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GENERAL PRINCIPLES OF OBTAINING SITUATIONAL ESTIMATES OF THE EQUIPMENT OF COMPLEX STRUCTURES OPERATION MODES

Abstract. The article is devoted to solving problems of creating methods for situational management of Complex Structures Operation Modes. The general principles of obtaining situational estimates of the operational status of power plant equipment are considered. The division of the situational management process into the main stages related to the operational reliability of the plant blocks was accomplished. When estimating a larger (almost unlimited) number of factors, a modified method of obtaining weights using a three-point system can be used. The procedure for obtaining expert estimates by the method of successive preferences is formulated, based on the interpretation of the Cherchmen-Akoff procedure (sequential preference procedure) with computer implementation.

Key words: factors, management, situation, power plant, situational control, object of control, efficiency of functioning, control procedure, reliability, control parameters.

General principles for obtaining situational assessments of the operational status of power plant equipment can be summarized in a series of symbolic expressions by means of which it is possible to describe the process of controlling the power plant (1-5), allows us to approach the assessment of the operational state of the equipment operating on it from the point of view of the situational approach. The current situation at the stations SЭt and S is determined by a number of economic parameters and reliability parameters Rэ* and Rн* which characterize the actual state of the operating equipment at time t. In this connection, a natural question arises about the dimension of the regime parameters, the control of which makes it possible to determine Rэ* and RH * and to obtain on their basis estimates of the situations SЭt and SHt according to (1).

$$S: St \times SЭt \times SHt\ U * \rightarrow SCt + 1\ , \tag{1}$$

where S is the complete situation (by definition);

St is current situation in the PP, formulated in the form of requirements that are required for the operation of the power plant under the conditions of covering the active and reactive loads; $S^{H}_{t}, S^{Э}_{t}$ are current situations associated with the actual mode of the plant, which are determined by the economy and reliability of equipment operating on it; U * is vector of multipurpose management; SCt + 1 is the new current situation at the plant as the Cartesian product of the preceding ones.

Under normal PP operation conditions, a cartesian product will be understood as a conjunctive convolution of current situations:

$$S^{C}_{t+1} \supseteq S_t \times S^{Э}_{t} \times S^{H}_{t} = \inf (S_t, S^{Э}_{t}, S^{H}_{t}). \tag{2}$$

Since the change in the current situation is made in this case by changing the composition of the power plant equipment, then the projection of these situations takes place in the general, regime space Ω, i.e.

$$\mathrm{Proj}(S^{C}_{t+1}) \supseteq \mathrm{Proj}(S_t) \cap \mathrm{Proj}(S^{Э}_{t}) \cap \mathrm{Proj}(S^{H}_{t}). \tag{3}$$

The format of the projections is determined both by the type of management U *, and the information level of the description of current situations, as noted above. The formation of the multipurpose management of vector U * within the framework of the described process is a multipurpose convolution of the form:

$$U^{*}= DE(KS_{t}, KS^{Э}_{t}, KS^{Н}_{t}), \quad (4)$$

where DE are defined by some logical-multiple operation, with the help of which the goals or criteria KSt, $KS^{Э}_{t}$ and $KS^{Н}_{t}$ are rolled up.

In the decision making process we usually consider as binary [1,2], we rewrite (4) in the following form:

$$U^{*}= DE_{1}[DE_{1}\ (KS^{Э}_{t}, KS^{Н}_{t}), KS_{t}]. \quad (5)$$

Here it is important to note that the convolutions DE1 and DE2 in (5) can in general be different. The system of expressions (1-5) is a formalized description of the process of managing a power plant from the standpoint of a situational approach. Change of the current situation at the plant is carried out in this case by changing the composition of the equipment running on it as one of the phases of operational management. In the very designation of the system of operational control of the number and composition of hydroelectric units, two interrelated aspects of management are objectively laid. On the one hand, this is an automatic regulation of the aggregate mode by working out the number, composition and distribution of the load between the units, this regulation is undoubtedly an integral part of the regime automation of the HPP. On the other hand, it is operational dispatch control, which is determined by the current changes, both the modes of the hydrounit and the plant. Here the main means of control is not so much the regime automatic (which carries out the process of regulation), but the ability of the person to make decisions. This duality was reflected even in the name of these devices: an automatic operator and rational management of the composition of aggregates. Both these names speak of the hybrid nature of such a management system. The first is in the immediate compound title, the second is through the concept of rational, that is, weighted effective.

The main characteristic, by means of which the economic work of the unit at the station is estimated, is the amount of energy resource consumption (water flow at the hydraulic unit or fuel consumption at the thermal unit) or its efficiency, which can be recalculated into cost parameters, for example, the costs associated with the production of energy at the plant [1]. Thus, if the actual efficiency of the block at time t is determined (**ηt**), then an economic evaluation of its operation mode can be obtained in the form

$$\mathbf{R}_{э}^{*}= \eta t\ . \quad (6)$$

Such a characteristic as the efficiency of the block based on the construction of its economic characteristics has been worked out quite fully, although the practical implementation encounters a number of intractable problems [2 ... 7]. Using a situational approach allows them to be successfully overcome. In contrast to the economy, the regime parameters characterizing the operational reliability of the unit are quite numerous. They form a multidimensional space of the form

$$R_{н}^{*}= (R_{m}^{*}, R_{в}^{*}, R_{эл}^{*}, R_{у}^{*}, R_{пр}), \quad (7)$$

where R_{m}^{*}, $R_{в}^{*}$, $R_{эл}^{*}$, $R_{у}^{*}$, $R_{пр}$ are parameters of temperature, vibration, electrical states, parameters characterizing the deviation of water and oil levels, air pressure at the monitored units of the unit, and a number of others. In principle the current deterioration of the unit can be used as a universal parameter characterizing the operational reliability of the unit operation, similar to the efficiency in assessing its efficiency. However, this complicated problem has not yet been solved methodologically. Absence of strict models for calculating the current wear of the power block makes it necessary to take an indirect account of operational reliability on the basis of control, and to change the numerous parameters in accordance with (6). This requires the development of special procedures for obtaining them, bringing the parameters to a single dimension, as well as ranking the monitored parameters, since the degree of their information value for decision making in the operational management loop is generally different.

Assessment of the importance (weight) of the monitored parameters of the unit, regardless of the current situation, but determined only by the degree of responsibility of control, behind a separate unit of the hydrounit. Such an assessment can be called "basic":

$$B(П_i)= (R_н^*, i =1, …, n), \quad (8)$$

where i is the number of the monitored parameter П, which determines the operational reliability of the unit $\mathbf{R}_н^*$.

Obtaining "current" estimates that characterize the degree of operational reliability of the unit at the time of acceptance of t. Obviously, these estimates are directly determined by the current situation at the plant.

$$T(П_i)= (R_н^*, j =1, …, к), \quad (9)$$

where j is the number of the monitored parameter П, the value of which at current time t deviates (or does not deviate) from the nominal value.

Determination of "resulting" estimates of operational reliability for each currently operating hydraulic unit. They can be obtained by imposing "current" estimates of controlled parameters on their "basic", in particular, as a product:

$$J(П_i)= (R_н^*, B(П_i) \bullet T(П_i), i = 1, …, n). \quad (10)$$

This will mean the formation of a certain level of description, which is the projection of the map f_1 in the general information space of the plant's regime parameters. Based on J ($П_i$), the DMO can make a decision related to changing or not changing the mode of the equipment running on the plant. In order to implement these steps, which are related to the operational reliability of the plant units, it is necessary to determine those sources of obtaining primary information, on the basis of which the above-mentioned indicators can be calculated, and subsequently used in the operational dispatching management of the plant from the positions of the situational approach. By methods of control and value, the information obtained on the operational status of the main equipment of a hydroelectric station can be divided into 3 main groups [1-8]:

a) automatic control for the operational state of HPP equipment using relay protection and automation devices;

b) periodic monitoring of the operational status of the equipment by semi-automated means by plant personnel or using an automated control system;

c) control checks and tests of units, elements and parts of the main equipment of hydroelectric power stations.

Let us dwell on each of these groups. Specific diagnostic information on the state of the elements of the nodes of the unit block is provided by relay protection and automation devices that monitor deviations (within the limits of permissible or emergency), temperature, electrical, chemical and other parameters of the regime from their normal value. The monitoring of the condition of relay protection devices is carried out automatically, according to the principle of "yes-no", that is a certain parameter of the regime deviates from the norm. The emergency deviations of the parameters of the regime are characterized by the unequivocal action of the relay protection devices to disconnect the equipment, which allows to stop the further development of the accident on it. Deviations of parameters close to emergency settings, but not exceeding them, are fixed by a warning signal. The appearance of a warning signal indicates abnormal operating conditions of the equipment and forces operational personnel to make a specific decision aimed at eliminating the cause of the signal.

Since the warning signal is not emergency, control aimed at preventing an emergency may be called preventive control in normal modes. The warning signaling covers almost all the elements of the aggregate block and its auxiliary equipment, which means that it is possible to obtain a practically complete volume of diagnostic information, its operability [1-8]. In addition to Relay Protection and Automatic Equipment, periodic monitoring of the state of assemblies and elements of the main equipment is carried out by means of standard measuring sensors in a semi-automated way by plant personnel, or by means of an automated control system. With its help it is possible to carry out not only check of the facts of functioning of equipment elements (for example, as the fact of operation of preventive protections), but also to receive an objective volumetric quantitative estimation on average size and dispersion of the measured parameter. This is due to the fact that the measuring sensors are installed at many points of the monitored element and their number, as a rule, considerably exceeds the number of RPA sensors. The value of information obtained on the basis of periodic monitoring is both in quantifying the current state of the equipment, and in the possibility of using it for forecasting the state in future periods of operation.

Questions of methodology and practice for assessing the state of equipment for a system of control checks and tests have been developed quite thoroughly. Control checks and tests are carried out after the vibration state of the hydraulic unit as a whole and its individual components and parts. In contrast to periodic monitoring, inspections and tests are much less frequent: when starting up and adjusting the hydraulic unit, preventive and diagnostic tests, in the output for repair to clarify its volume and commissioning after repair to assess its effectiveness, as well as for special tests. It should be noted the special importance of vibration control. In particular, with its help it is possible to increase the reliability of the diagnosis, i.e. identification of the place, nature and extent of damage to the generator. Despite the attractiveness of obtaining the most accurate and complete characteristics of the operational state of the equipment, with the help of tests, it is first and foremost necessary to further improve and develop operational methods and standard monitoring tools, in order to detect the faults that have arisen with quite high accuracy at early stages of their development. In addition, the diagnostic information obtained as a result of control checks and tests, quickly becomes obsolete, which requires its current refinement and correction. Thus, the system of existing control, due to the operational reliability of the unit, allows obtaining diagnostic information about the state of the equipment that can be used in the preventive management of the equipment operating at the plant [1-8].

Basic estimates of operational reliability of hydraulic units, determined on the basis of the fact of operation of preventive protection. Sufficiently objective information about the current operational status of the equipment is provided by the operation of relay protection and automation devices. To account for the condition of the equipment in the normal mode of operation can be limited to information obtained on the fact of the warning alarm on the hydraulic units. Therefore, if a system of information analysis of the fact of the operation of preventive protection is created, it is possible to obtain estimates of the operational state on the basis of sufficiently representative information.

The idea of such an analysis is as follows. Any precautionary protection, when triggered, causes a different response in the DMO. This is because the importance of the information obtained for DMO depends on which or what protection has worked. In other words, each preventive protection has its own "information weight". Therefore, to implement the analysis, it is necessary to weigh all preventive protections in terms of their effect on the operational reliability of the entire aggregate unit. As a procedure allowing to carry out the process of "weighing", you can use the method of expert assessments [6-9].

At a number of hydro power stations, studies were carried out aimed at obtaining "weights" of warning signaling using the emergency assessment procedures [6-8]. Let us formulate the purpose of such an examination. Using the proposed list of protections, operational personnel should assess the importance of each protection, in terms of deciding whether to stop or replace hydraulic units [6-9]. For example, if from the DMO point of view, the signaling about the rise in the temperature of the footplate of the hydrogenerator affects the operational reliability of the generator to a greater extent than the signaling about the inclusion of a reserve oil pump, then the weight of the first protection should be higher. The degree of difference in "weights" in the general case is determined by experience and established norms of management, as well as the procedure used to obtain expert estimates.

Table 1 shows the total "weights" of precautionary protection in percentages of the elements of the aggregate block. Total "weights" of elements such as turbine, turbine bearing and so on, were 2-3 times less than those allocated. The allocated elements of the aggregate block made it possible to determine the most important operational factors (by the "weight" of the preventive protection included in them), characterizing the operability of the main units of the hydrounit and the block transformer. To the same group of factors, undoubtedly, it is necessary to include the vibrational state of the hydroelectric unit, the influence of which was not considered here due to the absence of standard vibrating sensors at the present time. The analysis of the received information showed that more than 60% of the "weight" of all preventive protections is related to the operating conditions of the block transformer, thrust bearing, bearing and winding of the generator. It is obvious that such a control method, under the operating condition of the hydraulic unit, provided that the "weight" scale of specific factors is obtained, allows using them in the decision-making process of the DMO on changing the operation mode of HPP [12].

Table 1 – Total "weights" of precautionary protection for the elements of the aggregate block in percent

Element of the aggregate block	HPP		
	Novosibirsk	Krasnoyarsk	Votkinsk
Block transformer	24,17	26,48	22,43
Winding of the generator	13,12	20,64	17,31
The thrust bearing of generator	18,21	17,01	14,31
Bearing of the generator	11,48	9,05	10,01
The amount of "weight"	66,98	73,18	64,06
Turbine	5,8	6,74	5,61
Turbine bearing	4,27	3,77	6,34
Other elements and ancillary equipment in the amount of	22,95	16,31	23,99

Let us dwell on the procedures for obtaining expert estimates and on the possibility of their adaptation to the conditions of operational management of the plant regime. Expert assessments relate to the class of heuristic information and give the opportunity to obtain various factors of importance or weight, using both the accumulated experience of the DMO, as well as a deep knowledge of the specifics of the equipment used. Therefore, the information obtained in this way has great managerial value, since it represents its qualitative characteristic, which can be expressed by a numerical measure called the weight [18]. The resulting group assessment of factors should be characterized a sufficient degree of agreement among experts on the parameters being evaluated. At the heart of expert estimates of the acquisition are some common properties.

Each event or factor corresponds to a real nonnegative number V, which is regarded as the true significance (value, utility) of this event (factor) 0, i.e. some number corresponds to some V. If the event (factor) Oj is more important than the factor O_k, then $V_j > V_k$. If the factors considered are equivalent, then $V_j = V_k$. If the estimates V_j and V_k correspond to the factors O_j and $O_к$, then (V_j+V_k) corresponds to the general result of O_j and $O_к$. This is a property of additivity of estimates.

First of all, it should be noted that the use of a procedure is determined by the number of factors assessed, provided that the expert group meets all the requirements: the number and competence of [10-12]. In the case of a significant number of factors considered (> 20), it is advisable to use either a paired comparison procedure or its interpretation (for example, a three-point evaluation procedure). If the list of factors does not exceed 15 ... 20 titles, the most effective weighing procedure is the successive preference procedure (the Churchman-Akoff procedure).

The procedure of pairwise comparisons of all factors is performed in pairs in order to establish the most important factor in each pair. If the factor A_i is more preferable than the factor A_j, then the estimate V_i is 1, and V_j is 0.

The results of the comparison are recorded in the matrix of paired comparisons, table 2. The matrix is square with an unfilled main diagonal, since the comparison of the factor with itself does not make sense. The expert evaluates the factors horizontally, the matrix corresponds to the following comparison results: factor A_1 is less preferable than A_2, A_3, A_4 and is more preferable than A_5; factor A_2 is more preferable than A_3, A_4, A_5, factor A_3 is more preferable than A_4, A_5, factor A_4 is more preferable than A_5.

Table 2 – Matrix of paired comparisons for five factors

Factor	A_1	A_2	A_3	A_4	A_5	Sum of scores
A_1	–	0	0	0	1	1
A_2	1	–	1	1	1	4
A_3	1	0	–	1	1	3
A_4	1	0	0	–	1	2
A_5	0	0	0	0	–	0

The results of the comparison show that the expert assigned the highest score to factor number 2 (the sum of points is 4), and factor 5 was, in his estimation, generally insignificant (the sum of points is 0). It should be noted a special case when, according to the expert, none of the factors considered in the pair has a preference, i.e., the i-th and j-th factors are equivalent. Then the estimate for them can be formed as follows:

$$V_i = V_j = 0{,}5. \quad (11)$$

The formalized procedure for obtaining expert estimates by the method of successive preferences, based on the interpretation of the Cherchmen-Akoff procedure (the procedure of successive preferences), specially developed for computer implementation. It should be noted that expert evaluations are more qualitative in terms of information completeness, if the weighing is carried out by the method of successive preferences. This procedure makes it possible to obtain "weights" taking into account that the weight of the highest priority protection can be less (more) of the sum of the "weights" of less priority. Thus, the received "weights" possess property of the integrated estimation that is their main advantage at decision-making at plant.

Suppose there are n factors that need to be weighed: O_1, O_2, …, On. One of the factors is assigned a baseline score (weight). Let the factor O_1 be assigned V_b. Factors are placed in order of priority, where the first priority is the most priority factor, and the latter is the least priority. For the sake of simplicity of the subsequent arguments, we assume that the ranked series of factors is the series O_1, O_2...On, i.e. so they were placed by an expert. The expert compares each priority factor with the sum of other, less priority ones. As a result of this consideration, the following inequalities are formed (in the particular case this may be equality). Suppose we have received such a set of conditions:

$$\begin{gathered} O_1 \underline{><} O_2 + O_3 + \ldots + O_n, \\ O_2 \underline{><} O_3 + O_4 + \ldots + O_n, \\ O_{n-1} \underline{><} O_n. \end{gathered} \quad (12)$$

At this point, the expert's work ends and computer processing takes place, consisting of two calculation procedures. Procedure 1. Inequalities of the form (11) are replaced by the equalities:

$$\begin{gathered} O_1 = O_2 + O_3 + \ldots + O_n, \\ O_2 = O_3 + O_4 + \ldots + O_n, \\ O_{n-1} = O_n; \end{gathered} \quad (13)$$

26-13 From the system of equations (13) is the weight of the least priority factor, which we call a, equal in this case to the weights of the factors O_n and O_{n-1}, i.e. a=V_n= V_{n-1}. Solving this system, we can obtain the value

$$a = V_б / 2^{k-2}, \quad (14)$$

where V_δ is base estimate; k is the number of factors considered. Weights of other factors are determined by the formula:

$$x_b = a \cdot 2^{b-2}, \quad (15)$$

where b is the ordinal number of the factor in the back-ranked series.

Procedure 2. The received estimates are adjusted in accordance with the conditions (15). Consideration of inequalities necessarily holds from below - upwards. The correcting term for the i-th factor is determined from expression

$$\Delta V_i = (V_{i+1} + V_{i+2} + \ldots + V_n) / C, \quad (16)$$

where C is an integer that scales the difference in the estimates of the weights obtained. Further, the estimation of the i-th factor is corrected.

If the inequality has the form $V_i > V_{i+1} + V_{i+2} + ... + V_n$, then it is replaced by an equality of the form:

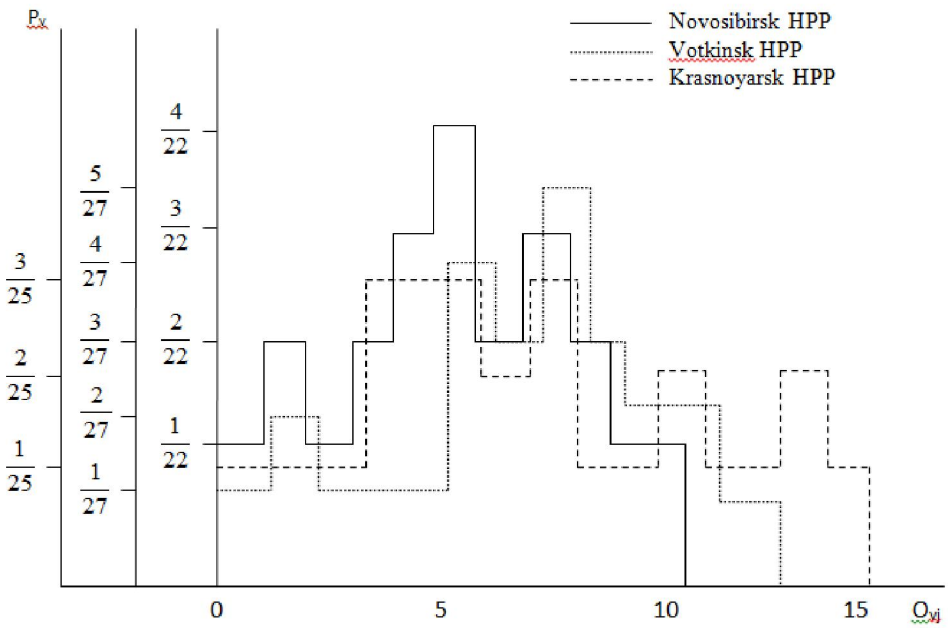
$$V_i = V_{i+1} + V_{i+2} + ... + V_n + \Delta V_i . \quad (17)$$

If the inequality has the form $V_i < V_{i+1} + V_{i+2} + ... + V_n$, then it is replaced by the following equation:

$$V_i = V_{i+1} + V_{i+2} + ... + V_n - \Delta V_i . \quad (18)$$

Consistently going from bottom to top, we pass to the following inequality of the form (18). Then these assessments are checked for statistical reliability, normalized and used in further work.

Procedure of a three-point evaluation. The processing of the results of the examinations carried out according to the formalized procedure of consecutive preferences for the Novosibirsk, Votkinsk and Krasnoyarsk hydropower stations made it possible to construct histograms – the distribution of weights for the list of factors (preventive protection) in question, which are shown in figure. Analysis showed that weight estimates can be assigned to one of three groups: priority, equal-priority and non-priority [6].



Graph of changes in the density of weight indicators

The weightings of the priority and non-priority groups have the lowest density of estimates. This suggests that the weights in these groups differ sharply. The density of the weights in the equal-priority group is much higher. From this it follows that the priority (weight) of factors in different groups is felt by experts in different ways: for the priority and non-priority groups, the experts' assessments are more delineated, for the equal priority, they are more blurred. Thus, when estimating a larger (almost unlimited) number of factors, a modified method of obtaining weights using a three-point system can be used: priority factors receive a score of 3, priority factors are rated at 2, and non-priority ones score 1. This method was used to assess preventive protection at Votkinsk HPP (39 items). Based on these considerations, and considering that these estimates should be recalculated periodically, the general procedure was adopted as a one-step procedure. The developed software package allows you to obtain expert estimates on the factors of interest to the DMO, as well as to calculate the qualitative characteristics of the expertise.

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ҚИЫН ҚҰРЫЛЫМДЫ ОБЪЕКТІЛЕРДІҢ ҚҰРЫЛҒЫЛАРЫНЫҢ ЭКСПЛУАТАЦИОНДЫ КҮЙІНІҢ ЖАҒДАЙЛЫҚ БАҒА АЛУЫНЫҢ ЖАЛПЫ ПРИНЦИПТЕРІ

Аннотация. Мақала қиын құрылымды объектілерді басқару әдістерін құру сұрақтарына арналған. Электростанция құрылғыларының эксплуатационды күйлеріне жағдайлық баға беру принциптерінің жалпы сұрақтары қарастырылды. Станция блоктарының эксплуатационды беріктілігін ескере отырып, жағдайлық басқаруды процессі негізгі бөліктерге бөлінді. Бағалау кезінде әсер ететін факторлардың саны тым көп болса, үш балды жүйе бойынша модификациялы әдіс қолданылады. Компьютермен іске асатын Черчмен-Акофф процедурасының (тізбектей қалайлар процедурасы) интерпритациясы негізінде тізбектей қалаулар әдісі арқылы эксперттік баға алу процедурасы анықталды.

Түйін сөздер: факторлар, басқару, жағдай, электр станциясы, жағдайлық басқару, басқару объектісі, жұмыс істеу тиімділігі, басқару процедурасы, беріктілік, басқару параметрлері.

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ОБЩИЕ ПРИНЦИПЫ ПОЛУЧЕНИЯ СИТУАЦИОННЫХ ОЦЕНОК ЭКСПЛУАТАЦИОННОГО СОСТОЯНИЯ ОБОРУДОВАНИЯ СЛОЖНЫХ ПО СТРУКТУРЕ ОБЪЕКТОВ

Аннотация. Статья посвящена решению вопросов создания методов ситуационного управления объектами со сложной структурой. Рассмотрены общие принципы получения ситуационных оценок эксплуатационного состояния оборудования электростанций. Выполнено разделение процесса ситуационного управления на основные этапы, связанные с учетом эксплуатационной надежности блоков станции. При оценке большего (практически неограниченного) числа факторов можно использовать модифицированный метод получения весов по трёхбалльной системе. Сформулирована процедура получения экспертных оценок методом последовательных предпочтений на основе интерпретация процедуры Черчмена-Акоффа (процедура последовательных предпочтений) с компьютерной реализацией.

Ключевые слова: факторов, управление, ситуация, электрическая станция, ситуационное управление, объект управления, эффективности функционирования, процедура управления, надежность, параметры контроля.

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