Large-capacity Adjustable-speed Pumped-storage Power System

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1. Overview

For frequency stability of the power grid, it is necessary to balance power demand and power supply. Pumped-storage power plants are able to be utilized as an adjustable power source with respect to the base load made up of large thermal power and nuclear power. In a conventional single-speed pumped-storage power system, output power in generating mode can be adjusted by the discharge of the pump-turbine. However, pump-turbine input in pumping mode is dependent on the actual pump head, it cannot be adjusted freely.

As a means to reduce the fuel cost of thermal power for the load adjustment, adjustable-speed pumped-storage power system was developed in Japan. The world's first unit was commissioned in 1990. This system has the ability to adjust the input power in pumping mode by varying the rotational speed. It is used for load frequency control operation during night-time which has low power demand. In recent years, the mass introduction of renewable energy has been promoted globally to reduce CO_2 emissions. With respect to fluctuation due to weather in photovoltaic power and wind power, the expected contribution to frequency stabilization from adjustable-speed pumped-storage power has been increasing.

In June 2014, Tokyo Electric Power Company (TEPCO) Kazunogawa Power Station Unit 4 (475 MVA / 460 MW) which is the world's largest adjustable speed unit began commercial operation.

2. Technical Content

Generator-motors used in single speed pumped-storage power plants are categorized into rotary electric machines called salient pole synchronous machines. These machines are excited by direct current through the magnetic poles arranged on the outer periphery of the rotor. On the other hand, with the adjustable-speed generator-motor, in order to vary the rotational speed, the double fed alternating current (AC) machine is applied. The machine generates a rotating magnetic field by supplying a low frequency AC from the AC excitation system. This frequency corresponds to the difference between the synchronous and rotational speeds. The rotor has slots on the outer periphery of the core formed by the laminating of electromagnetic steel sheets, the rotor coils are inserted to the slots for conducting the three-phase distributed winding. The coil end sections overhang the core in the vertical direction. A huge centrifugal force during operation poses a major technical challenge in terms of support for the overhang.

In conventional technology of the coil end section, large parts and special equipment for assembling is required. In general, pumped storage power plants are located in mountainous regions, which constitute a disadvantage in terms of transportation restrictions and site assembly construction period. There are also challenges in relation to ventilation cooling of the coil end.

Therefore, we developed an original U-bolt support system that varies from conventional technology. The U-bolt system is a structure in which a large number of non-magnetic, high-strength U shaped bolts are inserted into coil end sections. These U-bolt are fixed to high strength steel ring to support the centrifugal force on the coil. In this U-bolt system, no special large assembly equipment is required and construction period is short. Also, it does not interfere with the ventilation of the coil end. It also has an advantage in maintenance, through its partial dismantlement and coil inspection availability.

The unit's rated speed is at 500 ± 4% min^{-1}, for a large-capacity hydroelectric machine, this is a very high speed. The outer peripheral speed of the rotor reaches about 145 m/s at the rated operation. Although close to the limit of cooling capacity as an air-cooled machine, several radial ventilation ducts have been placed on the rotor core for the adoption of the ventilation system, which ventilates using the pressure generated by the rotor itself. Computational Fluid Dynamics (CFD) was used for evaluation of the complex flow around the rotor coil end portion. After completion of installation, the temperature rise of the rotor, stator coil and others measured in the commissioning test satisfied the required specifications.

The mechanical strength of the rotor is required to withstand a runaway speed of 730 min^{-1} of the pump-turbine (maximum speed attainable in case of emergency trip condition), during these same conditions, centrifugal accelerations attains about 1600 G. The rotor core of this unit applied for the first time, a 700MPa class electromagnetic steel sheet which is a high material strength in terms of conventional materials. The rotor coil end support structure including the U-bolt is configured to have a sufficient strength and stiffness. In order to not apply undue stress on the rotor coil during any operating conditions, support stiffness balance between the rotor coil end and the core section is essential. Current focus is on optimizing the structure through Finite Element Method (FEM). Also, with respect to the mica insulation of the rotor coil, not only electrical insulation performance, but also mechanical strength, was taken into particular consideration during development. Actual load tensile test and fatigue tests of the U-bolt with respect to these important coil end support structures were carried out. Further, actual stress measurements of principal component were carried out during commissioning test, equivalency between design values and actual stresses were confirmed.

3. Summary

TEPCO Kazunogawa Power Station Unit 4 was commissioned in June 2014; the frequency fluctuation suppressing effect of the unit during pumping operation was confirmed in the electric power grid of Tokyo. Also, while in generating mode, the wide operating range compared to conventional single speed systems, allows for flexible and efficient operation.

With respect to future introduction of wind power, photovoltaic power, and other intermitted renewable energy, adjustable-speed pumped-storage power systems will be required for the stability of the power grid.

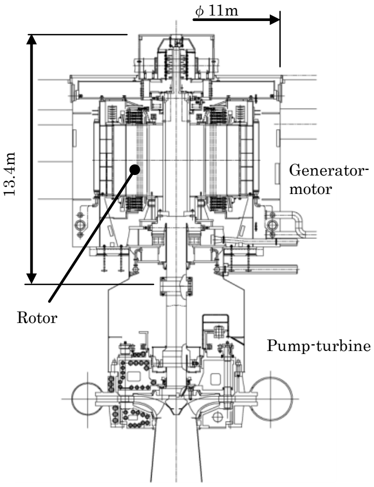

Fig. 1 Kazunogawa Unit 4 (475MVA/460MW)

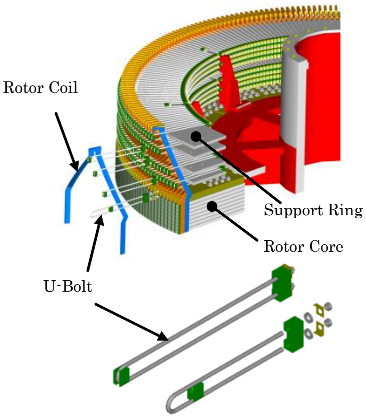

Fig. 2 Structure of rotor coil end

Fig. 3 Kazunogawa Unit 4 Upper exterior

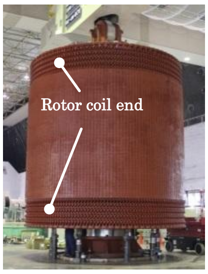

Fig. 4 Rotor

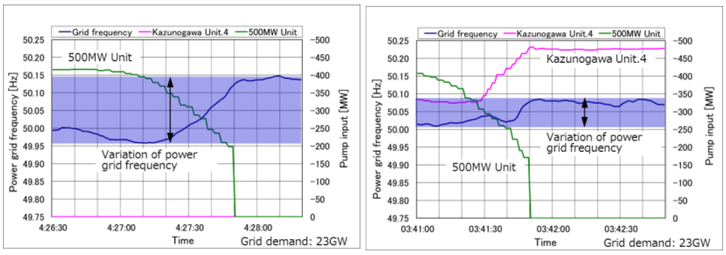

Fig. 5 Kazunogawa Unit 4
Grid frequency stabilizing effect during operation

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