Methodical Bases of Benchmarking Unique Objects of Electric Power Systems

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Abstract

One of the basic problems of electro power systems is absence of the normative documents regulating operation, maintenance service and repair of the capital equipment, which service life exceeds normative value. We shall name them «oldtech» (OT). The essence of the difficulties demanding overcoming is reduced to absence of methodologies a quantitative estimation of operative reliability and safety of OT, with the subsequent benchmarking of OT. Considering the science-intensive, bulkiness and labour input of the decision of this problem indisputable becomes necessity of development of the corresponding automated systems. In present article, some features of an estimation of an integrated indicator and benchmarking unique objects are resulted. To unique objects, which analogues on the set combination of versions of significant attributes are absent concern. For an illustration of recommended methods and algorithms technical and economic parameters of power units with SGI-400 are used.

Keywords. Benchmarking, oldtech, unique object, operative efficiency, integrated indicator, analysis, synthesis, technical condition

I. Introduction

One of the main problems of electric power systems (EPS) is to increase the operative efficiency of work (OEW) of the main equipment, devices and installations (objects), which service life is approximately equal to or even exceeds the calculated (nominal, park). We shall agree to name them «oldtech» (OT). This problem is far from new. Suffice it to refer to the publications of well-known specialists [1,2,3]. And, despite the fact that there is a systematic increase in many EPS in the relative number of OT (today this value exceeds 60%), "and the problem is still there." Why? After all, the unacceptable consequences of system accidents, initiated by OT, are well known. Of course, the death and injury of EPS personnel, environmental damage and large material costs attributed to climate change. Therefore, they often also speak. But why this problem is not solved anywhere?

To realize this, we need to agree that:

- ❖ The efficiency of EPS facilities in the modern sense is no longer economic efficiency. This is a complex (integral) concept that includes, along with efficiency of operation, reliability and safety of service. So what? These properties always been taken into account (the reader will say). Sure. But only the economic component of the OEW was quantified;
- ❖ There was no quantitative assessment of operational reliability and maintenance hazards. "Within the guaranteed period, the manufacturer (supplier) is responsible for hidden, and in the cases provided for by the contract, and for obvious defects" [4];

- At the end of the guaranteed service life of the object, our attitude to the OEW characteristic does not change. And how can it change if there is no corresponding regulatory framework for the maintenance and repair of OT? After all, we are accustomed to calculating reliability indicators on the basis at the design stage of objects based on a priori information about failures, defects and the duration of damage recovery in many objects of the same type. Now it is required to assess the operational reliability of work over the past month, week, day and even shift. But, if we are able to assess a quantitative assessment of the reliability of work at least at the design stage, then the danger of maintenance has always, including during design, been assessed only at a qualitative level;
- By the way, it is not safety that needs to quantified, but the hazard of maintenance. Security is either there or not. Only the danger changes;
- Quantifying the efficiency and reliability of work, as well as the risks of maintenance, is not an end in itself. It is necessary for operational comparison and ranking of EPS objects. In economics, this analysis usually called benchmarking, when specialists compare numerous properties of objects and, because of this comparison, increase the efficiency of their work. The number of compared indicators calculated in tens. The ranking results here are largely subjective, and the risk of making a wrong decision is great;
- Comparison and ranking of the OEW of EPS objects significantly simplified in the transition to the integral indicator. But reducing the risk of an erroneous decision is achieved only if the integral indicator characterizes the technical condition of the object;
- The use of Harrington's integral indicator [5] has become widespread in many branches of material production and in the service sector, which indicates the relevance of integral assessment. But Harrington's integral exponent is calculated as the geometric mean of the probabilities of realizations of a set of indicators, and therefore it has no physical meaning. "The calculation methodology, noted in [6], becomes a black box that gives out numbers that not have physical meaning."

Some of the features of the problem, briefly listed above, cause difficulties in solving it by the efforts of the EPS personnel. One of the possible ways to partially overcome these difficulties are the recommendations [3], the essence of which boils down to organizing centers for providing the OEW of EPS facilities at the branch research institutes of energy. The Center carries out: collection and analysis of statistical data on the technical condition of equipment, failures, repairs; identification of factors influencing the ERM; development of measures to increase the OEW; organization of staff training; conducting benchmarking. The practical implementation of these recommendations would undoubtedly have positive results. But they could not solve the problem for two reasons: there are no methods for quantitative assessment of the integral indicator of the OEW of objects and criteria for testing hypotheses about the nature of the discrepancy between these indicators.

II. Methodical bases of synthesis of integral indicators of the OEW and benchmarking of OT.

We will distinguish between same tipe, similar and unique EES objects. Objects that characterized by the same set of varieties of significant features will be referred to as "the same type". "Similar" considered objects that characterized by the same samples of varieties of significant features from their totality. We will refer to "unique" objects, as there are no analogues for the given types of features.

An example of same objects can be power units of power plants, their main equipment, devices and installations, an example of "similar" objects - switchgear switches (linear, block), and an example of a "unique" object - the only 500 MW steam turbine power installation in the EPS. This classification of objects is not given by chance. First of all, it testifies to the fact that there are numerous benchmarking tasks, methods and algorithms for their solution. And this feature determines one of the difficulties in solving the problem of improving the management of the OEW EPS. But all these methods and algorithms have a lot in common. To them concern:

❖ Ensuring the infallibility of the information base is one of the most important tasks of the automated system for operational benchmarking of objects. Information on the technical condition of EPS facilities formed according to the monthly reports of EPS enterprises (for example, form 3-TECH (energy)), test and repair protocols and dispatch logs. Naturally, these data differ significantly from the list of calculated indicators used in benchmarking, and the transformation of the initial data is one of the possible sources of errors. The recommended methods and algorithms for ensuring the error-freeness of the initial data, as well as the error-freeness of the database as a whole, are given in [7], and for the control of the accuracy of the calculated technical and economic indicators (TEI) - in [8].

❖ *Requirements for the estimates of integral indicators*. Along with the infallibility of the initial data, the calculation method should ensure objectivity, physical essence, and the availability of practical use of the integral indicator.

One of the main reasons for distorting the assessment of the integral indicator based on error-free initial data is the presence of interconnected TEI. In other words, some specific property of an object represented by several integral indicators. Thus, the significance (relative value characterizing the technical condition) of this property is unjustifiably increased, which leads to a distortion of the integral indicator and benchmarking. The solution to this problem would not present difficulties, bearing in mind the mathematical apparatus of the theory of correlation, if not one "but" - these methods are developed for one-dimensional random variables and a number of restrictions. Constraints include the correspondence of the distribution of random variables to the normal law and a considerable number of implementations.

The multidimensional character of the TEI realizations determines their difference from the normal distribution law. And if for any TEI the statistical distribution function resembles a normal distribution law, then on an adjacent time interval the assumption of such a correspondence will be erroneous with a high probability. As for the number of TEI, even in the presence of similar EPS objects, their number is naturally limited, and when classifying integral indicators, calculated in units. Overcoming these difficulties in [9] proposes to carry out the transition from constant critical values of TEI to “local” ones, calculated by simulation modeling of possible realizations of the correlation coefficients for fiducial distributions of TEI.

❖ *Providing the physical essence of the integral indicator*. Obviously, the recommendations for benchmarking EPS facilities should be objective and, as a rule, understandable to a specialist. Specific recommendations among a number of possible ones should not cause a smile. Inconsistency of recommendations with real possibilities not excluded, since in this complex system it is almost impossible to take into account all external factors. An example is the lack of spare nodes necessary for the repair of an object due to an accidental delay in their delivery. But with proper organization of maintenance and repair, such reasons can appear, but of course, far, not monthly. Since, in fact, it is necessary to compare the technical condition of objects the most important for OT are indicators characterizing the degree of "wear" of individual properties.

In reality, TEI vary from the nominal to the maximum permissible value. It is proposed to represent this interval as the interval of the possibility of the EPS object to meet the requirements for the technical state. Over time, as a result, of aging, these opportunities decrease. The change can be continuous or discontinuous. A relative portion of the utilized capacity referred to as “wear and tear”, and the remainder referred to as “residual resource”.

The amount of wear varies within [0;1], and the residual resource - within [1;0]. The transition to relative values of TEI called rationing. The advantage of rationing is also overcoming the difficulties of differences in the dimensions and scales of TEI, which does not allow for the possibility of their joint consideration. As random variables, wear estimates most fully characterized by statistical parameters. The methodology for overcoming the difficulties of joint consideration of TEI is given in [10].

- *Varieties of integral indicators of operational efficiency.* The transition from multiple TEI to integral indicators undoubtedly simplifies benchmarking if we can answer the following questions: how are integral indicators calculated how to choose integral indicators from a variety of possible ones, and how to compare these indicators taking into account their random nature.

It is known, that the number of indicators characterizing the average values TEI realizations and their scatter about 10. If, in addition, take into account complex indicators (similar to the coefficient of variation K_v), their total number may exceed the number of TEI. Thus, refusing to compare the set of possible TEI realizations and moving on to integral indicators, we encountered the problem of choosing from a set of possible types of integral indicators. Overcoming this difficulty is supposed to be carried out by assessing the analysis of the possibility of practical use and the relationship of integral indicators. The analysis made it possible to establish that the technical state of the object represented by two integral indicators that characterize the average wear and the degree of misalignment of the technical state of the object, and most independent. This is the arithmetic average of the normalized values of the calculated TEI and their coefficient of variation;

- Since the recommended benchmarking methodology based on comparing and ranking random wear values, conclusions and recommendations for increasing the OEW of objects cannot fail to consider this feature. Objects of the same type, for example, power generating units of power plants of the same type, and completely different ones, for example, steam and hydraulic turbines, compared in terms of wear. In both cases, the comparison is associated with an assessment of the appropriateness of the classification and is quite accessible, since the values of average wear compared. And the difficulties in solving this problem are again associated with the multidimensional nature of these indicators and the high risk of using a mathematical algorithm for testing hypotheses about the nature of the discrepancy between statistical parameters. The risk of an erroneous decision is due to the inadmissibility of applying to multidimensional values criteria that involve the comparison of statistical parameters of one-dimensional random variables. Overcoming these difficulties achieved by comparing two fiducial distributions, the first of which reflects the distribution of a set of normalized TEI realizations, and the second - a sample of TEI realizations for a given combination of varieties of features. At the same time, proposed to agree that if the statistical distribution functions differ randomly, then their distribution parameters also randomly differ.
- Science-intensive, cumbersome and labor-intensive, the high risk of an erroneous decision in manual counting necessitate the transition to automated systems for the synthesis of integral OEW and benchmarking of operational tasks of maintenance and repair. It noted that the above difficulties and ways to overcome them categorized as “explicit”. "Implicit" difficulties appear during the implementation of an automated system and are caused by numerous external factors specific to each EPS.

This article presents the features of the methodology for analyzing the error-freeness of TEI, assessing the integral indicator of the OEW (synthesis of TEI), benchmarking the maintenance and repair system and taking into account the random nature of the integral indicators using the example of a number of TEI of the SGI-400 combined cycle plant.

III. Features of the methodology of analysis, synthesis and comparison of TEI SGI -400.

Table 1 shows some average monthly TEI, that characterize the OEW of SGI -400 in the analyzed (t_j) and the previous month ($t_{(j-1)}$).

Table 1. Implementation of the average monthly TEI SGI -400

i	TEI name	Symbol	unit of measurement	Months of year	
				t_j	t_{j-1}
1	EE generation (total)	$E_Σ$	кWh10^3	241322,8	89617,9
2	EE release from the trunks of station	E_T	кWh10^3	235541,2	86858,1
3	Energy consumption in system of ON	E_{on}	кWh10^3	5781,6	2759,8
4	Natural gas consumption	B_g	t.м^3	45310,9	17077,5
5	Equivalent fuel consumption	B_f	t.e.f.	51783,8	19517,1
6	Specific consumption of equivalent fuel	b_f	g/кWh	219,85	224,7
7	Average power	P_{av}	MW	342,7	322,7
8	Efficiency (gross)	$η_g$	%	55,9	51,68
9	Feed water temperature	T_f	^{0}C	150,5	151,8
10	Flue gas temperature	T_{fg}	^{0}C	113,2	113,4
11	Vacuum	K_v	%	95,8	95,7

As follows from table 1, the reported indicators are not always convenient for comparing the OEW of the SGI. For example, these TEI do not answer the question about the reasons for a sharp decline in total electricity generation (EE), or a sharp decline in consumption EE in system of own needs (OW). On the other hand, the TEI "natural gas consumption" (B_g), "equivalent fuel consumption" (B_f) and "Specific consumption of equivalent fuel" (b_f) characterize economic efficiency quite fully. But they do not take into account that $b_f·η_g$=const, i.e. TEI efficiency (gross) $η_g$ as objectively characterizes the economic efficiency of a SGI unit, as well as TEI b_f. To take into account this discrepancy for the synthesis and benchmarking of TEI, it proposed slightly modify the list of analyzed TEI.

Namely:

- TEI $E_Σ$ and E_T. replace with TEI "coefficient of use of nominal performance" $K_p=E_Σ/P_n·t_j$;
- TEI E_{on} should be presented in relative units (%) according to the formula $εE_{on}=100·E_{on}/E_Σ$;
- instead of TEI P_{av}, introduce TEI "coefficient of use of installed capacity" $K_c=100P_{av}/P_n$;
- enter the TEI "coefficient of technical use", calculated by the formula $K_T=100E_Σ/P_{av}·t_j$.

Indicators K_p, $εE_{on}$, K_c and K_T will agree to call calculated. The results of the automated transformation of the reporting TEI of the SGI -400 into calculated TEI shown in table 2. It is easy to see that the transformation of TEI reduced to the input of the indicators K_p, K_c and K_T, well known in the theory of reliability.

Moreover, since $K_p=K_c·K_T$ - this ratio can be used to control the accuracy of their calculation.

Table 2. Implementation of the recommended list of average monthly TEI SGI -400

i	TEI name	Symbol	unit of measurement	Months of year	
				t_j	t_{j-1}
1	Coefficient of use of nominal energy	K_p	o.e.	0,84	0,30
2	Consumption in system of ON	$εE_{on}$	%	2,39	3,08
3	Coefficient of use of installed capacity	K_c	o.e.	0,86	0,81
4	Coefficient of technical use	K_T	o.e.	0,98	0,37
5	Efficiency (gross)	$η_g$	%	55,9	54,7
6	Feed water temperature	T_f	^{0}C	150,5	151,8
7	Flue gas temperature	T_{fg}	^{0}C	113,2	113,4
8	Vacuum	K_v	%	95,8	95,7

The next stage of the analysis (when the automated system is put into operation) is to determine the change interval of possible TEI realizations. For unique objects, these intervals are established and adjusted according to the monthly average TEI realizations for a number of years of observation. It should be borne in mind that the width of the interval increases with time (with a constant number of realizations) from the initial to the maximum permissible value, since TEI implementations vary from the nominal to the maximum permissible value. For illustrative purposes,

Table 3 shows the results of calculations of these intervals for each of the last four years and the width of the interval for four years. When analyzing these data, one should take into account the direction of the TEI change.

Table 3. Interval of changes in TEI SGI -400 realizations

TEI				Change interval				
i	Symbol	unit of measurement	Estimation	On years (j)				Maximum
				1	2	3	4	
1	K_p	o.e.	min	0,232	0,179	0,450	0,210	0,179
			max	0,699	0,747	0,787	0,875	0,875
2	εE_{on}	%	min	2,60	2,40	2,31	2,32	2,31
			max	3,23	3,15	3,71	4,68	4,68
3	K_c	o.e.	min	0,58	0,59	0,48	0,39	0,39
			max	0,73	0,78	0,79	0,88	0,88
4	$K_{т}$	o.e.	мин	0,37	0,27	0,60	0,37	0,27
			max	1,0	1,0	1,0	1,0	1,0
5	η_g	%	min	50,8	50,0	47,0	42,7	47,0
			max	54,3	54,6	54,3	56,8	56,8
6	T_f	^0C	min	152,0	153,2	156,2	149,7	149,7
			max	155,1	158,4	158,9	158,2	158,9
7	T_{fg}	^0C	min	113,3	112,9	112,5	113,1	112,5
			max	119,7	121,7	123,2	124,8	124,8
8	K_v	%	min	87,5	87,3	85,7	85,7	85,7
			max	96,8	96,4	93,5	96,3	96,8

Under the "direction of change», we mean the direction of change in TEI with an increase in the service life and wear of the object. For example, with an increase in the wear of a SGI TPS, the value of K_p decreases, and the value of εE_{on} increases.

The boundary values of the TEI change intervals serve not only as the basis for the interval method for monitoring the TEI error-freeness, but also as a necessary condition for the transition from the actual TEI values to the normalized values. For an arbitrary TEI (P_i) i=1,mp, the normative value will be denoted as Iz(P_i).

There are a lot ways to normalized TEI of EE objects. It is proposed [9] to carry out standardization, as a result of which the normalized estimate of the TEI will reflect the technical condition of the SGI, that is, the amount of wear (Iz).

Let us consider the sequence of calculations of the normalized TEI values for the coefficient of utilization of the nominal capacity K_p, which decreases with increasing service life of the SGI. In accordance with Table 2, K_p in the j-th month is equal to $K_p(t_j)=0,84$:

- according to table 3, we determine the interval of possible realizations

$$\Delta K_p=(K_{p,max}-K_{p,min})=0,696;$$

- the normalized value of K_p is calculated by the formula:

$$Iz[K_p(t_j)]=[K_{p,max} - K_{p,min}(t_j)]/\Delta K_p=0,05.$$

Thus, the wear rate does not exceed 5%.

Let us now consider the sequence for calculating the normalized value of the TEI εE_{on}, which increases with the service life of the SGI. According to table 2, εE_{on} in the j-th month is equal to $\varepsilon E_{on}(tj) = 2{,}39\%$:

- according to the data in table 3, we determine the interval of possible realizations $\Delta(\varepsilon E_{on}) = 2{,}37\%$;
- the normalized value εE_{on} is calculated by the formula:

$$Iz\ [\varepsilon E_{on}(t_j)] = [\varepsilon E_{on,max} - \varepsilon E_{on,min}(t_j)]/\Delta(\varepsilon E_{on}) = 0{,}034.$$

The results of similar calculations are shown in table 4. It also shows the estimates (*) of integral indicators ($M^*(Iz)$ and $K_v^*(Iz)$), characterizing the technical condition of SGI -400 for the j-th and for comparison - for (j-1) month according to the data tables 2 and 3.

Table 4. The results of calculating the normalized values of TEI

TEI		Month of year	
i	tip	j	j-1
1	$Iz(K_p)$	0.050	0.826
2	$Iz\ \varepsilon E_{on})$	0.034	0.629
3	$Iz(K_c)$	0.036	0.127
4	$Iz(K_r)$	0.027	0.863
5	$Iz(\eta_g)$	0.092	0.214
6	$Iz(T_f)$	0.087	0.228
7	$Iz(T_{fg})$	0.057	0.073
8	$Iz(K_v)$	0.090	0.099
$M^*(Iz)$		0.079	0.313
$K_v^*(Iz)$		0.42	1.093

Comparison of quantitative estimates of TEI SGI-400 in the j-th and preceding (j-1) month allows us to conclude:

- six TEI $Iz(K_p)$, $Iz(\varepsilon E_{on})$, $Iz(K_c)$, $Iz(K_t)$, $Iz(\eta_g)$ and $Iz(T_f)$ indicate that as a result of average repair of SGI-400 in (j-1) month significantly improved their quantitative estimates in the j-th month;
- two TEI $Iz\ (T_{fg})$ and Iz(Kv) - practically did not change;

The transition to integral TEI M*(Iz) and Kv(Iz) also indicates a significant improvement in the technical condition of SGI-400 after repair.

The apparent simplicity of the synthesis and benchmarking of the TEI SGI-400 is deceptive, since far from all TEI are taken into account, and the SGI -400 is not represented by a set of main equipment, devices, installations and their units. Comparing them (benchmarking) manually would be extremely cumbersome and time consuming. But there is one more feature that is not always taken into account in calculations.

Since the normalized TEI values, as well as the actual TEI values themselves, are random variables, and the number of TEI realizations for the given types of features may be quite small, the observed discrepancy of the integral indicators may be random, and the risk of making an erroneous decision is great.

As an example of solving this problem, we can consider the nature of the discrepancy between the integral indicators in the j-th and (j-1) -th months. However:

- because benchmarking is multidimensional (many comparison options);
- comparison in the framework of the theory of testing statistical hypotheses of one-dimensional random variables is associated with a high risk of erroneous decisions;
- assessment of critical values of integral indicators based on simulation is specific;

Comparison of random implementations of integral indicators, due to the high labor intensity, cumbersomeness and science intensity, should carry out automatically.

Conclusion

1. If the replacement of OT with modern facilities is currently impossible, and funds for their complete modernization are not enough, and at the same time, the occurrence of system accidents caused by OT is unacceptable, it is advisable to carry out partial modernization, eliminating the identified defects, with mandatory operational control of the technical state of the OT and clarification of the maximum permissible load values;
2. Centers for ensuring operational efficiency at branch research institutes of energy collect and formalize data on the technical state of OT, automated analysis and synthesis of this data, benchmarking, preparation of operational recommendations to improve work efficiency, development of appropriate methodological guidelines, professional development of personnel of launches in on-line mode;
3. Development of automated systems for monitoring the technical condition of OT, taking into account specific external factors. Improving the objectivity of recommendations on the effectiveness of the OT requires the approval of the form of the output documents with the management;
4. Some features of the formalization of data on the technical state of OT, ensuring the infallibility of the initial data, performing the standardization of technical and economic indicators, assessing integral indicators and some benchmarking results indicate the possibility of an objective assessment of the operational efficiency of OT and thereby reducing the risk of unacceptable consequences.

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