Large-capacity Adjustable-speed Pumped-storage Power System

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 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, which is dependent on the actual pump head, it cannot be adjusted freely.

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 current 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 plants are located in mountainous regions, which constitute a disadvantage in terms of transportation restrictions and site 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 75 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 other 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 strength U shaped bolts are used to support the rotor coil. The bolt support system that varies from conventional technology allows flexible and efficient operation.

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 intermittent renewable energy, adjustable-speed pumped-storage power systems will be required for the stability of the power grid.