525-MVA Generator-motor and Thyristor Starter Put into Service at the Tokyo Electric Power Co., Inc.'s Kannagawa Hydroelectric Power Station

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OVERVIEW: Unit 1 of the Tokyo Electric Power Co., Inc.'s Kannagawa Hydroelectric Power Station was put into commercial operation on December 22, 2005. Hitachi, Ltd. supplied a 525-MVA/464-MW generator-motor, the largest air-cooled generator-motor ever produced, and a 30-MW thyristor starter featuring state-of-the-art digital control for this power plant project. There has been a growing reassessment of hydroelectric power as clean energy that does not generate carbon emissions, and the increased generator-motor capacity and thyristor starter digital control technology developed for the Kannagawa Hydroelectric Power Station have attracted considerable interest for their beneficial impact on the global environment.

INTRODUCTION

PUMPED-STORAGE power plants exploit the height difference between an upper reservoir and a lower reservoir by releasing water into the lower reservoir through a turbine which runs a generator-motor as a generator to supply electricity to the power grid. A key advantage of hydroelectric power plants is that they can start to generate electricity in response to load changes very quickly, so are used extensively to supply high peak demands. At night the demand of electricity is low, but thermal power plants and nuclear power plants are not able to respond to sudden changes in electrical demand, with the result that surplus power is generated. This surplus power operates generator-motor as a motor that pumps the water from the lower reservoir back up to elevated reservoir where it is stored to be reused when demand is higher. In this paper, we provide a detailed description of a world's largest-class capacity generator-motor and a thyristor starter system implemented for the first time using digital control that were supplied to the Tokyo Electric Power Co., Inc.'s (TEPCO's) Kannagawa Hydroelectric Power Station (see Fig. 1).

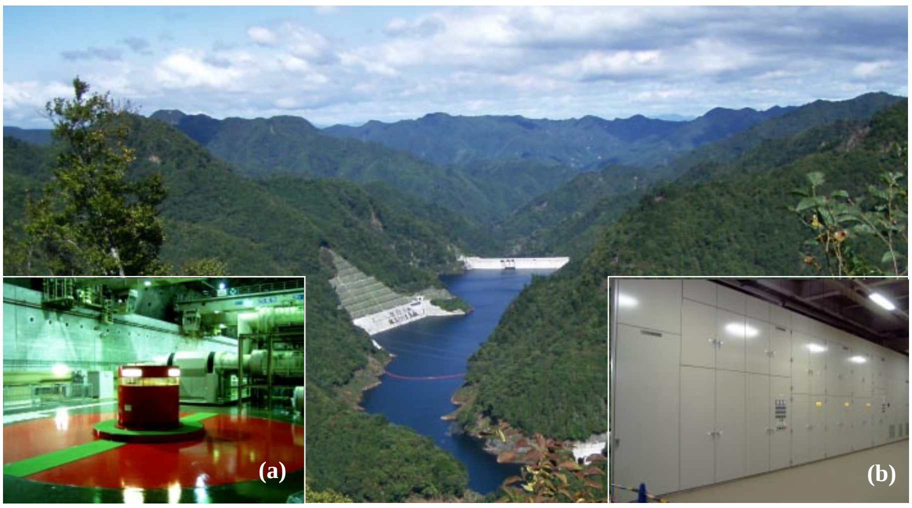


Fig. 1—View of Okukanna Lake (Ueno Village, Gumma Prefecture) and Equipment at the Power Plant. Background photo shows Okukanna Lake used as the lower reservoir for the Tokyo Electric Power Co., Inc.'s (TEPCO's) Kannagawa Hydroelectric Power Station. Insets show upper view of the generator-motor (a), and the thyristor starter panel (b).

KANNAGAWA HYDROELECTRIC POWER STATION OVERVIEW

TEPCO's Kannagawa pumped-storage power plant consists of two artificial bodies of water that serve as upper and lower reservoirs (Okumikawa Lake is the upper reservoir created by building Minamiaiki Dam on the upper reaches of the Minamiaiki River which is a tributary of the Shinano River near Minamiaiki Village in eastern Nagano Prefecture, Japan, and Okukanna Lake is the lower reservoir created by constructing Ueno Dam on the upper reaches of the Kanna River which is a tributary of the Tone River near Ueno Village in southwestern Gumma Prefecture, Japan), the water tunnels connecting the two reservoirs, and the power station building installed approximately 500 m underground between the two reservoirs on the Gumma Prefecture side. Fig. 2 is a map showing the location of the Kannagawa Hydroelectric Power Station.

Exploiting an effective head (height difference) of 653 m between the upper and lower reservoirs, the Kannagawa Hydroelectric Power Station is a pure pumped-storage plant that generates 470 MW of electricity per generator. Although this head is somewhat less than the 714 m of TEPCO's Kazunogawa Hydroelectric Power Station, the generator at the Kannagawa Station is capable of a maximum output of 470 MW by increasing the flow and output, which means that the Kannagawa Station generator-motor has a world record-breaking capacity of 525 MVA.

GENERATOR-MOTOR

Air Cooling

The greater the capacity of generator-motor, the more heat is generated inside the motors, so highly efficient cooling technology is critically important. Here we adopted a rim-duct ventilation arrangement because this approach does not require blowers for cooling which not only reduces the number of auxiliary pieces of equipment but also reduces the power required by the plant. This provides radial ventilation ducts in the rotor rim ensuring ventilation flow paths from the spider, radially along the axial end surface of the rotor rim, toward the periphery of the rotor rim. This increases the fan effect produced by the rotation of the rotor, and achieves self ventilation. Fig. 3 is a photograph showing the stator and rotor of the generator-motor.

In addition, eight condensers (water-cooled heat exchangers) with 1,060-kW heat-exchange capacity are mounted around the outside of the stator to cool

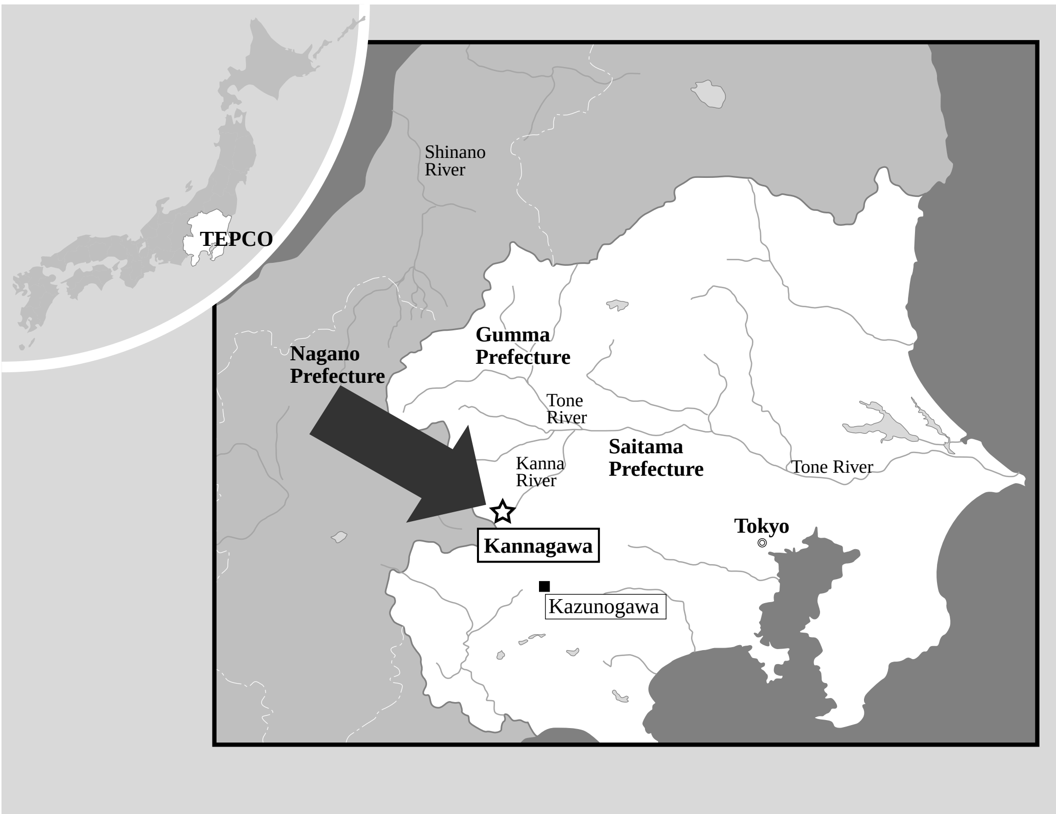


Fig. 2—Location of the Kannagawa Hydroelectric Power Station.
The power station is located where three prefectures intersect in Japan: Gumma, Nagano, and Saitama Prefectures.

Fig. 3—Generator-motor Stator and Rotor.
Photo shows the construction site prior to hanging the rotor into the stator.

TABLE 1. Generator-motor's Main Specifications
Table shows the comparison of specifications between the world's largest-class capacity air-cooled generator-motor installed at the Kannagawa Hydroelectric Power Station and a conventional generator-motor.

Item	Kannagawa G/M	Conventional G/M
Generator-motor capacity	525,000 kVA	475,000 kVA
Shaft output during pumping	464,000 kW	438,000 kW
Rated voltage	18,000 V	18,000 V
Rated power factor (generating/pumping)	0.90/0.95	0.85/0.95
Frequency	50 Hz	50 Hz
Rated speed	500 min^{-1}	500 min^{-1}
Maximum speed (runaway speed)	755 min^{-1}	740 min^{-1}
Centrifugal acceleration (during runaway speed)	Approx. 1,600 G	Approx. 1,520 G

G/M: generator-motor

the flow of air through the generator-motor. By fundamentally rethinking the conventional structure in which tubes for cooling water are wrapped around heat-dissipation fins, we developed a very compact

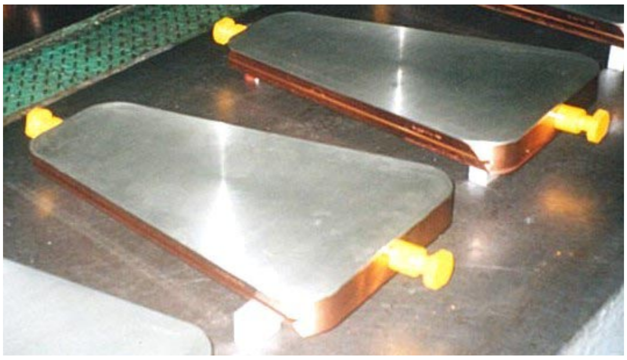


Fig. 4—Generator-motor Thrust Bearings.
Copper is applied to base metal as a substrate to enhance cooling efficiency.

high-capacity air condenser by covering the cooling tubes with copper much like a car radiator.

High-strength Rotor

Table 1 compares the specifications of the new generator-motor with a conventional one. One can see that a maximum centrifugal acceleration of approximately 1,600 G occurs at the outer periphery of the new generator-motor's rotor as a result of increased runaway speed. This led us to employ steel with an extremely high yield point for the rotor rim because of this extreme pulling by the centrifugal force toward the outer diameter of the rotor structure.

Bearing

A total load of the rotor mass of the generator-motor and the pump-turbine assemblies plus the hydraulic thrust load generated by the pump-turbine is 1,300 t, which is supported by the thrust bearing installed in the generator-motor. In order to efficiently cool the heat generated by the thrust bearing and minimize thrust bearing thermal deformation, copper with its excellent heat conductivity is used for the backing of the bearing base metal (see Fig. 4).

We also reexamined the oil circulation pump operation sequence of the lubricating oil cooling system, and found a way to alleviate stress on the bearing resulting from the heat cycle due to starting and stopping operations. This will extend the fatigue life of bearings.

Measures to Minimize Environmental Impact

In terms of finishes for the generator-motor, we sought to minimize adverse environmental effects while contributing to a better work environment by avoiding paints that contain lead and varnishes with volatile constituents.

THYRISTOR STARTER

Thyristor Converter for the Starter

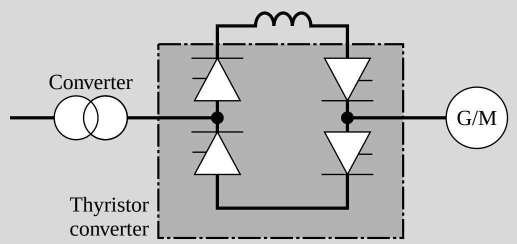
A thyristor starter is the system that brings the generator-motor of a pumped-storage plant from a stopped state to its rated speed when water is pumped to the upper reservoir. Fig. 5 shows the circuit diagram and specifications of the starter. Because the generator-motor has the largest single output of any generator ever developed, the static frequency converter to accommodate this capacity also incorporates a large-capacity (30 MW) thyristor converter with the following features:

(1) Application of large-capacity optical thyristor that provides excellent reliability

The converter is implemented by serially connecting 6-kV 1,500-A high voltage high capacity optical trigger thyristors, an approach that significantly reduces the number of main and trigger circuits and improves reliability.

(2) Compact implementation with direct cooling scheme

By adopting a deionized water-cooled scheme for cooling the converter, the converter can be implemented more compactly than when an air-cooled system was used.



Thyristor converter specifications

Item	Specification
Rated output	30 MW
Connection	3-phase bridge
Thyristor	6 kV 1,500 A, optical trigger
Thyristor configuration	9 units/arm × 12 arms

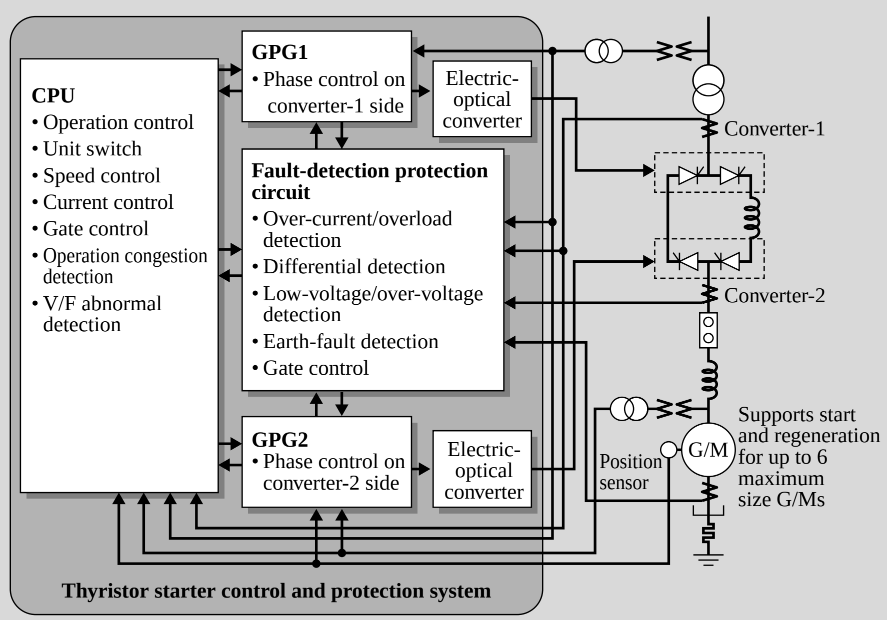
Fig. 5—Starter Circuit Diagram and Specifications.
Since the generator-motor has the largest single output in the world, the static frequency converter must also adopt large-capacity thyristor converter.

Digital Thyristor Starter Control and Protection System

Conventional thyristor starter control and protection systems for pumped-storage plants use analog circuits that are subject to age deterioration of setting values, take considerable time for maintenance checks, and have other drawbacks. This led us to adopt a digital thyristor starter control and protection system that is more reliable and maintainable. The new digital system has the following advantages (see Fig. 6).

(1) Fewer panels

Hardware circuitry was markedly reduced by



CPU: central processing unit V/F: voltage/frequency GPG: gate pulse generator

Fig. 6—Schematic of the Thyristor Starter Control and Protection System.
Current control and other control processing are handled by the CPU, and the individual fault detection and protection circuits from the CPU have thyristor converter protection capability.

having the speed control, current control, sequence control, and other control tasks performed by the CPU (central processing unit), and this enabled us to reduce the number of control panels from five to three (see Fig. 7).

Fig. 7—Thyristor Starter Control and Protection System.
Five panels have been reduced to three through reduction of hardware circuitry.

(2) Consolidation of fault detection and protection circuits

In the conventional system, the fault detection and protection circuits were configured separately for every element that required protection. The new digital system achieves better reliability and maintainability by integrating the fault detection and protection circuits on a single board and by standardizing the circuitry.

(3) Fewer adjustments during checks and inspections

By switching from analog to digital control circuits, the number of adjustments that are typically required with analog circuits has been greatly reduced, and the time required to perform inspections has been reduced by half.

(4) Bearing running-in support

The new control system features operating modes (i.e. operating in generating or pumping directions) to maintain any speed setting to support bearing running-in used by the thyristor starter. This enables the system to change to any speed or maintain any speed even when the thyristor is starting.

CONCLUSIONS

This paper provided a detailed overview of the world's largest-class capacity generator-motor and a thyristor starter system implemented for the first time using digital control that were supplied to the TEPCO's Kannagawa Hydroelectric Power Station. In light of growing concern about environmental issues, we are witnessing an upsurge of interest in hydroelectric power that does not deplete fossil fuels or produce large quantities of carbon emissions. Hitachi, Ltd. will continue to make significant contributions to solving environmental challenges through the development and provisioning of high-performance equipment and systems for hydroelectric power plants that have a more benign environmental impact than other types of power plants.

ACKNOWLEDGMENTS

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REFERENCE

(1) The Tokyo Electric Power Co., Inc., Kannagawa Hydroelectric Power Station, http://www.tepco.co.jp/gunma/kanna-gawa/11_0-j.html

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