iterations a little. Overcoming of this difficulty has been reached as application of a known method of common random numbers [7], and new approaches, in particular:

- applications of criterion of Kolmogorov for the supervision of correspondence of random numbers program simulated a samples to the uniform law. "Classifying" a samples not only reduces fluctuations of implementation $\alpha^*(\Delta_m)$ and $\beta^*(\Delta_m)$, but also fulfills protective functions from imperfection of program implementation a samples at small m and disturbances of a computer;
- removal of agency of distribution of the random quantities adding to a samples up to a data set, i.e. $F_n^*(y)$;

On fig.4. Experimental dependences $\beta(S)=f[\alpha(S)]$ for m=10, M=30 and δ=0.5 are reduced. Analogous dependences are received and for of some other value m, M and δ.

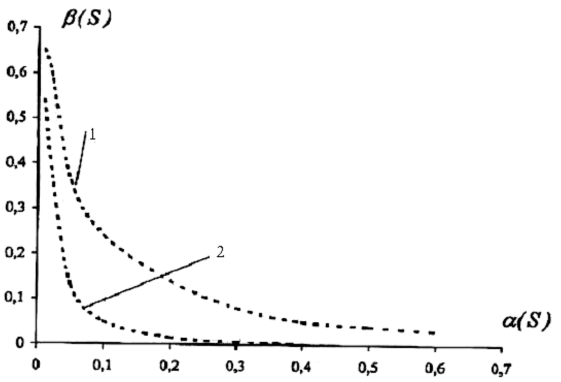

Fig.4. Curve variations of dependence $\beta(S) = f[\alpha(S)]$ at m =10; M=30 and δ =0,5 for criteria (S): 1 – C_R and Δ_{AVR}; 2- Δ_m

Analysis of these data has allowed to conclude:

- the least value β(S) at 0<α(S)<1 occurs for criterion Δ_m;
- value β(S) at 0<α(S)<1 for criteria C_R also Δ_{AVR} are practically peers and is essential above, than for criterion Δ_m. In other words, difference of allocations $F_m(\tau)$ also $F_M(\tau)$ is determined not so much by an average or average quadratic value of their deflections, how much the greatest divergence.

Risk of an erratic solution and some outcomes of accounts. Traditionally, admissible errors at adoption initial or of alternative hypotheses are set, and as a rule, is received, as $\alpha_c \le 0.1$ $\beta_c \le 0.1$. If again to convert to curves fig.2 it is easy to note, that the sum $\alpha^*(\Delta_m)$ and $\beta^*(\Delta_m)$ in process of body height Δ_m varies. First she is diminished, then magnified. Physically the sum $\alpha^*(\Delta_m)$ also $\beta^*(\Delta_m)$ matches to risk of the erratic solution, caused by a random in character Δ_m^*. Generally the risk of an erratic solution is peer

$$\gamma(\Delta_m) = A \cdot \alpha(\Delta_m) + B \cdot \beta(\Delta_m) \qquad (5)$$

where A and B – a relative significance of aftereffects of an erratic solution, where A+B=1. Then it is obvious, that to some value Δ_m there will match minimum value $\gamma(\Delta_m)$ which will be optimum. Having determined $\Delta_{m,opt}$, we receive essentially new effect: α_c also β_c are not set, and pay off proceeding from demands $\gamma(\Delta_m) = \gamma(\Delta_{m,onm})$.

Instance. One of the fundamental indexes of reliability PU is the mean of duration of recovery at emergency cutoff $M_\Sigma^*[\tau_\alpha]$. Under arranged data value $M_\Sigma^*[\tau_\alpha]$=65hrs. At number of implementation M=145 also it is determined as an average arithmetical implementation τ_a. However $M_\Sigma^*[\tau_\alpha]$ insufficiently full mirrors an aspect of cutoff PU and the aftereffects coupled to it. Failures can lead to sudden cutoff (automatically or manually) to be eliminated by cutoff PU under the emergency request (the possibility of cutoff is determined by supervisor EES). Failures can be repeated and at start-up from unloaded reserve or of emergency repair. In each of the enumerated events $M^*[\tau_a]$ and an aftereffect of cutoff PU are various. Is how much essential differ $M^*[\tau_a]$ from the averaged index $M_\Sigma^*[\tau_a]$. In the capacity of $M^*[\tau_a]$ we shall survey average duration of sudden cutoffs $M^*[\tau_{sd}]$ of each PU. The conducted accounts, as one would expect, have displayed, that the distribution function $F_M^*(\tau_a)$ is essential differs from distributions $F_{m.i}^*(\tau_{sd})$ and consequently was nonrandom differ $M_i^*[\tau_a]$ and $M_i^*[\tau_{sd}]$ with i=1,n$_б$. Further the collection of implementation of duration of emergency repair has been surveyed at sudden cutoffs of all PU with M=55 and $M_\Sigma^*[\tau_{sd}]$=37hrs. Outcomes of comparison $M_\Sigma^*[\tau_{sd}]$ and assessments $M_i^*[\tau_{sd}]$ for each PU are reduced in table 1.

Matching of duration of emergency repairs at sudden failures
of power-generating units 300 MW.

Table 2

i	m_i	$M^*[\tau_i]$	Δ_m^*	$\gamma^*(\Delta_{onm})$	$\Delta_{m,\alpha}$	$\Delta_{m,\beta}$
1	13	101	0.25	0.01		
2	8	21	0.09	0.18	0,15	0,24
3	8	6	0.27	0.0		
4	6	49	0.31	0.05		
5	4	29	0.09	0.25	0,29	0,27
6	3	7	0.37	0.0		
7	5	6	0.38	0.0		
8	8	3	0.56	0.0		

As follows from this table of an assessment $M_i^*[\tau_{sd}]$ for PU with station numbers 2 and 5, peer, accordingly 21hrs. and 29hrs. (in difference from others PU) is random differ from $M_\Sigma^*[\tau_{sd}]$=31hrs. Given tables 1 together with fig..4. Allow to trace algorithm of an adoption of a decision. As a result of account most (least) safe are secreted PU. In our event it is the eighth (first) PU, and the divergence speaks difference of "weak links» PU and tame duration their emergency repair.

Conclusions

The fundamental outcome of the conducted probing is development of the automized system, allowing to determine and compare indexes of individual reliability PU with a state district power station in view of a random in character of an initial conditions, to submissive staff conforming references and by that, to contribute in junction from the intuitive problem solving, depending from the greatest (least) reliability PU, to a quantitative justification of solutions.

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