Utilization of an appreciable part of the most economical water-power resources leads to an increase of the cost of construction of hydroelectric power stations and decreases the proportion of hydroelectric plants in the electrical-energy balance.

The future development of energy resources is geared mainly to the construction of large thermal stations with high steam parameters and of atomic power plants. However, an increase of their participation in the electrical-energy balance of the country necessitates the startup of highly adaptable stations—hydroelectric, pumped storage, and special peak-load stations. This determines the expediency of maintaining a certain level of the proportion of hydroelectric stations in the balance of capacities, which can be achieved by increasing the installed capacity of projected hydroelectric plants during construction in two stages and by expanding the existing hydroelectric plants.

As is known, the structure of the capital expenditures in the construction of hydroelectric stations is such that the cost of the additional capacity is appreciably (by a factor of 4-5) lower than the thermal stations being replaced. According to the data of design organizations the cost of an additional kilowatt of capacity of the large Siberian hydroelectric plants varies from 15 rubles/kW for the Krasnoyarsk hydroelectric station to 32 rubles/kW for the Boguchansk station. For the hydroelectric power stations of the European part of the USSR these values vary from 74 rubles/kW for the V. I. Lenin Dnieper hydroelectric plant to 108 rubles/kW for the Tsimlyansk and Perevoloksk hydroelectric stations. This leads to the endeavor to increase the installed capacity of hydroelectric stations in order to improve their technical and economic indexes, particularly to reduce specific capital investments. It is obvious that such an increase of capacity under conditions of the adopted stream-flow control can be justified only at a certain level of development of the electrical-energy system. Up to now a part of the installed capacity of a hydroelectric plant cannot be used in the system (doubling of capacities occurs), or additional investments in the construction of transmission lines are needed. In this connection the problem of the development of the capacity of hydroelectric stations by additional units arises.

The urgency of this problem will increase as the economical water-power resources are exhausted and the proportion of hydroelectric stations in the systems decreases, which is confirmed by the examples of development of the installed capacity of units abroad and by the first designs for the construction of second units at certain hydroelectric plants of the USSR.

Thus, 25 years after the startup of the Grand Coulee plant on the Columbia River (USA) the problem arose of increasing its installed capacity by a factor of about 2.8 [2]. Such an increase was possible, on one hand, owing to the change of the state of the watercourse after realization of the American-Canadian plan of creating a series of large regulating reservoirs on the Columbia River above the plant. On the other hand, an increase of the peak load in the interconnected system and an increase of the share of large thermal-electric plants in the structure of the capacities of the system created the premises for introducing a peak capacity at the plant.

At the Kariba hydroelectric plant on the Zambesi River (South Africa), constructed in 1956-1962 with an installed capacity of 600 MW, the possibility of a subsequent expansion of the installed capacity to 1500 MW was provided for by the construction of a second underground power-house.

Certain of our constructed hydroelectric power stations which were recommended for expansion as a result of the studies performed by planning organizations can also serve as an example. This is the V. I. Lenin Dnieper hydroelectric station, the expansion of which became possible and expedient after putting into service the Khakovsk and, in particular, the Kremenchug hydroelectric stations with an annual storage reservoir. The backwater in the
DEVELOPMENT OF STATION CAPACITY BY ADDITIONAL UNITS

Fig. 1. Curves of the dependence of economically justifiable specific investments on the break in time between construction stages. Broken curves) for $\beta = 0.15$; solid curves) for $\beta = 0.30$; 1) $K_{rep} = 50$ rubles/kW; 2) $K_{rep} = 75$ rubles/kW; 3) $K_{rep} = 100$ rubles/kW.

Fig. 2. Limiting values of the break in time between construction of the first and second units of a hydroelectric power plant.

The ratio between the capacities of the first and second stages of the station when designing new installations is a technical and economic problem, for the solution of which we need to: a) determine the maximum possible period of immobilization of the portion of investments which were made during the basic construction; b) determine the permissible minimum volume of work done in anticipation of the second stage and consider in so doing the differences in the cost of concrete in relation to the volume of construction work on the first and second stages; c) select the replaced version for the controlled hydroelectric stations being constructed by additional stages with consideration of the fact that the additional capacity will not as a rule give an additional generation or its increment will be insignificant; d) determine the efficiency of the first stage of the station being constructed; e) examine the problems of the fuel effect of the peak capacity of the second stage; f) analyze and evaluate the existing criteria of efficiency from the point of view of their applicability to the problem of determining the economic efficiency of a hydroelectric station being constructed in two stages.

The selection of the optimal value of the additional capacity at existing stations and the determination of the ratio between the capacities of the first and second stages of the station when designing new installations are a technical and economic problem, for the solution of which we need to: a) determine the maximum possible period of immobilization of the portion of investments which were made during the basic construction; b) determine the permissible minimum volume of work done in anticipation of the second stage and consider in so doing the differences in the cost of concrete in relation to the volume of construction work on the first and second stages; c) select the replaced version for the controlled hydroelectric stations being constructed by additional stages with consideration of the fact that the additional capacity will not as a rule give an additional generation or its increment will be insignificant; d) determine the efficiency of the first stage of the station being constructed; e) examine the problems of the fuel effect of the peak capacity of the second stage; f) analyze and evaluate the existing criteria of efficiency from the point of view of their applicability to the problem of determining the economic efficiency of a hydroelectric station being constructed in two stages.

The construction of the second stage of a hydroelectric station is expedient if the actual additional investments $K_{II}$, including expenditures for transmission lines, prove to be less than those economically justifiable with consideration of the time factor. These expenditures can be represented, on the basis of [3], by the equation

$$K_{ec} = \frac{(\rho_{rep} + \epsilon) \cdot \lambda_{N} \cdot K_{rep} + \mu_{f} \cdot \lambda_{H} \cdot \lambda_{E}}{(\rho_{11} + \epsilon) + (\rho_{con} + \epsilon) (1 + \eta)^{3} \cdot \beta} > K_{II},$$

where $K_{ec}$ are the economically justifiable specific investments per 1 kW of increment of available power of the station with consideration of transmission lines; $\beta$ is the proportion of work done in anticipation of the second stage.