Dams and Reservoirs under Changing Challenges – Schleiss & Boes (Eds)
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Development of small hydropower plant utilizing pumped storage power plant's dam

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ABSTRACT: The Kazunogawa dam, which is the lower dam of the Kazunogawa pumped storage power plant, is a concrete gravity dam with a height of 105.2 m, and its reservoir has an effective storage capacity of 8.3 million m^3. In the Kazunogawa hydropower plant, discharge outlet structures were installed in the Kazunogawa dam to discharge the river inflow downstream for river conservation measures. In order to utilize the river inflow and the dam head effectively, Tokyo Electric Power Company Co., Inc. (TEPCO) decided to construct the Tsuchimurogawa hydropower plant, which has a maximum output of 350 kW with an effective head of 89.94 m at a maximum discharge of 0.5 m^3/s, just downstream of the Kazunogawa dam. It began commercial operations in December 1999. The development of the small hydropower plant utilizing the pumped storage power plant's dam makes it possible to prevent areas of water scarcity and allows for the effective use of renewable energy.

1 INTRODUCTION

TEPCO has been engaged in the development of pumped storage power generation in order to ensure high quality and a stable power supply. TEPCO's Kazunogawa hydropower plant is located near the Tokyo metropolitan area where electricity consumption is high.

The general layout of the Kazunogawa project is shown in Figure 1. The Kazunogawa hydropower plant is a pure pumped storage power plant with an effective 714 m head with a maximum discharge of 280 m^3/s and a maximum generation output of 1600 MW with four motor-generators. Table 1 describes the features of the upper dam and the lower dam.

In order to utilize the discharging river inflow and the dam head effectively, TEPCO decided to construct the Tsuchimurogawa hydropower plant, which has a maximum output of 350 kW with an effective head of 89.94 m at a maximum discharge of 0.5 m^3/s, just downstream of the Kazunogawa dam. It began commercial operations in December 1999.

After completion, the plant produced a total power generation capacity of around 12,000 MWh, and reduced CO_2 emissions by approximately 11,000 tons, which was calculated based on the capacity of the coal thermal power plants.

In this paper, the planning and the design of the small hydropower plant including the electrical equipment will be reported on.

2 INFLOW AND DISCHARGE IN THE KAZUNOGAWA DAM

The Kazunogawa dam is a concrete gravity dam with a height of 105.2 m, and its reservoir has an effective storage capacity of 8.3 million m^3. In the Kazunogawa hydropower plant, after completing the designated storage to the reservoir, the storage of water from the river inflow into the reservoir has not been permitted by the government due to river conservation measures.

Therefore, some discharge outlet structures were installed in the Kazunogawa dam to discharge the river inflow downstream. The relationship between the river inflow into the reservoir and the discharge of it downstream is shown in Figure 2.

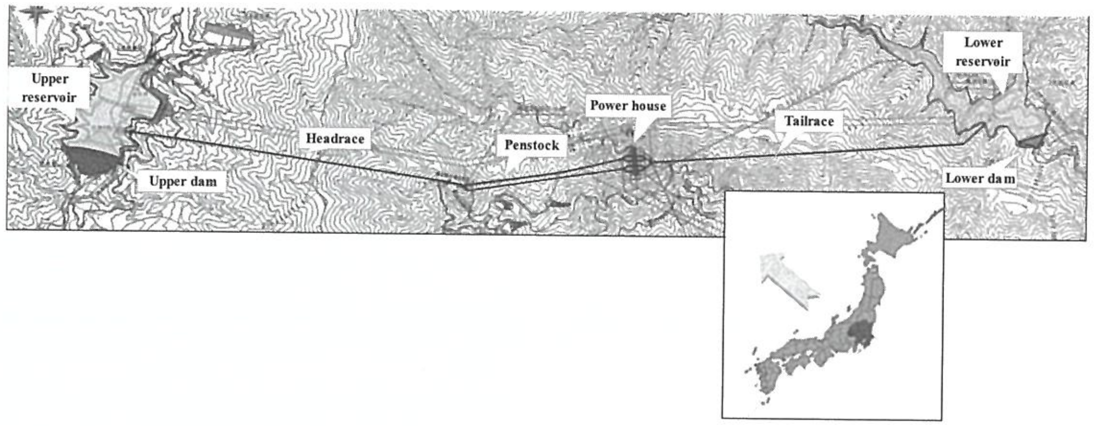

Figure 1. The location and the general layout of the Kazunogawa project.

Table 1. The features of the dams of the Kazunogawa project.

Item	Upper dam	Lower dam
Dam type	Rockfill (Centre core)	Concrete gravity
Height (m)	87	105
Crest length (m)	494	264
Volume (m^3)	4.11 million	0.62 million
Effective storage capacity (m^3)	8.30 million	8.30 million

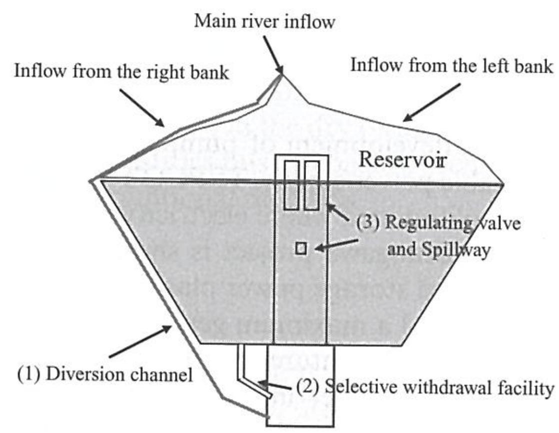

Figure 2. Inflow into the reservoir and its discharge into the downstream in the Kazunogawa dam.

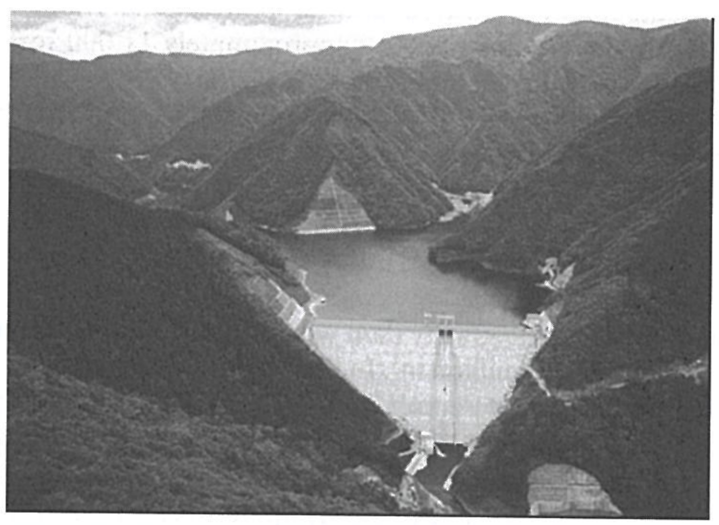

Photo 1. Overview of the Kazunogawa dam and the reservoir.

Their functions are as follows:

1. Diversion channel
   The inflow from the main river and the right bank has been discharged from the diversion channel. The maximum discharge is 0.25 m^3/s, which was calculated based on the mean inflow for ten years in the Kazunogawa dam.
2. Selective withdrawal facility
   The selective withdrawal facility, whose maximum discharge capacity is 2.0 m^3/s calculated based on the mean inflow for ten years in the Kazunogawa dam was installed to discharge the inflow from the left bank. This facility is used as the intake of the Tsuchimurogawa hydropower plant, which produces 350 kW with a maximum turbine discharge of 0.5 m^3/s.
3. Regulating valve and spillway
   When the inflow into the reservoir exceeds 2.25 m^3/s or there is a flood, the water is discharged from the regulating valve and the spillway. The design flood is 480 m^3/s based on the Creager's curve of the Kazunogawa dam site, whose catchment area has 13.5 km^2.

3 OVERVIEW OF THE TSUCHIMUROGAWA HYDROPOWER PLANT

The features of the Tsuchimurogawa hydropower plant are shown in Table 2. The development of the Tsuchimurogawa hydropower plant utilizing the Kazunogawa dam makes it possible to prevent areas of water scarcity from forming and allows for the effective use of renewable energy. Further, it is possible to reduce the costs and shorten the construction period by utilizing the existing discharge outlet structure as shown in Figures 3 and 4.

Table 2. The features of the Tsuchimurogawa hydropower plant.

Generation type	Dam and Run-of-river type
Maximum output (kW)	350
Maximum turbine discharge (m^3/s)	0.5
Effective head (m)	89.94
Annual energy generation (MWh)	1,225

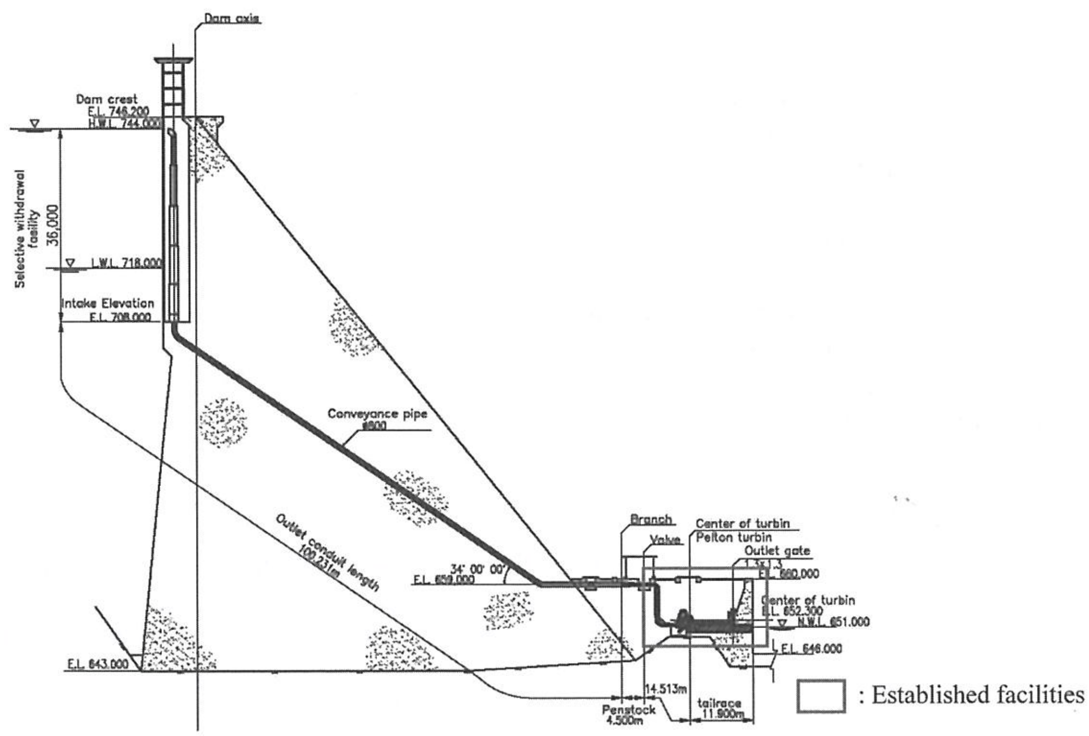

Figure 3. Overview of the Tsuchimurogawa hydropower plant.

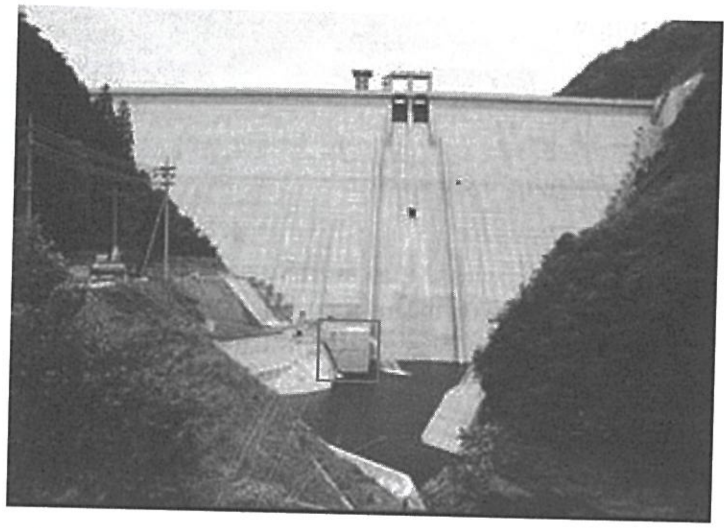

Photo 2. Overview of the Kazunogawa dam and the location of the Tsuchimurogawa hydropower plant.

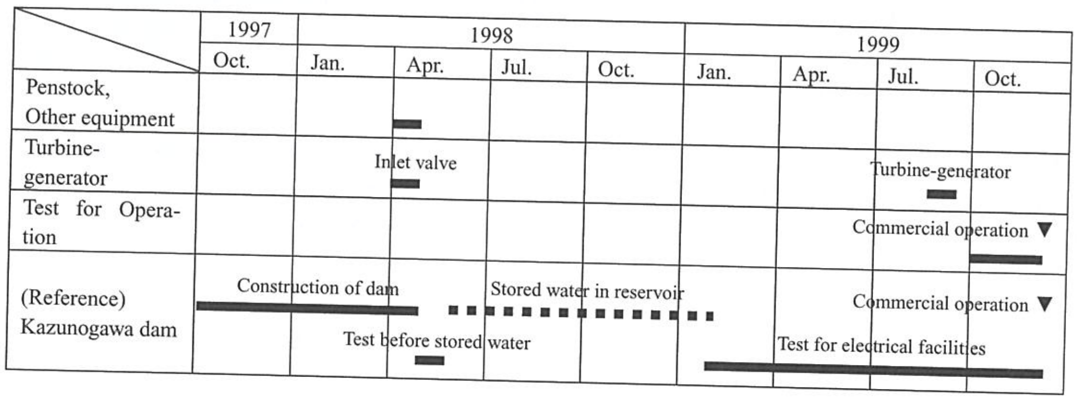

Figure 4. Construction schedule of the Tsuchimurogawa hydropower plant.

4 PLANNING AND DESIGN OF FACILITIES

4.1 *Planning of the waterway route*

Since the development planning of the Tsuchimurogawa hydropower plant was carried out during the construction of the Kazunogawa hydropower plant, it is possible to utilize the discharge outlet structure of the Kazunogawa dam as the intake effectively and ensure in advance that the area of the power house is just downstream. Further, the waterway route was determined to be the shortest distance from the intake to the power house in order to reduce the friction loss in the penstock.

From an environmental perspective, it is necessary to prevent areas of water scarcity so that the location of the outlet was selected in the stilling pool of the Kazunogawa dam.

As a result of these efforts, the decision of the waterway route called for the reduction of the construction costs and the shortening of the construction period.

4.2 *Optimization of the development scale*

Empirically, the optimum development scale of the run-of-river generation type becomes the load factor from 40% to 65% based on the common operation manner in Japan.

The comparison of the economic efficiency was carried out via the three cases, which were the turbine discharge of 0.44 m^3/s, 0.50 m^3/s and 0.52 m^3/s respectively, as shown in Table 3.

As a result, the optimum development scale was determined to be 350 kW with a turbine discharge of 0.5 m^3/s at the Tsuchimurogawa hydropower plant.

Table 3. The comparison for the optimum development scale.

Cases / Items	Turbine discharge (m^3/s)		
	0.44	0.50	0.52
Load factor (%)	50	47	45
Maximum output (kW)	300	350	360
Annual energy generation (MWh)	1,146	1,225	1,236
Economic effectiveness	1.02	1.00	1.01

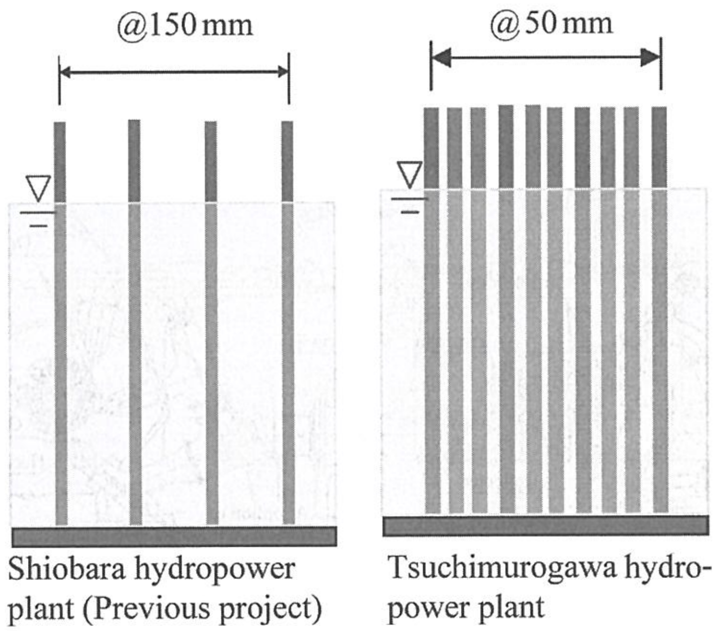

Figure 5. Overview of the screen bar space for the selective withdrawal facility.

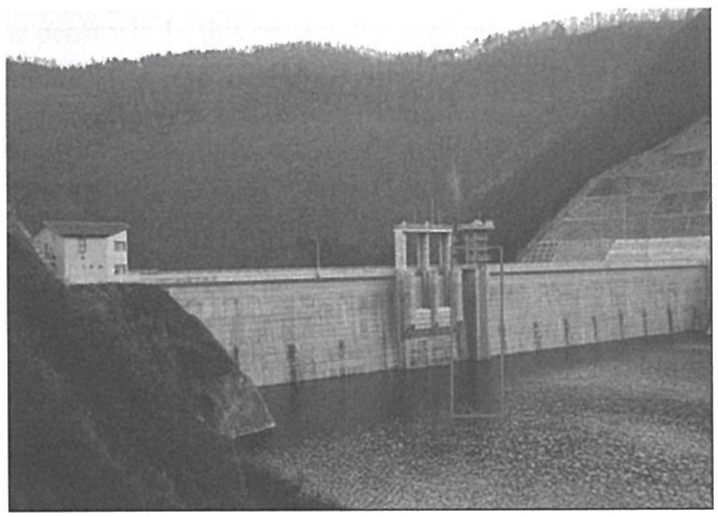

Photo 3. The intake of the Tsuchimurogawa hydropower plant from the upstream of the Kazunogawa dam.

4.3 *Design of the screen bar space for the selective withdrawal facility*

Since it is necessary to prevent an inflow of reservoir rubbish in order to prevent turbine trouble, a screen, whose bar space is narrower than the previous project, was installed in the selective withdrawal facility as shown in Figure 5.

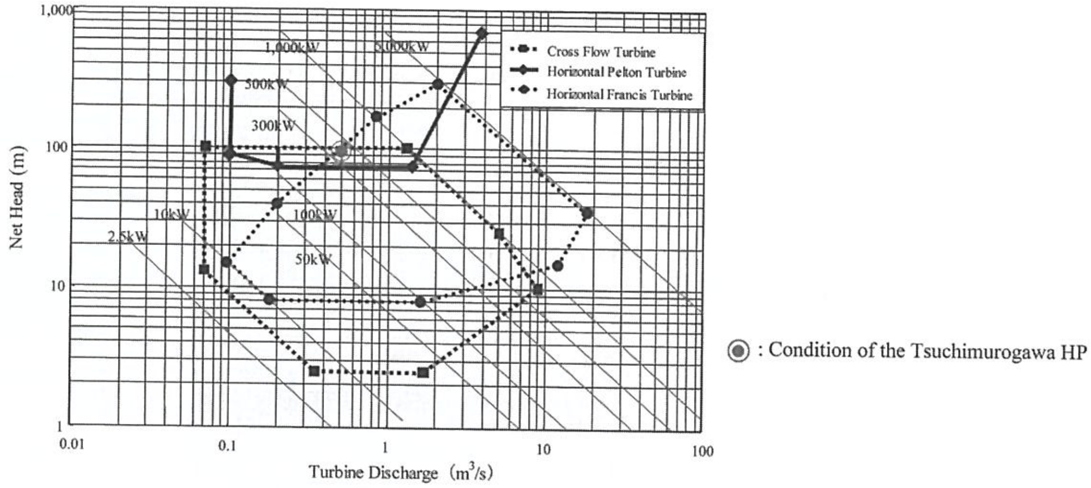

Figure 6. The application chart of the small-size hydro turbine.

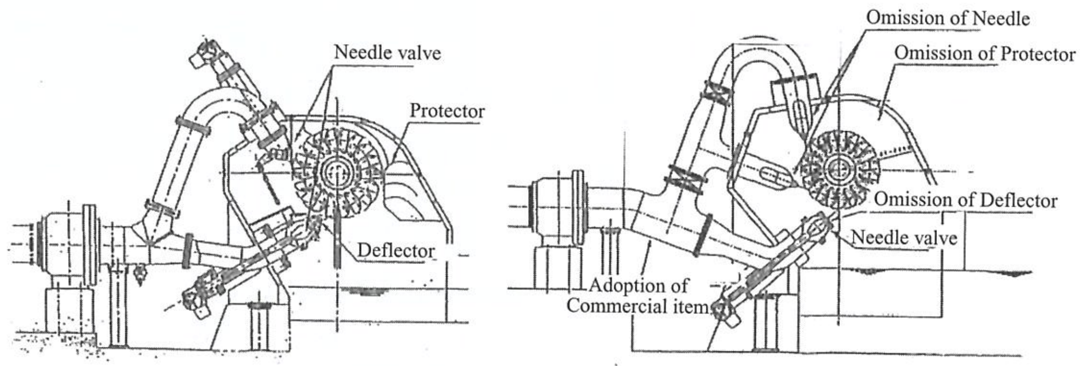

Figure 7. The comparison between the conventional type and the new type of the pelton turbine.

4.4 *Design of the electrical equipment*

4.4.1 *Selection of the turbine type*

The application chart of the small-size hydro turbine which is the relationship between the head and the turbine discharge is shown in Figure 6. According to this figure, the three turbine types, that are the cross flow turbine, the horizontal pelton turbine and the horizontal francis turbine, meet the conditions of the Tsuchimurogawa hydropower plant.

As a result of the comparison of economic efficiency, maintenance conditions and so on, given that the horizontal pelton turbine was superior to the others, we decided to adopt it.

4.4.2 *Design of the electrical equipment*

Generally, the horizontal pelton turbine is used for small generation capacity, and the numbers of runners and the jets of it have various combinations. The pelton turbine can regulate the output by changing the number of nozzles during the operation, and high efficiency operations can be obtained even in the low turbine discharge area.

In designing the turbine, research has been carried out by TEPCO and an electrical manufacturer in order to reduce the construction costs through improving the specifications.

As a result, the new simplified pelton turbine was applied to the Tsuchimurogawa hydropower plant as shown in Figure 7.

The special features of the new simplified pelton turbine are as follows:

1. Reduction of the two needle valves among the three one

   To improve the turbine efficiency, the single runner and three jets pelton turbine was determined. It is possible for the designed structure to regulate the output utilizing a one needle valve and two conventional valves. As a result, the needle valve, which has a complicated structure, was decreased from three to one.

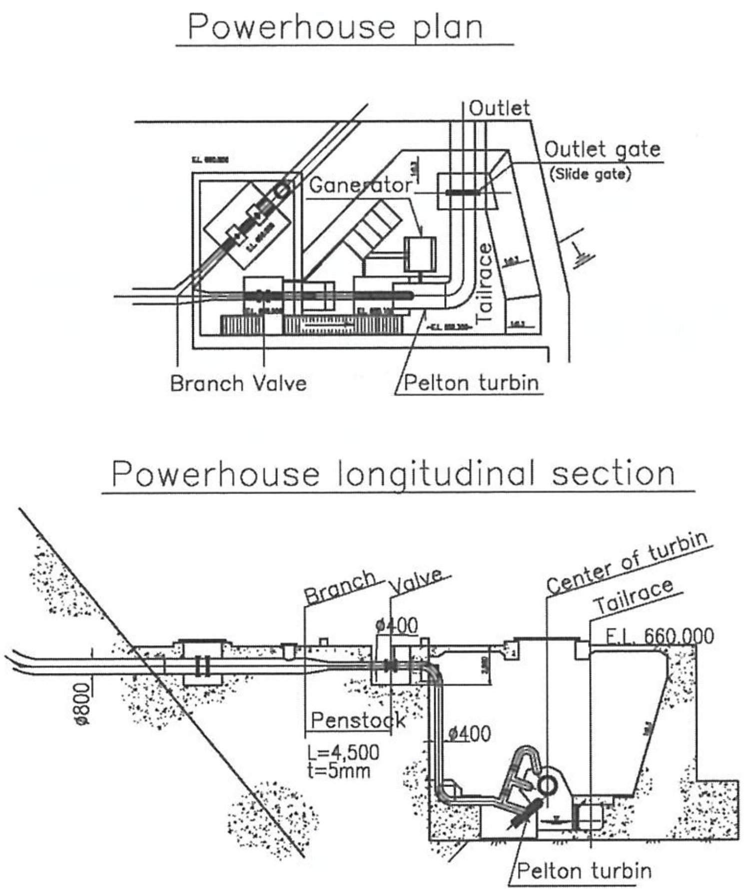

Figure 8. Overview of the new simplified pelton turbine.

2. Omission of the deflector
   At Load interception, the deflector must change the direction of the jet water to rev down the turbine-generator. During its working, the needle valve is closed in order to suppress the water pressure rise in the penstock. In this project, the application of the new turbine-generator, this is proof against a rev up at load interception, made it possible to leave the deflector out.
3. Omission of the protector
   The protector is generally installed to prevent the jet water from flying in all directions due to deflector changes at the load interception and hit the runner again. With regards to the aforementioned, the application of the new turbine-generator is proof against the rev up at load interception making it possible to omit the protector.
4. Adoption of the commercial equipment
   The branch between the nozzle with a needle valve and the nozzle without needle valves was adopted by the commercial equipment due to satisfying the requirements.

The new simplified pelton turbine is shown in Figure 8. Further, its installation is described as shown in Photo 4.

5 RESULTS OF OPERATIONS

The Tsuchimurogawa hydropower plant began commercial operations in December 1999.

After completion, the plant produced a total power generation capacity of around 12,000 MWh, and reduced CO_2 emissions by approximately 11,000 tons, which was calculated based on the capacity of coal thermal power plants as shown in Figure 9.

In accordance with this figure, the plant was operated according to the original plan until 2006. However, since the operating conditions of the Kazunogawa reservoir has been

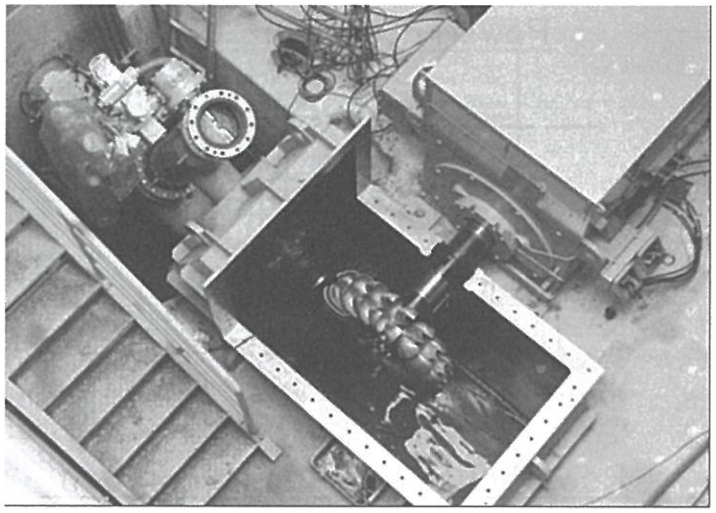

Photo 4. Installation of the new simplified pelton turbine of the Tsuchimurogawa hydropower plant.

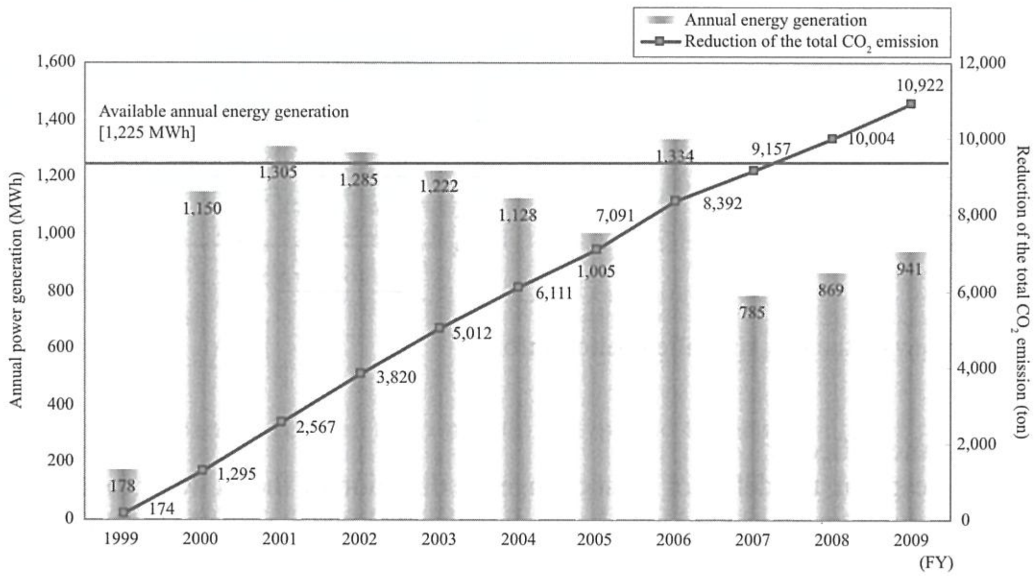

Figure 9. The results of the operations after completion.

changed under keeping closed to the low water level of the Kazunogawa dam, the plant has been affected by that.

6 CLOSING REMARKS

TEPCO is implementing a variety of activities to expand the utilization of renewable energy.

The development of a small hydropower plant utilizing the pumped storage power plant's dam makes it possible to prevent areas of water scarcity and allows for the effective use of renewable energy. Further, it is possible to reduce the costs and shorten the construction period by utilizing the existing discharge outlet structure and a simplified design of the turbine-generator.

Based on these results, the Togawa hydropower plant, which has a maximum output of 240 kW with a 50.55 m effective head at a maximum discharge of 0.6 m^3/s just downstream of the Imaichi pumped storage power plant, will be completed by 2011.

REFERENCE

New Energy Foundation, Japan, 1996. *Guide Manual for Development Aid Programs and Studies of Hydro Electric Power Projects.*