Method of Evaluating Efficiency in Gas-Piston Power Stations

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***Abstract* —Increase of an efficiency work of thermal power stations concerns to the most important and actual problem. The importance of this problem caused both regular increase in cost of fuel, and increase in park of the equipment which service life exceeds settlement. In these conditions, traditional methods of maintenance of an efficiency work demand perfection. One of the most important objects of electro power systems are gas piston power station. Mobility, ecological compatibility, reliability and profitability of work concern to their doubtless advantages. Data on experience of their operation practically are absent, as well as methods of comparison of efficiency of their work. The method and algorithm of periodic (monthly) comparison of an overall performance powerful gas piston power stations manufactures Wartsila (Finland) by calculation of an integrated parameter of the importance of realizations of monthly average values of technical and economic parameters is resulted. As a result, to the Management of these power stations and the Management of a power supply system results of the analysis of technical and economic parameters, and as methodical support - given to the recommendation on increase of an efficiency work.**

Keywords — method, comparison, efficiency, reliability, profitability, gas-piston power station.

I. INTRODUCTION

In the modern conditions, described increase of park of the growing old capital equipment of EPS and increase in cost of fuel, the urgency of a problem of increase of an efficiency work of *power stations (PS)* essentially increases [1].

Known methods of the basic decision of this problem demand considerable additional expenses, which are not always accessible [2]. Significant successes here reached as due to transition from quality standards of efficiency of the decision of operational problems to quantitative estimations, and perfection of methods of comparison of an efficiency work of *thermal power stations (TPS)*.

Traditionally such comparison is spent on the basis of one of the basic *technical and economic parameters* (TEP). As a rule, this actual value of the *specific charge of conditional fuel (SCCF)*. However, this way considers reliability of work PS insufficiently. And for this reason, the risk of the erroneous decision of operational problems can be significant. The account of reliability of work demands attraction to comparison corresponding TEP. However, there are difficulties in simultaneously taking into account several TEPs. Overcoming of these difficulties reached by calculation integrated parameter.

Features of calculation of an integrated parameter.

To the basic difficulties of an estimation of an integrated parameter concern:

- Distinction of units of measure TEP;
- Distinction of scale of measurement TEP. Summation of duration of the emergency idle time (t_e), measured in hours, and service life (T_{sl}), measured in years is useless;
- Distinction of an orientation of measurement TEP. The increase in coefficient of use of the installed capacity testifies to increase of overall performance PS, and increase in the charge in system of own needs - to its decrease;
- Interrelation of change of some TEP. For example, the increase in development of the electric power in the set interval of time conducts to decrease in the specific charge of conditional fuel. Presence interconnected TEP leads to errors of an estimation of an integrated parameter;
- Small duration of an interval on which measured compared TEP (month, quarter, week, change). The shorter the time interval over which the comparison of the efficiency of the thermal power plant is carried out, the higher the effect of reducing therisk of an erroneous decision. The small intervals of the control, but also exclude an opportunity of application of separate parameters;
- Possible distinction of technological processes leads to distinction describing them TEP, and consequently, and to reduction of number TEP simultaneously describing compared PS;
- Used TEP should characterize an efficiency work of all compared PS. By comparison of efficiency work TPS and HPS use TEP «the specific charge of conditional fuel» for generation of electrical energy is inadmissible.

Ranging PS by way of decrease in efficiency of their work allows to establish the most reliable and economic PS, to learn «weak component», to establish sequence of use of reserve capacity, and ranging of versions of attributes - to reveal the most significant factors.

II. TRANSFORMATION TEP GAS PISTON POWER STATIONS

The purpose of work. The method of a quantitative estimation and objective comparison of efficiency work *gas piston power stations (GPPS)* with the simple cycle, working in semi-peak a mode resulted. Some analogue of the decision of a problem of comparison of efficiency work GPPS is comparison of an efficiency work of the same power unit's capacity 300 MW of *steam-turbine power stations* (*STPS*) on gas-oil fuel [3-6]. It concerns to power units, which service life essentially exceeds settlement, speed of change of power characteristics is significant, and therefore use of standard methods of calculation of optimum loading of power units connected with greater risk of the erroneous decision.

As is known [7] GPPS in comparison with the others TPS have high efficiency, a low level of emissions of harmful substances, are reliable, capable to work long time at partial loadings without damage to a technical condition and without decrease in efficiency. The specific charge of gas makes 256 g/kWh the electric power, and between-repairs period - 12 years. These features characterized with a number of monthly average values TEP, basic of which are: the specific charge of conditional fuel (U_f), the charge of the electric power on own needs (W_{on}), actual value of generation of the electric power (W_{Σ}^{f}), coefficient of use of the installed capacity ($K_U = W_{\Sigma}^{f} / W_{\Sigma}^{r}$, where $W_{\Sigma}^{rp} = P_{rp} \cdot T_M$, P_{rp} - rated power GPPS, $T_м$ - duration of month, $T_м$=730 h), number *gas piston installations* (GPI), disconnected on emergency repair (n_e) [10].

At calculations TEP it appears necessary and some nameplate data PS. Namely: rated power and number GPI power stations (P_i and n_i), year of input power stations in operation ($t_{y,i}$). In the illustrative purposes in (table 1) quantitative estimations of basic monthly average values, TEP GPPS together with P_i, n_i and t_i are resulted. As it has noted been above, to the basic conditions of an estimation of an integrated parameter concern presence of interrelation TEP with efficiency work GPPS, identity of units of measure and scale TEP.

TABLE I. SOME NAMEPLATE DATA AND MONTHLY AVERAGE VALUES TEP

TEP	Symbol	Unit of measure	Gas piston power station					
			PS1	PS2	PS3	PS4	PS5	PS6
Year of input	$t_{y,i}$	years	2006	2006	2006	2007	2008	2009
Rated power and number GPI	P_i; n_i	MW	8,7x10	8,7x10	8,7x10	8,7x12	16,6x18	8,7x12
Development el. energy	W_{Σ}^{f}	thousand MWh	17.526	20.542	21.176	42.224	95.477	33.373
The charge el. energy on o.n	W_{on}	thousand kWh	280.8	370.9	428.6	652.5	1.175.2	411.2
The specific charge of conditional fuel	U_f	g/kWh	292,3	281,3	274,0	267,0	272,1	276,9
Number GPI disconnected on emergency repair	n_e	piece	3	1	1	1	4	1

Among monthly average values TEP noted and set in (table 1), sizes $t_{y,i}$, W_{Σ}^{f} , W_{on}, P_i, n_i and n_e do not characterize overall performance GPPS. So, overall performance GPPS is defined not by year of input PS in operation, and service life which is calculated as $\Delta t_{sl} = (t_c - t_{y,i})$ where t_c - current year of operation GPPS. Size W_{on} is defined, first of all, by capacity PS and cannot be used for comparison of efficiency work PS. The opportunity of use changes while translating absolute values W_{on} in relative under the formula $\delta W_{on} = W_{on} / W_{\Sigma}^{f}$

Alongside with operating ratio of the established capacity for the characteristic of overall performance GPPS can be used TEP - monthly average number of hours of use of the established capacity (T_u), and for fuller characteristic of reliability PS - factor of idle time GPI in emergency repair $K_e = n_e / n_i$, where n_i – number GPI, n_e - number GPI, disconnected on emergency repair. Thus, overall performance GPPS characterized by following TEP: Δt_{sl}, U_f, δW_{on}, T_u, K_u and K_e. Results of their quantitative estimation according to (table 1) are resulted in (table 2).

In [4] it offered two methods of overcoming of distinction of dimension and the scale, simultaneously considered at comparison TEP. It is a method based on transition to relative sizes of deviation TEP from the reference value and an interval method.

In (table 3) data on an orientation of change TEP concerning change of efficiency work GPPS, about the minimal and maximal values of realizations TEP, about length of an individual interval, settlement sizes of boundary values of five intervals of scope TEP (the five-point system of an estimation of the importance of actual value TEP is accepted) and, conterminous with serial numbers of intervals of scope, the importance (point) TEP in view of an orientation of their change, the formula for calculation of sizes of relative deviation TEP are resulted.

Considering distinction of monthly average values of scope of change TEP considered GPPS on months of year, resulting scope TEP determined on minimal and maximal sizes TEP within previous year for all considered GPPS. For this scope, the length of an individual interval and boundary values of intervals of scope is calculated.

TABLE II. THE MONTHLY AVERAGE QUANTITATIVE ESTIMATIONS TEP, DESCRIBING EFFICIENCY WORK

TEP	**Symbol**	**Unit of measure**	**Gas piston power station**					
			PS1	PS2	PS3	PS4	PS5	PS6
Service life	T_{sl}	year	12	12	12	11	10	9
The charge el. energy on o.n.	δW_{on}	%	1,60	1,81	2,02	1,55	1,23	1,23
The specific charge of conditional fuel	U_F	g/kWh	292,2	281,3	274,5	267,0	272,1	276,9
Conditional number of business hours with a rated load	T_u	h.	201	236	243	404	320	319
Coefficient of use of the installed capacity	K_u	%	27,5	32,3	33,3	55,3	43,8	43,7
Factor of idle time in emergency repair	K_e	%	30	10	10	8,3	22,2	8,3

In the illustrative purposes in (fig. 1), a-d laws of change K_u, T_u, δW_{on} and U_f on months of year are resulted.

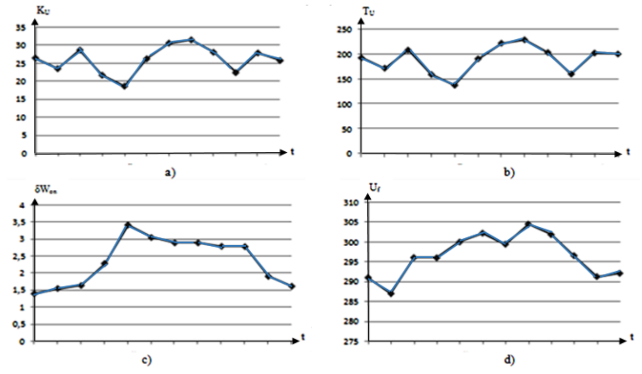

Fig.1. Dynamics of change TEP on months of year

Let's consider the problem on interrelation of these TEP. A necessary condition of an objective estimation of an integrated parameter is independence TEP [5]. In (table 4) results of calculation of factor of correlation Pirson (according to table 5) and Spirman (according to table 6) are shown. Considering, that number of realizations samples TEP equal 6 critical values of factors of correlation for criteria Pirson and Spirman identical and is equal 0,989, it is possible 0,05 [9] to approve with a significance value, that among analyzed TEP the interrelation is significant only for K_u and T_u, that proves to be true (fig.1) and formulas of their calculation. This method of the analysis refers to as a method of the decision of «inverse problem», when the result of one of comparisons and if it proves to be true is known in advance it is possible to trust and to other similar calculations of algorithm of calculation.

The above-stated testifies to inexpediency of sharing K_u and T_u for calculation of an integrated parameter.

Thus, the following independent TEP are a subject to the subsequent transformation: Δt_{sl}, U_f, δW_{on}, K_u and K_e

TABLE IV. RESULTS OF AN ESTIMATION OF FACTORS OF CORRELATION OF REALIZATIONS TEP

№	**Criteria**	**Serial number TEP**					
	Spirman / **Pirson**	**1**	**2**	**3**	**4**	**5**	**6**
1	T_{sl}	/////////	-	-	-	-	-
2	δW_{on}	0.877	//////////	0.571	0.557	0.571	0.657
3	U_f	0.401	0.165	//////////	0.214	0.600	-0.029
4	T_u	-0.530	-0.505	-0.849	//////////	0.843	0.557
5	K_u	-0.581	-0.505	-0.849	1	//////////	0.314
6	K_e	0.194	-0.212	0.634	-0.464	-0.465	//////////

III. RESULTS OF THE ANALYSIS OF AN OVERALL PERFORMANCE

In results of calculation of relative values TEP (table 5) under the formulas resulted in table 3 are resulted. As possible deviation TEP pays off concerning scope of their change these deviations, as a matter of fact, characterize size of deterioration PS. The size of the integrated importance of deterioration (In(Iz)) is more, the overall performance PS below. The average arithmetic relative deterioration characterizes a parameter of deterioration (Iz(PS)) as a whole. It is obvious, that both In(Iz) and Iz(PS) allow to range compared GPPS and to estimate overall performance PS.

In (table 6) results of calculation by an interval method of estimations of an integrated parameter of importance TEP, a serial number compared PS in ranging to a number and estimations of an overall performance considered GPPS as a whole are resulted.

In [4] it has been shown, that result of ranging PS in both ways differ: due to transformation to an interval method of continuous estimations TEP in discrete; results of ranging of integrated parameters of the importance discrete TEP, at small number TEP, happen are a little bit integrated. This distinction is observed and at comparison of (tables 5, 6).

The opportunity of sharing TEP concerns to greater advantages TEP with a discrete scale of measurement with a qualitative scale of measurement.

TABLE III. DATA ABOUT SETTLEMENT TEP GPPS

№	The name of a parameter	Symbol	Realization		Length individual interval	Intervals of change	The importance of an interval	The formula of calculation of a relative deviation
			min	max				
1	Service life, year	T_{sl}	0	35	7	≤ 7 8 - 14 15 - 21 22 - 28 > 29	5 4 3 2 1	$\sigma T_{сл} = \frac{T^{ф}_{сл} - T^{min}_{сл}}{T^{max}_{сл} - T^{min}_{сл}}$
2	The charge el. energy on o.n., %	δW_{on}	1,0	3,3	0,5	≤ 1.50 1,51 - 2,00 2,01 – 2,50 2,51 – 3,00 > 3.01	5 4 3 2 1	$\sigma\delta W_{сн} = \frac{\delta W^{ф}_{сн} - \delta W^{min}_{сн}}{\delta W^{max}_{сн} - \delta W^{min}_{сн}}$
3	The specific charge of conditional fuel, g/kWh	U_f	260	300	8	≤ 268 269 – 276 277 – 284 285 - 294 > 295	5 4 3 2 1	$\sigma У_{т} = \frac{У^{ф}_{т} - У^{min}_{т}}{У^{max}_{т} - У^{min}_{т}}$
4	Coefficient of use of the installed capacity, r.u.	K_u	0,23	0,70	0,1	≤ 0,33 0,34 – 0,43 0,44 – 0,53 0,54 – 0,63 > 0,64	1 2 3 4 5	$\sigma К_{и} = \frac{К^{max}_{и} - К^{ф}_{и}}{К^{max}_{и} - К^{min}_{и}}$
5	Factor of idle time in emergency repair, r.u.	K_e	0	0,5	0,1	≤ 0,10 0,11 – 0,20 0,21 – 0,30 0,31 – 0,40 > 0,41	5 4 3 2 1	$\sigma К_{ав} = \frac{К^{ф}_{ав} - К^{min}_{ав}}{К^{max}_{ав} - К^{min}_{ав}}$

TABLE V. RESULTS OF CALCULATION OF MONTHLY AVERAGE RELATIVE DEVIATIONS TEP

Parameters	Gas piston power stations					
	PS1	PS2	PS3	PS4	PS5	PS6
Service life	0,343	0,343	0,343	0,314	0,288	0,257
The charge el. energy on o.n.	0,261	0,352	0,443	0,239	0,100	0,100
The specific charge of conditional fuel	0,805	0,533	0,363	0,175	0,300	0,425
Coefficient of use of the installed capacity	0,904	0,802	0,761	0,313	0,557	0,560
Factor of idle time in emergency repair	0,600	0,200	0,200	0,166	0,444	0,166
Integrated parameter of the importance of deterioration	2,913	2,210	2,210	1,207	1,589	1,508
Integrated parameter of deterioration PS	0,583	0,442	0,424	0,242	0,318	0,302
Serial number PS in ranging to a number	6	5	4	1	3	2
Efficiency work PS	Satisf	Satisf	Satisf	Good	Good	Good

TABLE VI. AVERAGE MONTHLY OPERATIONAL EFFICIENCY OF A GPPS

Parameters	Gas piston power station						Total
	PS1	PS2	PS3	PS4	PS5	PS6	
Service life	4	4	4	4	4	4	*24*
The charge el. energy on o.n.	4	4	3	4	5	5	*25*
The specific charge of conditional fuel	2	3	4	5	4	4	*22*
Coefficient of use of the installed capacity	2	2	2	4	3	3	*16*
Factor of idle time in emergency repair	3	5	5	5	3	5	*26*
Integrated parameter of importance TEP	11	14	14	18	15	17	*89*
Serial number PS in ranging to a number	6	4-5	4-5	1	3	2	
Efficiency work	Satisf	Satisf	Satisf	Good	Good	Good	Good

Classification GPPS can be executed and on size of scope of an integrated parameter of some monthly average values. In table 7 values of an average quadratic $\sigma^*[\delta W_{on}]$, $\sigma^*[U_f]$, $\sigma^*[K_u]$ and factor of a variation of monthly average values TEP $r_{on} = \sigma^*[\delta W_{on}] / \delta W_{on}$, $r_f = \sigma^*[U_f] / U_f$ and $r_u = \sigma^*[K_u] / K_u$ within a year of work are resulted. On these data, ranging considered PS is lead. with which decrease in efficiency work PS conducts to increase in disorder TEP. According to (table 7), the greatest disorder is observed on PS1 and PS6, average disorder - on PS2 and PS3, and insignificant - on PS4 and PS5.

Table 7, shows an average quadratic deviation and factor of a variation of monthly average estimations TEP.

TABLE VII. STANDARD DEVIATION AND COEFFICIENT OF VARIATION OF AVERAGE MONTHLY ESTIMATES OF THE TEP

Parameters	**Symbol**	**Unit of measure**	**Gas piston power station**					
			PS1	PS2	PS3	PS4	PS5	PS6
The charge el. energy on o.n.	$\sigma^*[\delta W_{on}]$	%	0,67	0.67	0.42	0.39	0.25	0.37
	$\mathbf{r}_{on}$	r.u.	0,28	0.27	0.18	0.2	0.18	0.23
The specific charge of conditional fuel	$\sigma^*[U_f]$	g/kWh	4,97	6.60	5.78	3.43	2.88	6.94
	$\mathbf{r}_f$	r.u.	0,015	0.022	0.02	0.013	0.01	0.024
Coefficient of use of the installed capacity	$\sigma^*[K_u]$	r.u.	3,61	2.80	4.88	3.62	4.41	5.34
	$\mathbf{r}_u$	r.u.	0,13	0.099	0.15	0.066	0.097	0.127
Serial number PS in ranking to a number			5-6	3-4	3-4	1-2	1-2	5-6

Certainly, operational and to operation personnel PS, as well as management PS and a power supply system methodical support which essence is reduced to an estimation of technical condition PS, results of its comparison with an efficiency work of others similar PS, data on «weak parts» and to it similar data is desirable.

Below the sample of results of the automated analysis of monthly average values, TEP is resulted. These results can serve as the basic document at carrying out recommended by Rules of technical operation of monthly discussion of data TEP and methodical support of accepted decisions.

IV. CONCLUSION

1. The method and algorithm of an estimation of an integrated parameter overall performance gas piston power stations are developed;
2. The integrated parameter allows:
   – to range compared gas piston power stations on an overall performance, reflecting their reliability and profitability;
   – to estimate in five-point system an overall performance gas-piston power station;
   – the mechanism of practical use of this method is developed
3. Increase of an overall performance gas piston power stations is reached by the monthly notice of the management of a power supply system and power stations results of the analysis of technical and economic parameters that provides necessary methodical support at the decision of operational problems;
4. Along with monthly average values of technical and economic parameters the important role is played with sizes of scope of these parameters. Equality of monthly average values of technical and economic parameters yet does not mean equality of an overall performance of power stations. The scope is more the technical condition is worse. Decrease in scope leads to increase of an overall performance.

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