Название: Improving the Energy Efficiency of Pumped-Storage Power Plants

Другие названия: Повышение энергоэффективности гидроаккумулирующих электростанций

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Краткий осмотр (реферат): Possible ways to improve the energy efficiency of hydroelectric generating sets of pumped-storage power plants (PSPPs) are studied. The Kiev PSPP is used as an example to show how its generating sets can be upgraded. It is concluded based on studies conducted that synchronous motor-generators should be replaced with asynchronized motor-generators. The feasibility of changing over the turbine to variable-speed operation is shown.
Рассмотрены возможные пути повышения энергоэффективности гидроагрегатов гидроаккумулирующих электростанций. На примере Киевской ГАЭС показаны способы модернизации её энергоблоков и на основании проведённых исследований сделаны выводы о целесообразности замены синхронных генераторов-двигателей асинхронизированными генераторами-двигателями. Показана целесообразность перевода гидротурбины в режим работы с переменной частотой вращения.

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PUMPED-STORAGE HYDROELECTRIC PLANTS

IMPROVING THE ENERGY EFFICIENCY OF PUMPED-STORAGE POWER PLANTS

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Possible ways to improve the energy efficiency of hydroelectric generating sets of pumped-storage power plants (PSPPs) are studied. The Kiev PSPP is used as an example to show how its generating sets can be upgraded. It is concluded based on studies conducted that synchronous motor-generators should be replaced with asynchronized motor-generators. The feasibility of changing over the turbine to variable-speed operation is shown.

Keywords: pumped-storage power plant (PSPP), hydroelectric generating set, efficiency, asynchronized motor-generator, variable speed

National and international experience suggests that reversible hydroelectric generating sets of pumped-storage power plants (PSPPs) built in the 1980s are equipped with synchronous motor-generators (SMG) usually integrated with radial-axial turbines.

Since the 1990s, a number of countries have conducted studies related to the improvement of the efficiency of hydroelectric generating sets operating over wide pressure head ranges [1 – 3]. These studies show that the efficiency of hydroelectric generating sets can be improved substantially by changing over their turbines to variable-speed operation.

This conclusion was successfully validated at a number of Japanese and European PSPPs [4]. Changing over hydroelectric generating sets to variable-speed operation improves their efficiency by 3 to 5%, the range of variation in pressure head being wide (from H_r to $0.5H_r$).

To change over a water turbine to variable-speed operation and to generate electric power of prescribed quality ($U = U_r$, $f = f_r$), designers had to develop special converting devices. Depending on the amount of change in the turbine speed, the role of such converters may be played by reduction gears, oil clutches, pole-changing generators, thyristor power converters (TPC) in the stator circuit of synchronous machines, and asynchronized generators (AG). An analysis of the strengths and weaknesses of such converting devices reveals that TPCs and AGs are only practicable at real PSPPs.

Over the last 10 years, some world's leading companies (Hitachi, Mitsubishi, Andritz) have manufactured and put into operation more than 20 asynchronized motor-generators (AMGs) at a number of 60 to 400 MW PSPPs of Japan, Germany, and Slovakia. In Russia, studies on the use of AMGs at Russian power plants were initiated by the RusHydro Company and have been conducted for five years now.

The use of thyristor power converters involves a number of problems [5] such as their high cost for high-power hydroelectric generating sets and need for additional space at the PSPP to accommodate them.

The studies conducted by the VNIIE (currently the R&D Center of FGC UES) made it possible to create, in cooperation with the Élektrotyazhmash (Kharkov) and Élektrosila (St. Petersburg) plants, asynchronized turbogenerators and condensers [6, 7]. After manufacturing and commissioning the first-ever asynchronized generator at the Iova HPP in the 1960s [8], there were no further developments of asynchronized generators.

The use of AMGs at PSPPs allows generating electric power of required quality in both voltage and $f_r$equency, irre-

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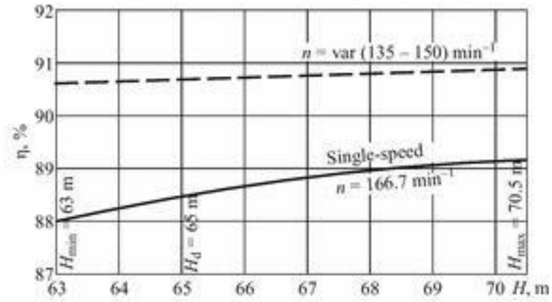

Fig. 1. Plot of $n = f(H)$ for the hydroelectric generating sets of the Kiev PSPP: for n = var the maximum efficiency is equal to 90.9%, average operating efficiency $\eta_{av.op}$ = 89.0% in turbining mode and η_{max} = 89.3%, $\eta_{av.op}$ = 85.2% in single-speed mode.

spective of the rotor speed. AMGs as generators of reversible generating sets make it possible to resolve a number of technical problems that are of high importance for modern electric-power systems. Such problems include:

— maintaining high quality of produced electricity during disturbances in grids;

— abandoning shunt reactors in powers lines;

— extending the controlled-voltage range at plant busbars;

— decreasing the response time of control of active power and voltage;

— maintaining high dynamic stability during generation and consumption of much reactive power;

— improving the reliability of the power plant due to the higher fault tolerance of AMGs (operation with faulty excitation system) and the higher reliability of other generating sets with synchronous generators;

— providing very long-term asynchronous operation without excitation under high electric load.

It is true that these problems can be resolved at the cost of some complication of the design of the generator and excitation system, which raises the cost compared with that of conventional synchronous generators.

We believe that synchronous generators of PSPPs that have finished their useful life should be replaced with asynchronized motor-generators of the same rating. This would make it possible, first, to change over reversible generating sets to variable-speed operation, which would considerably raise their efficiency during great variations in head, and second, to help electric-power systems to resolve the above problems.

That such an approach to the upgrading of generating sets of PSPPs is expedient may be exemplified by the USSR's first Kiev PSPP built on the right bank of the Kiev Reservoir at a distance of 2.5 km from the Kiev HPP. It was intended for peak-load operation, short-term reserve, and reactive power generation. The first hydroelectric generating set was commissioned in 1970, and the last in 1972.

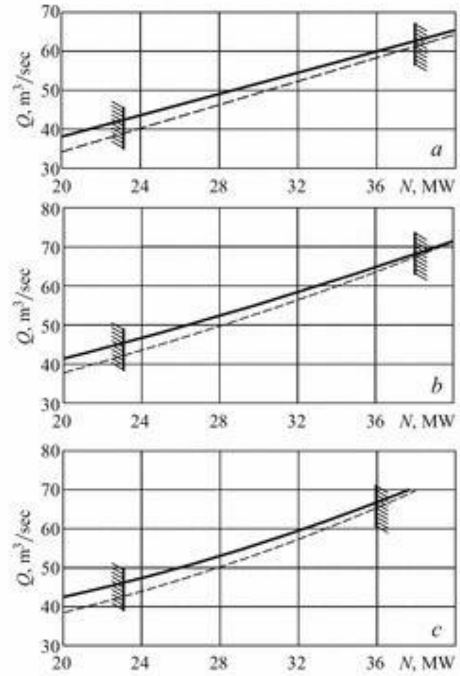

Fig. 2. Plot of $Q = f(H)$ for the hydroelectric generating sets of the Kiev PSPP in turbining mode: *a*, H_{max} = 70.5 m; *b*, design head H_d = 65 m; *c*, H_{min} = 63 m; solid lines, n = 166.7 min^{-1}; dashed lines, n = var.

The PSPP includes six generating sets of which three are reversible. The reversible sets consist of an SVO-733/130-36 generator and an ORO-15-V-455 water turbine. The irreversible sets include a generator of the same type and an RO-115/697-V-300 water turbine. The diameter of the runner is 4.55 m; the design head is 72.2 m. The plant operates in two modes: turbining (3 h a day) and pumping (7 h a day). The installed capacity of the power plant is 235.5 MW (in turbining mode) and 135 MW (in pumping mode). All the hydroelectric generating sets have already finished their useful service life and should be replaced.

It is proposed to install new runners of the same type and specifications and to change over them to variable-speed operation, and to replace the generators with new AMGs with the same output parameters (S_r, P_r, Q_r, U_r) and dimensions.

The study [5] on the hydroelectric generating sets of the Kiev PSPP and calculations for their turbines (Fig. 1) indicate that the maximum efficiency is increased by 2.6% in turbining mode, especially at minimum pressure, and the average operating efficiency is increased by 3.8%. The efficiency is increased over almost entire range of operating conditions of the turbine, which leads to a higher electricity output due to the lower water flow rate in the turbining mode (Fig. 2).

For hydroelectric generating set operating with variable speed in pumping mode, the improvement of the efficiency