Case Studies: Our Supply of Hydropower Plants

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Abstract

When we supply hydropower generation facility, we manufacture the main electrical equipment such as generators and substation equipment in-house and we order the hydro turbines and peripheral auxiliary equipment from a hydro turbine manufacturer. On-site construction work is managed by our construction department. The large amount of equipment assembled functions as a hydropower generation facility. No two hydropower plants are the same in terms of water usage conditions and effective head at the location where they are installed. Under these circumstances, determining the specifications of the procured equipment, the plant engineering, on-site construction work, and project process management, are all important in realizing customer requests.

Hydropower generation attention is increasing and is expected to continue in the future. To realize a decarbonized society through hydropower developments, we are working to pass on skills and expertise to new generations and conducting total plant engineering services from the initial planning phase to maintenance and repair management.

1 Preface

Examples of recently supplied hydropower plants include new installations, scrap-and-builds, partial renewals, and overhauls of existing equipment. We manufacture the following main electrical equipment in-house: generators, control panels, Cubicle type Gas Insulated Switchgear (C-GIS), main transformers, station transformers, and DC power supplies. We engineer to determine specifications for both hydro turbines and hydro turbine peripheral equipment, and also place orders with hydro turbine manufacturers. New products and technologies are applied to the control panel.

We are also strengthening activities aimed at improving the quality of the plant supplies in the engineering. As an example, we conduct a rotation test on generators during our pre-shipment self-inspection in the factory. Additionally, during on-site construction works and testing, we are strengthening our collaboration with each supplier. For that, we assign engineers to perform the overall coordination work for the on-site plant installation and test. This paper introduces four hydoropower plants completed in 2020, 2021, and 2022.

2 Introduction of Case Studies of Supplied Plant

2.1 Ichifusa No. 2 Power Plant of Kumamoto Prefectural Enterprise Bureau

2.1.1 Overview of Hydoropower Plant

This hydoropower plant uses water stored in the reservoir of the Kono Dam on the Kuma River in the Kuma River system, and directs it through an intake located on the left bank of the dam. This is a dam conduit-type hydoropower plant that directs the remaining amount of water after subtracting the amount of water used for irrigation to a pressure regulating water tank, passing through a penstock, and generating a maximum output of 2400 kW using a single water turbine generator, which is then discharged into the Kuma River. The power generated by this hydoropower plant is stepped up to 66 kV and transmitted to the power utility grid. This is a scrap-and-build construction project in which existing equipment is removed and newly manufactured hydro turbine generation facility is installed.

2.1.2 Supplied System Overview

The main supplied items are as follows.

Fig. 1 Generator

An external appearance of the vertical shaft synchronous generator is shown. At this power plant, the generator is installed on the barrel. For hydraulic turbine inspection, the inspector gains access to it from the supervisory lane located beside the barrel.

Fig. 2 Control Panels

This switchgear array accommodates an integrated control unit and transmission line protective relays.

(1) Hydro turbine
Type: Vertical shaft single-runner single-discharge spiral Kaplan turbine
Maximum output: 2480 kW
Maximum flow rate: 14.0 m^3/s
Effective head: 20.15 m
Rotation speed: 400 min^{-1}
(2) Generator
Type: Vertical shaft rotary field outlet duct circulated type three-phase synchronous generator
Output: 2700 kVA
Voltage: 6600 V
Number of poles: 18 poles
Frequency: 60 Hz
(3) Distribution switchgear/control panel
Medium voltage cubicle: 5 panels
Control panel and low voltage board: 12 panels

Fig. 1 shows the generator, and Fig. 2 shows the control panels.

2.1.3 Technical Features

(1) Electrification of runner vane operating mechanism

Fig. 3 shows the runner vane servomotor, and Fig. 4 shows the hydro turbine control panel and speed governor control panel. The hydraulic operating mechanism of the runner vane has been changed to an electric mechanism, which eliminates the need for auxiliary equipment and is easier to maintain, in addition to eliminating the need for oil, which is an issue with hydro power. The operating mechanism is mounted on top of the generator exciter. Additionally, the drive for the runner vane passes through the main shaft, which adjusts the opening degree of the runner vane at the tip of the runner.

Fig. 3 Runner Vane Servomotor

Since the vertical shaft generator is installed, the runner vane control mechanism of the Kaplan hydro turbine is mounted atop the exciter.

(2) Rotor test performed before factory shipment

The performance of this generator can be confirmed by conducting a rotation test in the factory, which eliminates on-site test items and contributes to shortening the construction period.

Fig. 4 Hydro Turbine Control Panel and Speed Governor Control Panel

An external appearance of the hydro turbine control panel and the speed governor control panel is shown. Control equipment of guide vanes and runner vanes is accommodated.

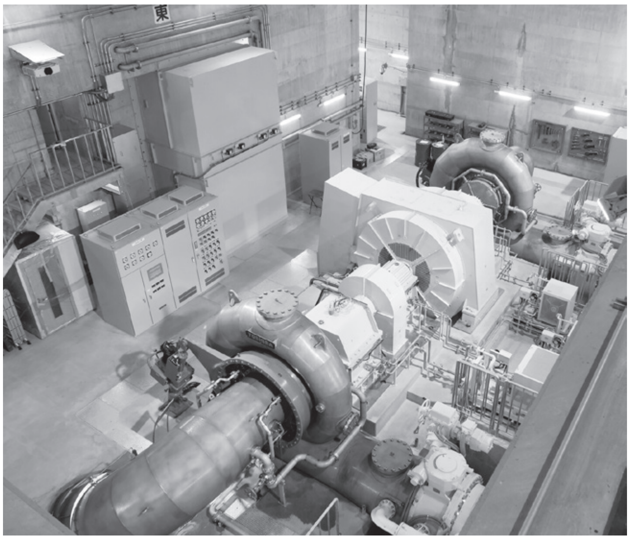

Fig. 5 Hydro Turbine Generator

The hydro turbine control panel is allocated. It is used for the control of hydro turbine generator, inlet valve, and main machine body.

Fig. 6 C-GIS

An external appearance of the C-GIS for the substation facility is shown.

2.2 Yamba Hydoropower Plant of Gunma Prefectural Corporate Affairs Bureau

2.2.1 Overview of Hydoropower Plant

The Yamba Hydoropower Plant takes water from the Yamba Dam and generates a maximum output of 11,700 kW using a double-hung Francis turbine. Power is transmitted to the transmission line of TEPCO Power Grid, Incorporated.

2.2.2 Supplied System Overview

The main supplied items are as follows.

(1) Hydro turbine
Type: Horizontal shaft double-runner single-discharge spiral double-hung Francis turbine
Maximum output: 12,600 kW
Maximum flow rate: 13.6 m^3/s
Effective head: Max. 105.80 m
Rotation speed: 600 min^{-1}

(2) Generator
Type: Horizontal shaft rotary field outlet duct circulated type three-phase synchronous generator
Output: 12,400 kVA
Voltage: 6600 V
Number of poles: 10 poles
Frequency: 50 Hz

(3) Main transformer
Type: Oil-immersed self-cooled type
Number of phases: 3-phase
Capacity: 12,400 kVA
Voltage: 6.45 kV/F69 – F67.5 – R66 – F64.5 kV

(4) Gas Insulated Switchgear (GIS)
Type: C-GIS
Rated voltage: 72 kV
Rated breaking current: 20 kA
Configuration: Circuit breaker, disconnector, earthing switch, etc.

(5) Switchgear, control panel
Medium voltage cubicle: 8 panels
Control panel and low voltage panel: 21 panels

Fig. 5 shows the hydro turbine generator. Fig. 6 shows the C-GIS. Fig. 7 shows the main transformer.

Fig. 7 Main Transformer

The main transformer is shown. It is a step-up transformer to raise the generator output voltage up to the power transmission voltage (grid voltage).

2.2.3 Technical Features

(1) Runner seal cooling during single-runner operation of the turbine

The horizontal shaft double-runner single-discharge spiral double-wheel Francis turbine was used, and by switching between a single-runner and double-runner operation, it was possible to cope with variable head and variable flow. During a single-runner operation, the runner of the stationary unit spins idly, causing the runner seal of the stationary unit to generate heat due to wind damage. As a method for dissipating (cooling) heat from the runner seal, we adopted a method that air-cools the runner seal by automatically fully opening the guide vanes and related piping of the stopped unit. Air cooling eliminates the need for auxiliary equipment for cooling water injection and the need to manage cooling water usage.

(2) Redundancy of Programmable Logic Controller (PLC) power supply

The PLC power supply for generator control has been duplicated to improve system reliability.

2.3 The Onogawa Hydoropower Plant of Oita Prefecture Public Enterprises Bureau

2.3.1 Overview of Hydoropower Plant

This hydoropower plant has been in operation for more than 60 years, and as it has deteriorated significantly, the equipment, including the power plant building, has been updated. It began operation in December 2021, with a maximum output of 10,100 kW, and is connected to the 66 kV Prefectural Distribution Line – "Onogawa Dainan Line" and then transmitted to the power utility's grid system.

2.3.2 Supplied System Overview

The main supplied products are as follows.

(1) Hydro turbine

Type: Vertical shaft single-runner single-discharge spiral Francis turbine
Maximum output: 10,510 kW
Maximum flow rate: 26.0 m^3/s
Effective head: 46.444 m
Rotation speed: 257 min^{-1}

(2) Generator

Type: Vertical shaft rotating field outlet duct circulated type 3 Phase synchronous generator
Output: 11,000 kVA
Voltage: 6600 V
Number of poles: 28 poles
Frequency: 60 Hz

(3) Main transformer

Type: Oil-filled self-cooled type
Number of phases: 3 phases
Capacity: 11,000 kVA
Voltage: 6.45/66 kV

(4) Outdoor switching equipment

Type: Open type
Rated voltage: 72 kV
Rated breaking current: 31.5 kA
Configuration: Circuit breaker, disconnector, transformer, lightning arrester

(5) Complete switchboard

Medium voltage cubicle: 7 panels
Control panel and low-voltage panel: 18 panels

2.3.3 Technical Features

(1) On-site assembly of the generator

The generator at this hydoropower plant has 28 poles and is large, so the insulation method is a heat press method. The generator was, therefore, assembled on-site rather than at the factory. The stator was delivered in two pieces, the coils of the split parts were fitted on-site, and the connections were insulated. In addition, the rotor was delivered separately, including the main shaft, rim, rotor windings, and field lead wires, and assembled on site, insulating the connections between the rotor windings and field lead wires. After the stator and rotor were assembled, a withstand voltage test was conducted on-site to confirm the effectiveness of the insulation. Fig. 8 shows the on-site generator assembly.

(2) Application of next-generation control panel

The control panel uses our company's "full-functional integrated control and protection system

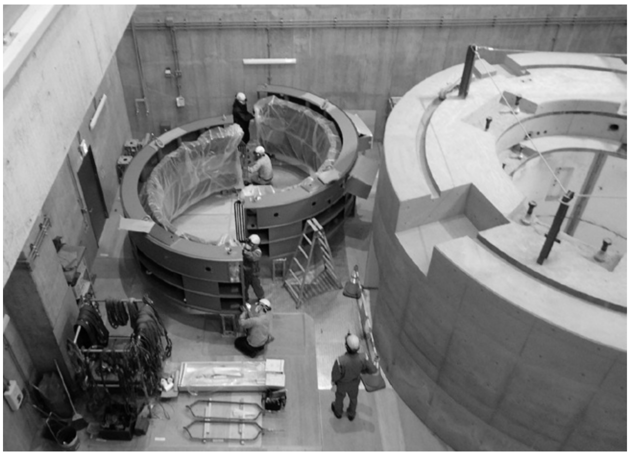

Fig. 8 **A View of On-Site Generator Assembly**

The generator stator is assembled on the site.

(next-generation control panel)”. The next generation control panel consists of a MASTER panel and a SLAVE panel. By installing the MASTER panel in the control room and the SLAVE panel near the hydro turbine and auxiliary equipment, cable installation work was reduced and construction time was shortened. Since this power plant is a power plant using a vertical shaft water turbine generator, it is divided into four floors from the third basement floor to the first floor above ground. SLAVE panels were installed on the first basement floor and the first floor to shorten the construction period.

(3) Countermeasures against submergence risk of substation facilities

Since this hydoropower plant was installed near a river embankment, in consideration of flooding water levels, the installation height of the outdoor substation facilities installed outdoors was raised 3 m above Ground Level (G.L.). When increasing the height by 3 m, we decided on the height of the equipment stand and the height of the concrete to avoid any seismic problems. **Fig. 9** shows the substation facilities.

2.4 Nishi-Tenryu Hydoropower Plant of Public Enterprise Bureau, Nagano Prefecture

2.4.1 Overview of Hydoropower Plant

This hydoropower plant was built in 1961 at the end of an agricultural irrigation channel and has operated mainly by utilizing water that flows through the channel during the non-irrigation season when agricultural water is not used. In addition to updating aging equipment, this construction work included

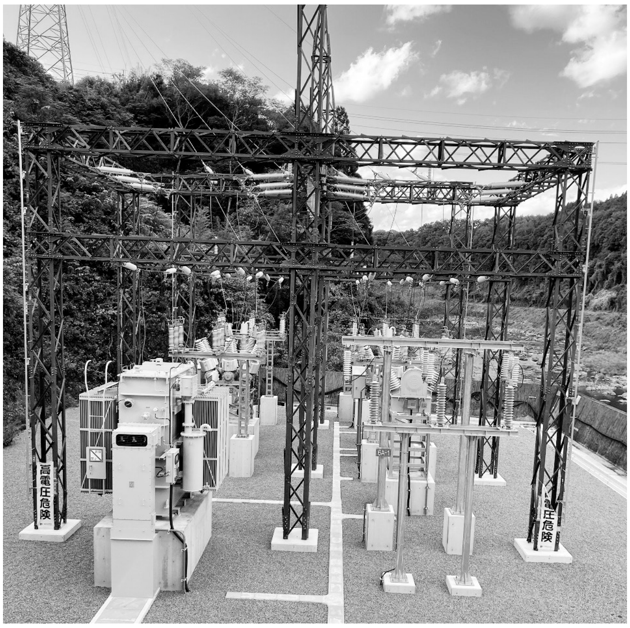

Fig. 9 **Substation Facilities**

An external appearance of the substation facilities is shown.

changing the number of water turbine generators from one to two without changing the maximum amount of water used, with the aim of making use of surplus water during the irrigation season and allowing year-round operation.

2.4.2 Overview of Supplied System

(1) Hydro turbine: 2 units

Type: Horizontal shaft single-runner single-discharge spiral Francis turbine

Maximum output: 1516 kW (per unit)

Effective head: 63.95 m

Maximum flow rate: 2.78 m^3/s (per unit)

Rotation speed ：720 min^{-1}

(2) Generator: 2 units

Type: Horizontal axis rotary field outlet duct circulated type three-phase synchronous generator

Output: 1600 kVA (per unit)

Voltage: 6600 V

Number of poles: 10 poles

Frequency: 60 Hz

(3) Main transformer: 1 unit

Type: Oil-filled self-cooled

Number of phase: 3 phases

Capacity: 3200 kVA

Voltage: 6.45/22 kV

(4) GIS: Complete set

Type: C-GIS

Rated voltage: 24 kV

Rated breaking current: 25 kA

Configuration: Circuit breaker, disconnector, earthing switch, etc.

(5) Complete power distribution switchgear

Medium voltage cubicle: 7 panels

Control board and low voltage board: 18 panels

Fig. 10 shows the hydro turbine generators.

2.4.3 Technical Features

(1) We have adopted our main product, the "fully-functional integrated control and protection system (next-generation control panel)", and delivered an integrated control panel that performs common control of multiple power generation equipment. Fig. 11 shows the integrated control panel.

(2) We also delivered a monitoring and control device that can be used to remotely display and operate measurement and protection items, as well as to assist with daily report output. It is expected that we will realize further advanced maintainability through active use of Internet of Things (IoT) in the future.

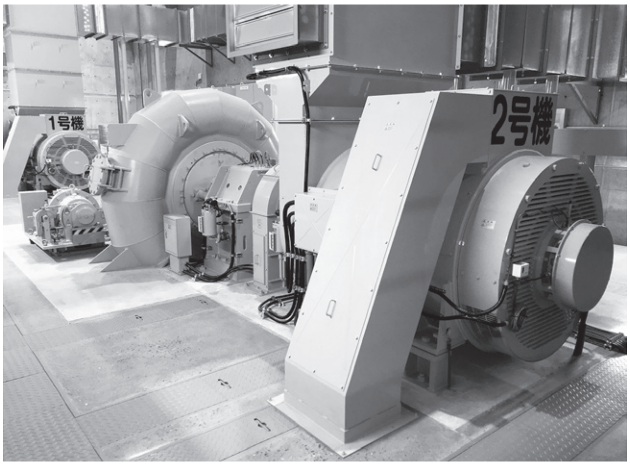

Fig. 10 Hydro Turbine Generators in Power Plant

Two units of horizontal shaft Francis turbine generators are installed.

Fig. 11 Integrated Control Panel

The next-generation control panels are adopted here. Since this power plant has two hydro turbine generators, the integrated control panel is installed to assure a common control of multiple generators.

3 Our Initiatives to Improve Quality of Hydropower Plants

3.1 Rotation Test Conducted Before Generator Shipment

3.1.1 Implementation Scope and Purpose

Rotation tests are performed on all horizontal axis machines and those that can be tested (depending on output and rotational speed) on vertical axis machines before shipping. This allows for the checking of the performance of the vertical axis machine in advance. Fig. 12 shows the rotation test in the factory, and Fig. 13 shows the completed generator on-site.

3.1.2 Results

By conducting a factory rotation test to confirm performance before the on-site water test, the assembly situation can be grasped in advance, and the on-site generator test can be omitted, contributing to a shorter on-site assembly process.

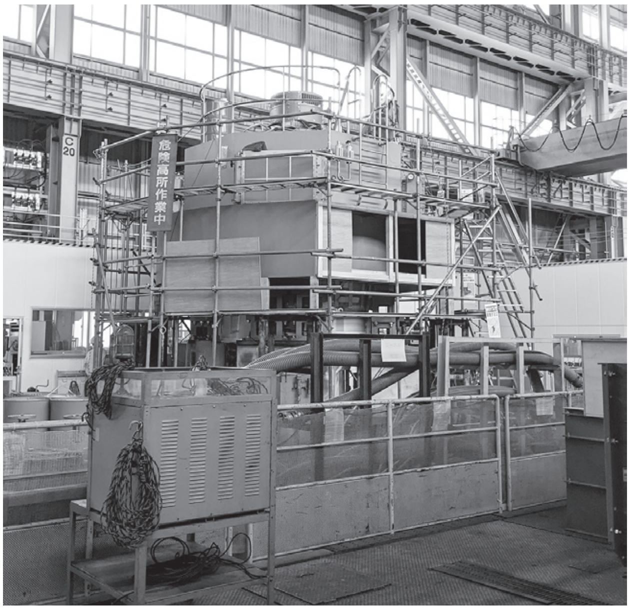

Fig. 12 A View of Rotation Test in Factory

A view of a rotation test in the factory is shown. The generator is temporarily assembled before shipment and its rotor is rotated to examine the performance characteristics.

Fig. 13 A View of Completed Generator On-Site

The tested equipment exhibited in **Fig. 12** is shown in the state of actual installation on-site.

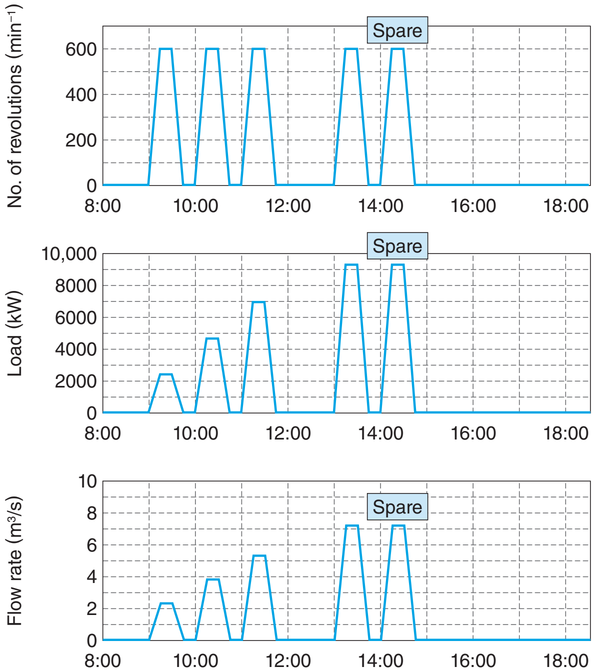

Fig. 14 Water Usage Plan for Water Immersion Test (Excerpt from Test Plan)

Before implementation of the load shutdown test, the amount of water to be consumed is explained to the customer and the water immersion test is then carried out at the site.

3.2 Project Co-Ordination Engineer for On-Site Plant Test

3.2.1 Purpose

To make a large amount of electrical equipment, hydro turbines, auxiliary equipment, and other mechanical products that work together on-site, sufficient consideration must be given in advance to verify the performance of the individual equipment and the combination of these equipment. For this reason, a project co-ordination engineer for the on-site plant test formulates a test plan early, including test items, processes, water operation, and securing power supply for the test.

3.2.2 Implementation Details

(1) Examine the consistency of the on-site construction schedule and equipment delivery, and the on-site construction and testing schedule, and create a waterless/watered test plan and test schedule according to the progress on site.

(2) Plan power outages, power reception, water charging, discussed and collaboration with customers.

(3) Establish safety management and hold points for testers for each device, judge the results of each test, give permission to start the next process, and provide feedback to the site.

(4) Consider water consumption patterns and water test implementation guidelines. There are often restrictions on the amount of water that customers can use at each site, and we discuss in advance what to do if we are unable to proceed due to equipment testing. **Fig. 14** shows the water usage plan for the water immersion test.

(5) Make a comprehensive judgment on the test results.

3.2.3 Effects

(1) A system for managing local information and providing instructions to the local area was established.

(2) Achieved stronger collaboration with customers.

(3) Reliable testing was carried out by coordinating schedules with on-site construction.

(4) The quality of test plans and report summaries was improved.

4 Postscript

We introduced four hydoropower plants that were completed in 2020, 2021, and 2022. With the increased use of hydro power, which is attracting attention worldwide as an energy resource for the realization of a decarbonized society, there is an increasing need for the ability to handle hydropower plant engineering. We have a long history in hydropower generation. Passing on these skills and expertise to the next generation is also an important initiative for sustainable business, so we are working to strengthen the inheritance of technology. The supplied examples introduced here were handled by our new generation engineers.

We carry out integrated total plant engineering for power generation equipment from the planning and basic design stages, including actual planning, manufacturing, installation work, testing and adjustment, and maintenance management. We will continue to build up our track records in order to supply even more reliable equipment in the future. We are determined to do our best to contribute to the spread of the use of hydoropower generation facilities.

Finally, we would like to express our deep gratitude to our customers – Kumamoto Prefectural Enterprise Bureau, Gunma Prefectural Corporate Affairs Bureau, Oita Prefecture Public Enterprises Bureau, and Public Enterprise Bureau, Nagano Prefecture, as well as all those involved with these projects for their guidance and cooperation.