EXAMPLES OF CREATIVE THINKING

MULTICRITERION ANALYSIS IN TECHNICAL-ECONOMIC CALCULATIONS OF HYDROPOWER AND WATER-MANAGEMENT FACILITIES

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One of the most important and pressing problems of improving the technical-economic apparatus in the power industry is a revision of pricing. The existing systems of rates for electricity no longer corresponds to the established costs of energy resources, construction materials, and equipment. Another no less important aspect of the problem is consideration in electricity rates of its quality. The economic measures on stabilization of the frequency of the current undertaken by the USSR Ministry of Power and Electrification (Minénergo) in the past 2 years showed that economic leverage is an effective means in solving technical problems. The use of self-financing when substantiating the effectiveness of facilities being newly created or reconstructed requires a more detailed consideration of the operating regimes of power stations, including when maneuvering the capacity. When solving this problem a differentiated approach is needed to an economic evaluation of electric energy and power, which is generated according to a variable load curve in conformity with the planned regime or in a regime of prompt regulation of random loads – maintenance of the frequency of the current and voltage, control of interconnected systems, emergency loads, etc. Performance of the latter functions by hydrostations and pumped-storage stations requires the creation of highly maneuverable equipment with an increased operating life in start-stop and transient regimes. The creation of such equipment is related to a substantial increase of expenditures on increasing its reliability. An economic effect from its introduction can be achieved only by introducing a differentiated calculation with consideration of the functional characteristics of the power stations in the power system.

In the case of the multipurpose use of water resources, the introduction of self-financing is still more significant. If a multipurpose hydro development is constructed by a department of the power industry, then incorporation into a water-management complex (WMC) should be carried out only under the condition of the participation of the appropriate ministries and departments in financing the construction and operation of common structures of the hydro development – dam, reservoir, outlet works, etc. Expenditures on compensation of the lands being submerged when creating a reservoir are included in the estimate of constructing the hydro development. But in a number of cases reservoirs by means of irrigation and additional water supply make it possible to convert arid and semiarid lands into a highly productive land fund. Conditions are thereby created for obtaining high yields of valuable crops and construction of cities, towns, industrial centers, etc., with all proper amenities.

The cost of the productive land fund being created should be transferred by the appropriate ministries and departments to the account of the ministry constructing the multipurpose hydro development, for example, to the account of Minénergo.

If a multipurpose hydro development is being constructed, more exactly financed, by the USSR Ministry of Reclamation and Water Management (Minvodkhoz) and a hydroelectric station is constructed at the hydro development, then Minénergo should finance not only the construction of the powerhouse of the hydrostation with the equipment but should also share in financing the construction and operation of common structures of the hydro development – dam, reservoir, outlets, etc. It is clear from the aforesaid what significance the problem of self-financing and self-supporting has for the hydropower industry.

The use of renewable hydropower resources has still not obtained complete consideration of its national economic importance in the methods and instructions on planning. The economic problem of renewable and nonrenewable energy resources is practically not taken into account. Furthermore, even the actual capital investments in construction and operation when comparing a hydrolectric station (HES) and condensing steam power station (CSS) are not completely revealed, as a result of which the national economic effectiveness of using renewable hydropower resources is not completely revealed.

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TABLE 1

V_i	V_1	V_2	V_3	Points	Evaluation of significance
V_1	0,5	1	1	2,5	0,56
V_2	0	0,5	1	1,5	0,33
V_3	0	0	0,5	0,5	0,11
Total				4,5	1

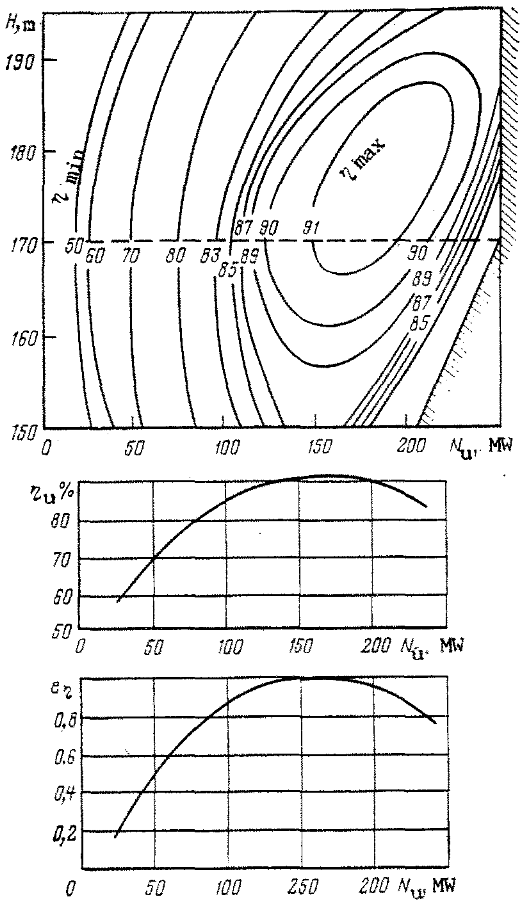

Fig. 1. Operating characteristic of the unit of the Chirkey hydrostation with respect to efficiency (H = 170 m).

In the existing instructions capital investments in fuel production and its maintenance during the service life of a thermal power station are still not taken into account in an explicit form when comparing thermal power stations with hydroelectric stations. Wrong ideas about the comparative cheapness of CSS in comparison with HES are thereby created. The specific capital investments per kilowatt of installed capacity of a thermal power station using fossil fuel (without investments in the fuel facilities and transport) are almost always less in comparison with a hydroelectric station. Therefore, Minénergo, receiving a plan of putting the capacities of power stations into operation with the allocated capital investments inevitably should give preference to the construction of CSS.

In an integrated approach to the development of the power industry, Minénergo ought to allocate means for participating in the financing of the construction of the fuel facilities, fuel transport, and investments for maintaining fuel production during the entire operating period of the CSS.

The corresponding means should be entered as a separate item in 5-yr plans.

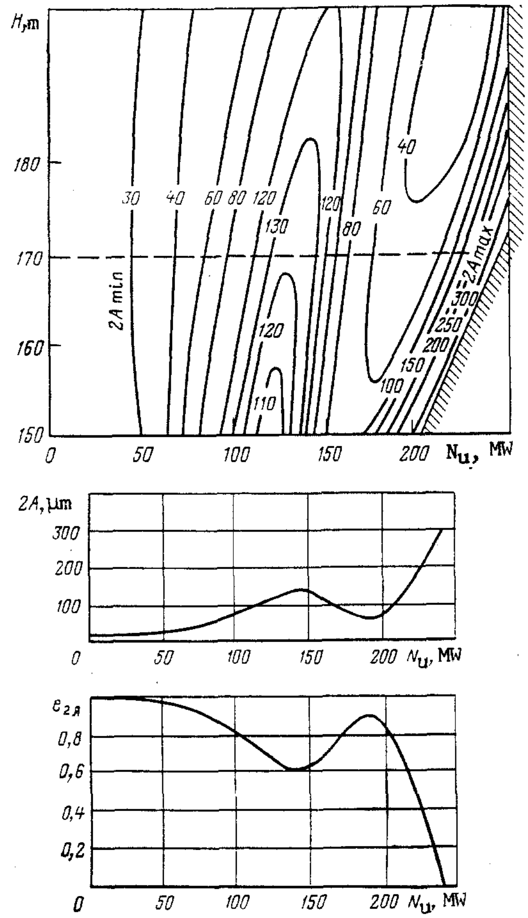

Fig. 2. Operating characteristic of the unit of the Chirkey hydrostation with respect to vertical vibration (upper crosspiece).

After converting Minénergo to complete self-financing the problem of fuel provision of power stations should obtain the proper economically substantiated solution. Explicit consideration of investments in fuel production and transport will make it possible to dispel the myth about the "cheapness" of thermal power stations: "When planning investments it is necessary to take into account that for replacing each ton of reference fuel fourfold less invesments are needed in the hydropower industry than for the same increase of the production of oil and twofold less than in the coal industry. This is explained by the renewability of hydropower resources, by the possibilities to maintain the achieved level of power production without any expenditures in contrast to the production of fossil fuels,* The aforesaid permits considering necessary the improvement of the methods of techinical—economic substantiation of hydropower facilities.

The use of the methods of dynamic discounted costs calculated with consideration of the time factor was a considerable contribution to the method of technical—economic calculations in the power industry. If the variants being compared are characterized by different investments and annual outlays and times of constructing and mastering the facilities, then under other identical conditions the optimal variant can be selected according to the criterion of the minimum dynamic discounted costs

$$\bar{C}_\tau = \sum_{t=1}^{T} (E_s K_t + \Delta O_t)(1 + E_{s.d})^{\tau - t} \to \min, \qquad (1)$$

where K_t and ΔO_t are the capital investments and increment of the annual outlays in year t; E_s, standard comparative profit-to-additional investment ratio; $E_{s.d}$, standard present value

*A. A. Troitskii, Planovoe Khozyaistvo, No. 10 (1984).

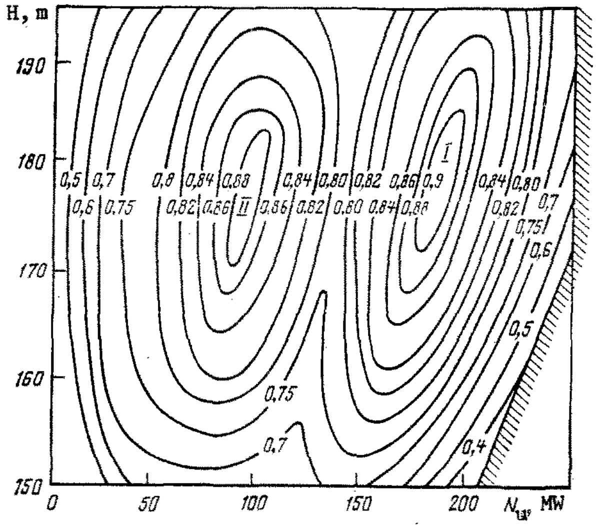

Fig. 3. Integral operating characteristic of the unit of the Chirkey hydrostation.

factor (a coefficient taking into account the time factor); τ, year of discounting, which should be the same calender year for all variants; T, time of constructing and mastering the facilities. In this method one goal is set – minimization of the discounted costs. other factors – social, nature conservation, fuel-saving policy, etc. – are taken into account only in the form of constraints. Renewability and nonrenewability of the energy resources being used are not taken into account economically, the effect of individual types of power stations on the quality of electricity and vitality of the power systems is not additionally taken into account. The economic effect from maneuverability is estimated roughly only for a pumped-storage station. The high maneuverability of hydroelectric stations is not taken into account.

The method of minimum discounted costs is theoretically applicable under the condition that all other goals are equally provided in all variants being compared. The impossibility of equal attainment of certain goals is replaced by the requirement of satisfying the corresponding standards, for example, meeting the standards on wastewater treatment, etc. But such goals as minimization of the consumption of fossil fuel, provision of vitality of power systems, working conditions in the production of fuel, of the operating personnel of CSS and HES, etc., which wehn comparing a HES with a CSS have not obtained due reflection in the method of discounted costs, still remain.

Under present-day conditions, when restructuring of the economy is being carried out with all invariability, a broader formulation of the problem of substantiating the construction of hydropower facilities and optimization of their operation is necessary. It is necessary to introduce a method of multicriterion optimization in the hydropower industry and water management. The problem of the optimal provision of the set of several goals – economic, social, defense, nature conservation, quality of electric power, savings of nonrenewable resources, savings of labor resources, increase of labor productivity at a CSS with fuel production and at HES – is solved in the method of multicriterion optimization. One of the goals, which in a number of cases is considered most important, is minimization of discounted costs. Certain goals can be conflicting, for example, minimization of costs and reduction of damage inflicted on nature.

The index of multicriterion effectiveness is the coefficient

$$E_j^* = \sum_{i=1}^{n} V_i l_{ji}, \tag{2}$$

where E_j^* is an integral index of multicriterion (multigoal) effectiveness of variant j; V_i is a weight coefficient or estimate of the significance of the goal i; ℓ_{ji} is the estimate of the effectiveness of variant j with respect to attaining the goal i.

Usually the numerical value of the weiggt coefficient V_i is determined in fractions of unity, then $\sum_{i=1}^{n} V_i = 1$

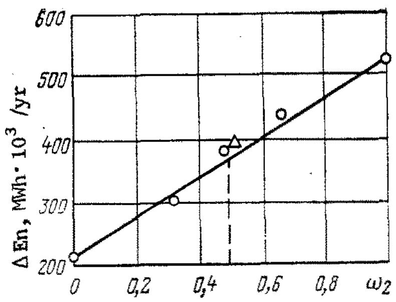

Fig. 4. Annual energy losses of the Chirkey hydrostation for a different structure of the criterion of quality of the units.

For an ideal variant, for which all goals are completely satisfied, the value $E^* = 1$. For real variants $E^* < 1.0$. The largest value of E^* determines the best variant in which the set of established goals is optimally satisfied.

The optimality criterion can be written in the form

$$E^* \rightarrow \max .$$

On the domain of definition of index E are imposed constraints with respect to the conditions of the prescribed consumption of electricity, permissible parameters of individual power facilities, etc.

In the simplest cases the values of ℓ_i for the parameters being minimized, for example, the discounted costs, are determined by the ratio $\ell_{j\mathrm{cost}} = \bar{C}_{\min}/\bar{C}_j$, and for those being maximized, for example, maneuverability of the power system ε, $\ell_{j\mathrm{man}} = \varepsilon_j/\varepsilon_{\max}$.

In the case of a large number of variants, for increasing the accuracy of the calculations the values of ℓ_{ji} are determined from the difference of the limit values of the corresponding indices, for example,

$$l_{j\mathrm{cost}} = \frac{\bar{C}_{\max} - \bar{C}_j}{C_{\max} - C_{\min}};$$

$$l_{j\mathrm{man}} = \frac{\varepsilon_j - \varepsilon_{\min}}{\varepsilon_{\max} - \varepsilon_{\min}}.$$

There are other complex determinations of ℓ_{ji} or combined determination of $v_i \ell_{ji}$. If in all variants all goals except the discounted costs are equally satisfied, then according to the multicriterion method the most effective will be the same variant as according to the method of minimum discounted costs.

The difficulties of using the method of multicriterion optimization consists in estimating the values of the weight coefficient V for the prescribed goals.

There exists different methods of determining the significance of the criterion functions in model (2). One of the most common is based on Delphi (expert evaluation) methods. The simplest are the ranking and pair comparison methods [6]. We will examine the basic principles of expert evaluation by these methods for an example.

Suppose a multicriterion evaluation of various design is being carried out with respect to three criteria: 1) cost savings; 2) quality of product; 3) impact on the environment. In the compared variants of the designs the indices characterizing the cost effectiveness of investments, quality of the product being produced, and the effect on natural objects are within permissible limits (standards). The problem is to select that variant which makes it possible to improve the design jointly with respect to the three criteria. We denote: V_1 is the evaluation of the significance of the criterion of minimum cost; V_2 is the same for the criterion of maximum quality of the product; V_3 is the same for the criterion of minimum anthropogenic influences on nature.

The method of ranking the criteria according to their significance in evaluating the design presumes arranging the criteria in descending order of their importance, for example, $V_1 > V_2 > V_3$. The numerical value of the coefficient V_1 is assigned inversely proportional to the place occupied in the ranking series, i.e., in the given case $V_1' = 1$, $V_2' = 1/2$, $V_3' = 1/3$. Keeping in mind that the values of V_1 should be normalized by the condition $\sum_{r=1}^{n} V_i=1$, we have $V_i = V_i' \Big/ \sum_{i=1}^{n} V_i'$. In this given case $V_1 = 0.55$, $V_2 = 0.27$, $V_3 = 0.18$.

The method of pair comparisons is based on a pairwise comparison of various criteria according to their significance. If a criterion has priority over another one with respect to significance, then it is ascribed one point, otherwise a 0. If this priority is not obvious, i.e., the criteria being compared are comparable in their significance in the general evaluation of the design, then they are each ascribed 0.5 point. A "tournament" table of the results of the pairwise comparisons of the evaluations of the significance of the criteria can be compiled, for example, for the case $V_1 > V_2 > V_3$.

It is seen from a comparison of the results of the expert evaluation that both methods give values of the coefficients V_i with an admissible accuracy for such calculations.

A multicriterion analysis of designs with a developed system of criterion properites, for example, an evaluation of the effectiveness of multipurpose water-management systems, when the number of criteria being evaluated can be dozens, is carried out with the use of complex procedures [6].

Another method of assigning the coefficients of significance is an analysis of a multitude of decisions being made in practice, when the D.M. (decision maker) intuitively, on the basis of his own experience, compares possible decisions with respect to several criteria. Comparing the decisions being accepted and those rejected, one can single out the priority of the most significant criteria. One such method applicable to problems of determining the form of the multicriterion function is given in [4].

An example illustrating such a method of determining evaluations of the importance of criteria can be the solution of the multicriterion problem of optimizing the intrastation regime of a HES. For simplicity we will confine ourselves to two goals: 1) to maximally use the energy, assigning the operating regime of the HES with the largest possible efficiency; 2) to provide reliable operation of the equipment both at the current time and during a long operating period. We will consider the ability of the units to operate a long time with markedly variable regimes with minimum vibrations, wobbling of the shaft, cavitation, and permissible temperatures of heating of the components of the units to be the operating reliability of the equipment.

Figure 1 shows the operating characteristic of the unit of the Chirkey hydrostation. Isolines with η_{max} and η_{min} are singled out on the characteristic.

Figure 2 shows the characteristic of vertical vibration of the upper crosspiece of the unit, one of the properties of which reflects the state of the equipment with respect to its reliability.

The generalized characteristic in the case of two goals is defined as

$$E = V_1 l_\eta + V_2 l_m,$$

where V_1 and ℓ_η is the coefficient of importance and degree of attaining the best indices with respect to efficiency; V_2 and ℓ_m is the same with respect to the hydromechanical indices of operation of the unit.

Having taken for simplicity an equilibrium model $V_1 = V_2 = 0.5$, we can plot the operating characteristics of the unit, which is shown in Fig. 3. The integral characteristic of the index E as a function of the head and power of the unit $E = f(H, N_u)$ has two optimal zones: 1) loads with a maximum efficiency and 2) loads with minimum hydromechanical effects.

Figure 4 shown the annual energy losses of the Chirkey hydrostation in relation to the structures of the criterion function of quality of the units. When $V_2 = 0$ the distribution was drawn with respect to minimum power losses and when $V_2 = 1$ with respect to maximum reliability. As is seen from the graph (Fig. 4), the relation between annual energy losses and the coefficients determining the structure of the criterion function of quality is practically linear. The actual energy losses during the year, reflecting the real strategy of the personnel in managing the intrastation operating regimes of the HES correspond to the equilibrium model of the criterion function $V_1 = V_2 = 0.5$.

The state of the units during the overhaul period, available head on the hydrostation, and optimal structure of the criterion function of quality are corrected depending on the operating conditions. For example, for heads less than the design priority can be given to the reliability criterion, since in this zone the vibration and cavitation properties of the turbine worsen considerably. An analogous correction can be made also during wear of the unit in the overhaul period on the basis of information from a diagnostic system monitoring the state of the equipment.

CONCLUSIONS

1. In the hydropower industry and water management, with the introduction of self-supporting and self-financing, it is necessary to improve methods of substantiating hydropower and multipurpose water-management facilities.

2. It is recommended to supplement the widely used method of minimum dynamic discounted costs by the more general method of multicriterion (multigoal) optimization.

3. The method of multicriterion optimization in the hydropower industry and water management is open to public discussion.

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