IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Renovation of the pumped-storage system from fixed speed to adjustable speed at Okutataragi power station

To cite this article: Yuya Yokoyama *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **240** 082004

Renovation of the pumped-storage system from fixed speed to adjustable speed at Okutataragi power station

Yuya Yokoyama[1], Kazuo Yamamoto[1], Kiyohito Tani[2]

[1] Hydro Power Group, Power System Engineering Center,
The KANSAI Electric Power Co., Inc.
6-2-27, Nakanoshima, Kita-ku, Osaka, 530-6691, Japan
[2] Hydraulic R & D Laboratory, Hitachi Mitsubishi Hydro Corporation
1-1, Saiwaicho 3-chome, Hitachi, Ibaraki 317-8511, Japan

E-mail: [1] yokoyama.yuuya@c5.kepco.co.jp

Abstract. Okutataragi Power Station is located in Tataragi, Asago City Hyogo Prefecture, Japan. The maximum total output is 1932 MW. It is the largest capacity commissioned hydropower station in Japan. In order to reduce the fossil fuel cost and improve the efficiency of generation in partial load, KEPCO decided to enlarge the LFC (Load Frequency Control : This control changes the generation output at intervals of several minutes to 10 minutes in order to compensate the load change and maintain the grid frequency.) capacity by the renovation of existing pumped-storage power station from fixed speed to adjustable speed. Now, the commissioning test of the first unit was finished and the installation of the second unit is proceeding.

1. Introduction

1.1. Outline of Okutataragi Power Station

Okutataragi Power Station is the largest capacity (1932MW) commissioned hydropower station in Japan, which is owned by The Kansai Electric Power Co., Inc. (KEPCO) is located in Tataragi, Asago City, Hyogo Prefecture, Japan. The operation of Okutataragi Power Station started on July 1975 with maximum plant output 1212MW (303MW×4units). After that, unit No.5 and 6 (360MW×2units) were introduced in correspondence with the increasing demand and for improving the reliability of electric power supply. Okutataragi Power Station is a pumped-storage power plant which uses the Tataragi Dam as a upper reservoir, and Kurokawa Dam as a lower reservoir.

Figure 1. Location of Okutataragi P/S

Figure 2. Overview of Okutataragi P/S

1.2. Outline of adjustable speed pumped storage system
Figure 3 shows the system configuration of the fixed and the adjustable speed types. The adjustable speed type has a cylindrical rotor with three phase windings which are excited by AC field current from the cycloconverter (CYC). The rotor can generate rotational flux by AC excitation of the rotor windings. The electrical rotation direction of the rotor flux can be changed to forward or backward of the rotor's mechanical rotation by interchanging the phase of the excitation current. The rotor flux is the addition of the mechanical and the electrical rotational speed. Therefore, rotating speed of rotor flux can be maintained at synchronous speed by adjusting the electrical rotating speed so as to compensate the speed difference between the rotor mechanical rotating speed and the stator flux rotating speed, even if the rotor's mechanical rotating speed is not equal to synchronous speed corresponding to the grid frequency.

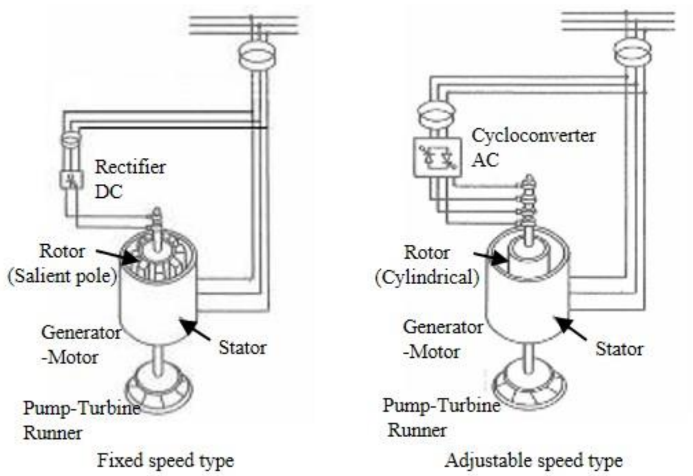

Figure 3. System configuration

1.3. Purpose of renovation
The adjustable speed pumped storage system has two major benefit. One is the LFC operation as a demand side. Second is the improvement of the pump-turbine efficiency at turbine mode, especially at the partial load. The fossil fuel cost reduction by supression of the thermal power for LFC at night and the contribution for the grid stability are expected by the renovation of the adjustable speed.

2. Outline of renovation
The civil engineering equipment and major electric facilities reuse the existing ones. The 2 (two) sets of generator-motor and the DC exciter are replaced by the doubly-fed asynchronous machine and the AC exciter. The partial load efficiency and the operation range of the replaced pump-turbine runner are improved.

3. Detail of renovation

3.1. The reuse of the civil and electric facilities

Figure 4 shows the parts of the renovation around the generator-motor and table 1 shows the comparison of specifications between before and after the renovation. This renovation mainly consists of the replacement of the generator-motor, the exciter and the pump-turbine runner.

Due to the revision of the overhead cranes regulation, the overload operation cannot be permitted. Therefore, the electromagnetic design of the generator-motor was modified to reduce the rotor weight within the rated cranes capacity, while guaranteeing the required flywheel effect and the electromagnetic characteristics.

Moreover, this project planned to reuse the Main Transformer, Phase inversion Line Switch, Synchronous circuit breaker and so on.

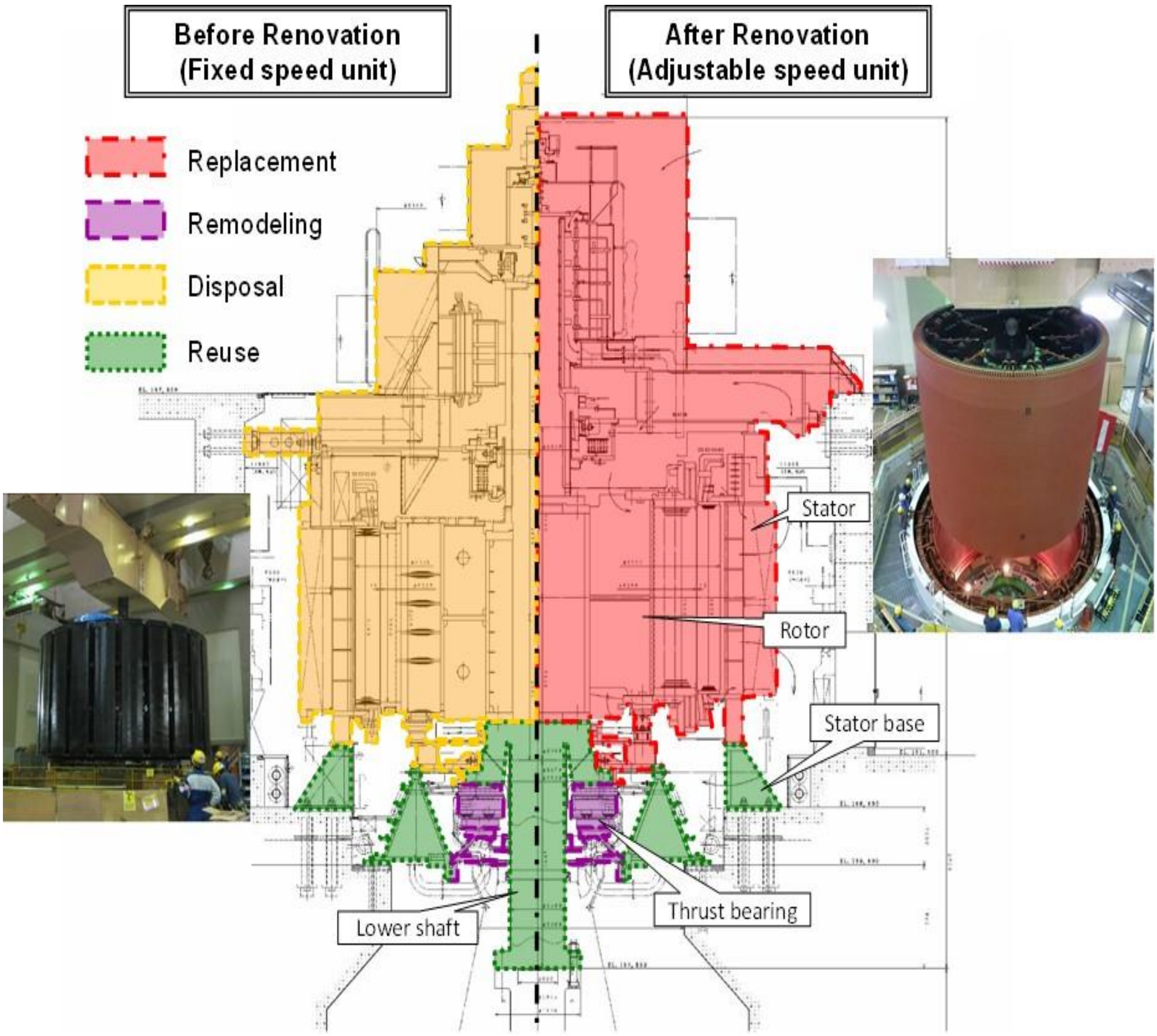

Figure 4. Renovation area

Table 1. Main equipment specification

	Item	Conventional unit (fixed speed)	Adjustable speed unit
Generated Output	---	303 MW (power factor 0.95)	303 MW (power factor 0.95)
Pumping Input	---	320 MW (power factor 1.0)	320 MW (power factor 1.0)
Generator-Motor	Type	Salient-pole type rotor	Cylindrical rotor
	Capacity	320 MVA	350 MVA
	Speed	300 min^{-1}	280 ~ 315 min^{-1}
	Range of input adjustment	0 MW	±45 MW
Pump-Turbine Runner	Type	Francis	Francis
	Runner Vane	6	4 + 4
	Output / Input	310 MW / 314 MW	311.7 MW / 311.7 MW
	Effective Head	383.4m	383.4m
	Water Discharge	94 m^3/s	94 m^3/s
Exciter	---	DC	AC

3.2. New design of pump-turbine runner

3.2.1. Overview. The new runner was designed for not only corresponding to the adjustable speed system but also increasing the amount of the generating electricity in middle-load operation by the efficiency improvement in the partial load operation, and extending the range of stable operation at adjustable-speed mode. In this renovation project, however, there are various constraints because of the diverting many parts used in existing systems. The diverted parts affecting the fluid design of the runner are the power transformer, the spiral casing, the stay ring, the discharge ring, the guide vane and others. The new pump-turbine runner was developed taking these constraints into account.

3.2.2. Design of pump input characteristics. The pump input power is constrained by the capacity of the diverted main transformer. Figure 5 shows the pump characteristic when the existing pump-turbine were used. The maximum input is limited by 312MW, even if the generator-motor and the AC exciter have a capacity above 312MW. This is a huge disadvantage to guarantee the wide input variation range.

Therefore, a pump input power was decided to 280 MW at the rated speed (300min^{-1}). As a result, it is possible to extend the stable operation range at the adjustable-speed mode, which is shown in figure 6. In addition, it is possible to have the same pump operating area above and below 300min^{-1} area. ”Adjustable speed runner” means the optimum designed pump-turbine runner for the adjustable speed operation.

In order to decrease the pump input power at the rated speed, it is necessary to decrease the pumping discharge. However, it is impossible to extend the maximum diameter and the height of the runner inlet, because of the diverted parts from existing systems such as the casing, etc. Therefore, it is managed to decrease the pumped discharge by designing the runner with a small blade angle at inlet (pump outlet) and by selecting the diameter that conforms to it.

Furthermore, evaluating the pump turbine efficiency in the case of the adjustable speed runner is adopted. It is confirmed that there is no extra loss compared to the existing runner.

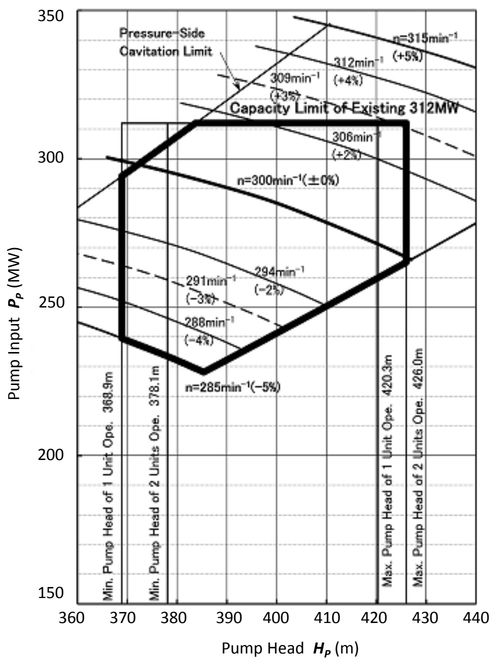

Figure 5. Operation range of adjustable-speed pumped-turbine using conventional runner

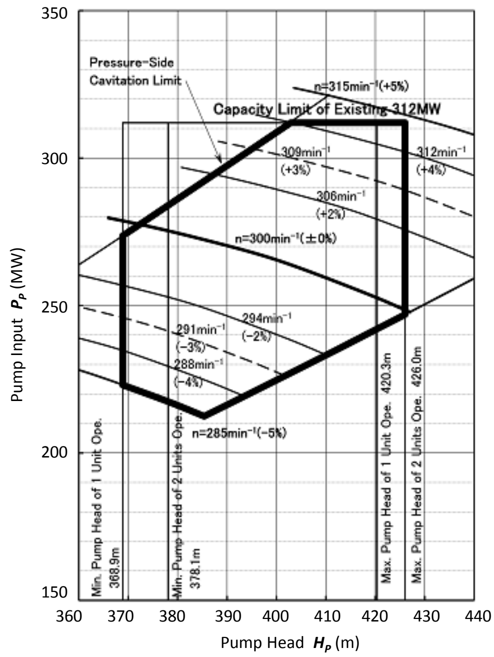

Figure 6. Operation range of adjustable-speed pumped-turbine using new runner

3.2.3. Improvement of partial load efficiency. From the past operation data of Okutataragi Power Station, it was noticed that partial load operation had been usually required. That is why, for designing the new runner, it is necessary to improve the efficiency in the partial load by shifting maximum efficiency point to the lower load operation area without reducing the efficiency at the maximum output.

In order to decrease the pumped discharge, an acute runner blade angle of the runner inlet (the pump outlet) is adopted, which contributes to the improvement of the partial load efficiency at the generation mode. To further improve the efficiency at partial load, the turbine outlet diameter is reduced. Reducing the peripheral velocity at the turbine outlet contributes to decreasing the low load operation loss, and to the improvement of the partial load efficiency. Compared to the efficiency of the turbines as shown in figure 7, the turbine efficiency of the runner corresponding to 280MW pump input, is better than that of the conventional runner (300MW) in the partial load operation.

According to the reduction of the runner outlet diameter, the part of the upper draft tube is modified.

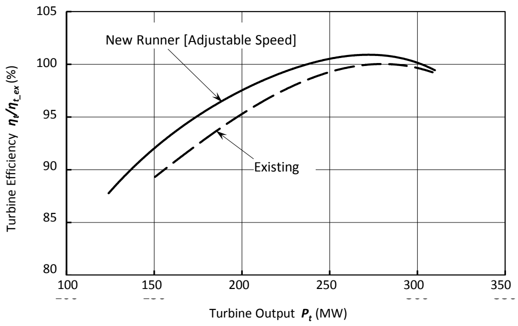

Figure 7. Comparison of turbine efficiency for existing runner and adjustable speed runner

3.2.4. Results of verification of characteristics. The characteristics of the new runner optimized for the adjustable speed in more detail was verified by the model test. As shown in figure 8, the new runner's efficiency in generation operation exceeds the conventional one for all the operation range. Especially, the efficiency is improved by 2% at the maximum output and 7% at 40% output (124MW) which compared with existing because of the improvement of the turbine efficiency and the effect of the adjustable speed operation.

Furthermore, its efficiency in pumping operation also exceeds the conventional one for all operation range is confirmed as shown in figure 9. Especially, the new runner's efficiency is improved by about 2% at the maximum head because it is possible to operate with higher efficiency even in the higher head condition thanks to the adjustable speed operation.

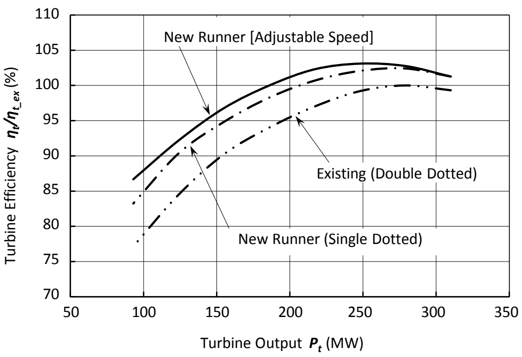

Figure 8. Comparison of turbine efficiency for runners

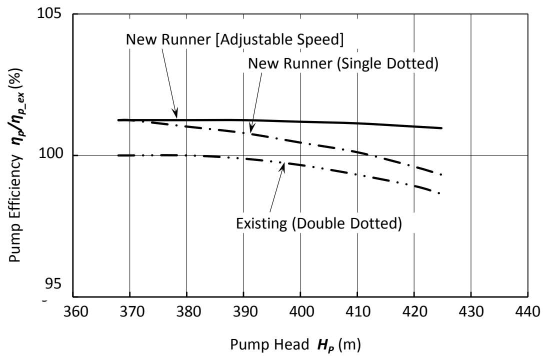

Figure 9. Comparison of pump efficiency for runners

The characteristics at the adjustable speed operation is shown in figure 10. Since the new runner is superior in cavitation performance of the compound pressure at the pump inlet, it is possible to expand the operating range at the adjustable speed pumping operation.

In accordance with the requirement from the grid operator, the maximum pump input (312 MW) is guaranteed at all the head range.

Furthermore, the operation range becomes wider by selecting the small negative slope of the pump input-head curve. A photograph of the new runner is shown in figure 11.

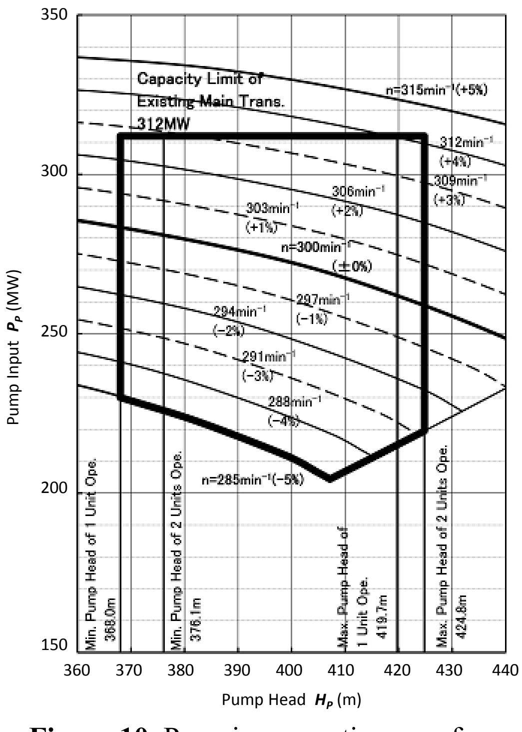

Figure 10. Pumping operation area for new runner

Figure 11. New runner

3.3. Secure space by existing tunnel expanding

It is necessary to secure a space inside the underground power house for installing the excitation equipment which enhances the adjustable speed operation. So, the excitation room was constructed by the excavation work near the existing underground power house. Unlike the case of newly building a power station, securing a space at the underground power house under operation was a problem from the beginning of the project. As shown in figure 12, in order to secure the installation space of the excitation device, a method of widening the existing tunnel is adopted. The existing tunnel was expanded by the mechanical drilling and blasting excavation to construct the new excitation room. The power house vibration is measured which caused by the construction work to prevent the other units having any trouble.

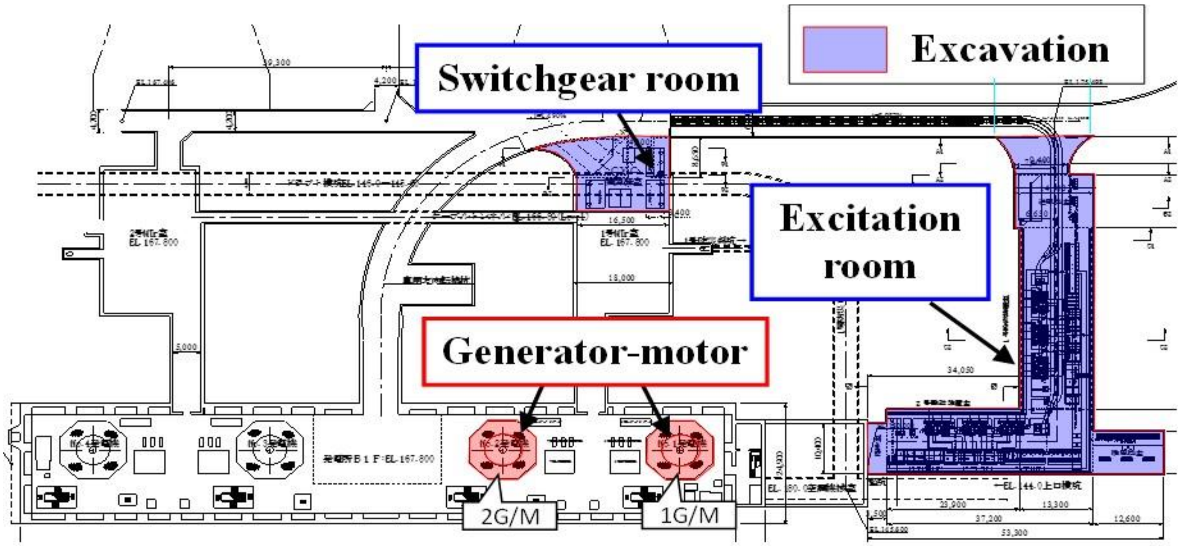

Figure 12. Excavation area

4. Status of Renovation

Currently, the commissioning test for the first unit has been finished and the installation of the second unit is underway. The first unit was put into commercial operation on March 2018, and the second unit is scheduled for February, 2019. After the commissioning, LFC capacity of the pumping operation of KEPCO will increase from 320MW (0.9% of the generation capacity of KEPCO) to 500MW (1.4%). This renovation is expected to contribute to the improvement of the grid stability. Furthermore, the efficiency improvement is expected to reduce the emission of greenhouse gases.

5. Conclusion

In order to reduce the fossil fuel cost and to improve the grid stability, the renovation of the adjustable speed for Okutataragi Power Station is proceeding. The greatest feature of the project is that the renovates is proceeding under many restrictions.

As for the pump-turbine, the adoption of the "Adjustable speed runner" realized wider operation range and 2-3% higher efficiency. And the first unit which had been put into the commercial operation fully realizes the purpose of the renovation.