History of Japan's First Commercial Hydroelectric Generation at Keage Power Station

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Abstract — **Kyoto Prefecture launched the 'Lake Biwa Canal Project' in 1881, intending to channel water from Lake Biwa to Kyoto. Its original objective was to use the water for waterway transportation, water wheels, irrigation, fire-fighting, etc., but midway through its construction work the project was refined so as to include the hydroelectric power generation, based on the investigation of the hydroelectric plant just started in Aspen, Colorado, USA. This refinement gave birth to the Japan's first commercial hydroelectric generation at Keage in Kyoto.**

This article overviews the history of construction and operation of the Keage Power Station.

Index Terms — **DC/AC-generators, Keage Power Station, Lake Biwa Canal, Pelton turbine, single/2/3-phase AC-generation.**

I. Introduction

Following the relocation of Japan's capital to Tokyo in 1869, Kyoto City, which had served as the capital of Japan for more than a millennium, suffered a drastic decline with its population dropping from 350,000 to 250,000. Thus, the local government of Kyoto launched the 'Lake Biwa Canal Project' in 1881, which envisioned channeling water from Japan's largest lake, Lake Biwa, to Kyoto, with the aim of restoring Kyoto's prosperity.

The original objective of this project was to use the water of Lake Biwa for waterway transportation, water wheels, drinking, irrigation, fire-fighting, etc., but midway through the construction work, it was also decided to use the water for hydroelectric power generation, based on the investigation of the hydroelectric plant just started in Aspen, Colorado, USA. This visionary decision to revise the project to include power generation, gave birth to the Keage Power Station, Japan's first commercial hydroelectric plant.

In this article the history of construction and operation of the Keage Power station is overviewed.

II. Historic Background Of The Birth Of The Keage Power Station

Sakuro Tanabe, a student at *Kobu-Daigakko* (presently, Faculty of Engineering, University of Tokyo), was sent to Kyoto for the land survey, starting in 1881 at MihogaSaki in Ohtsu on the shores of Lake Biwa, and resuming in 1882 at several locations between Ohtsu and Kyoto, through which it was found that the water level of Lake Biwa was 43 meters higher than the altitude of Keage in Kyoto [4]. Based on this survey work, Tanabe completed his graduation thesis entitled 'A Construction Project of the Lake Biwa Canal', which was presented to the Department of Civil Engineering, Kobu-Daigakko, in May 1883. Just after graduation he was invited to Kyoto as a prefectural officer in charge of designing and supervising the 'Lake Biwa Canal Project' launched by Kyoto Prefecture [4].

To construct the Lake Biwa Canal, a number of difficult issues had to be resolved, such as the tunnel construction in the path of the canal, the fulfillment of high excavation precision, the utilization of domestic materials, etc., for which a range of the most sophisticated measures were arranged.

Thus, the construction work on the Lake Biwa Canal was started in June 1885, divided into the *trunk canal* (from the MihogaSaki Intake through the Keage Junction to the Reizei Outlet) and the *branch canal* (from the Keage Junction to the OgawaKashira Outlet), reaching 19.3 km in total length, and was completed in March 1890, resulting in the water intake of 8.3 m^3/s from Lake Biwa [1,5].

In the midst of this construction work, two project engineers, Sakuro Tanabe and Bunpei Takagi, were sent to the USA in October 1888 to investigate not only the canal transportation systems run in the Potomac Canal (297 km from Washington, D.C., to Cumberland, Maryland) and the Morris Canal (172 km from Philipsburg to Newark, New Jersey), but also the hydraulic wheel facilities utilized for textile and paper production in Lowell and Holyoke, Massachusetts [4].

In fact, as soon as they arrived in Vancouver, Canada, in November 1888, they started for Washington to see the transportation system operated in the Potomac Canal, and then moved on to Newark to inspect the inclined equipment run in the Morris Canal. Observing the actual situatios, they found that the two railroads, Baltimore & Ohio Railroad and Morris & Essex Railroad, running along these canals, could transport within ten hours an amount that might take several days to transport through the cannels [1].

Subsequently, they visited Lowell and Holyoke, where they saw the revolutionary harnessing of hydraulic power for textile and paper production by means of giant water turbines

[4]. However, faced with the fact that steam turbines would potentially be much more practical than water turbines, they thought that it would be unwise to develop regional industries in Kyoto by adopting water turbines. Thus, they keenly felt that what they were attempting in Kyoto would be lagging far behind the trend in the USA [1,4].

On that occasion, they luckily happened to hear about the hydroelectric plant just started a few months before at a silver mine in Aspen, Colorado. They immediately took a train from New York to Aspen, where they observed a 150 hp Pelton turbine and two generators, supplying power to the mine to lift the ore 1,000 ft. They were so impressed with this break-through innovation that they dared to decide to incorporate power generation into the Lake Biwa Canal Project. Thus, early in January 1889, on their way back to Japan, they visited the Pelton Water Wheel Company just established in San Francisco, from which they ordered several Pelton turbines [4]. As soon as they returned to Kyoto late in January 1889, they prepared a proposal to add the construction of the Keage Power Station to the Lake Biwa Canal Project, and submitted it to Kyoto City, which was approved in January 1892 [4,5].

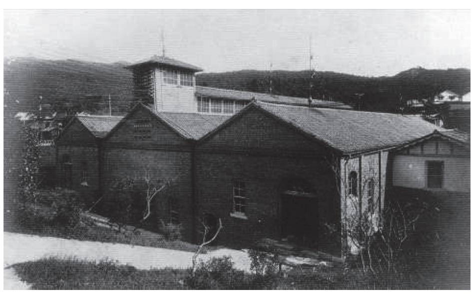

Fig. 1. Phase 1 Keage Power Station.

Fig. 2. Two penstock runs in Keage Power Station.

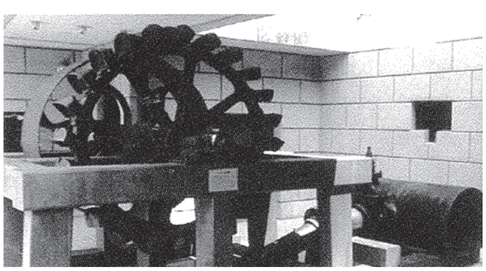

Fig. 3. One of installed Pelton turbines.

Consequently, the construction work on the Keage Power Station was started in January 1890, and was completed in May 1897 (see Fig, 1), provided with two penstock runs (see Fig. 2) and a total of 20 Pelton turbines (for example, see Fig. 3) for a hydraulic head of 32m [1,5]

III. Power Generation At The Keage Power Station

From June 1891 to May 1897, a variety of advanced DC- and AC-generators were installed one after another in the Keage Power Station, as shown in Table 1 [5], achieving a total capacity of 1,760 kW through the water intake of 6.9 m^3/s from the Lake Biwa Canal.

Specifically, these DC/AC-generators were installed, as briefed below:

(1) In June 1891, two Edison 80 kW DC-generators (see Fig. 4) were first installed in the Keage Power Station to supply power to the inclined equipment built in the station (see Fig. 5).

(2) In 1891 and 1894, a Thomson-Houston 75 kW and three GE 60 kW single-phase AC-generators, each operating at 125 Hz, were installed to meet the growing power demand for electric lights.

(3) In 1894 and 1895, two Stanley 60/80 kW and a Tokyo-Shibaura 60 kW 2-phase AC-generators, each operating at 133 Hz, were installed to meet the power demand for such industries as cotton spinning, textile production, etc. However, these 2-phase AC-generators soon became obsolete, resulting in the introduction of 3-phase AC-generators, as described below in (5).

(4) In 1895, two GE multipolar DC-generators were installed to supply power to the Kyoto Electric Railway Company, which operated Japan's first streetcars (see Fig. 6), running 6.4 km between Shiokoji (Kyoto Station) and FushimiAburakake.

(5) In 1896 and 1897, four Siemens 80 kW 50 Hz and two GE 100/150 kW 60 Hz 3-phase AC-generators were installed to meet the rising power demand for spinning, weaving, tobacco, metal foil working, and other industries. Thus, the Keage Power Station embarked on 3-phase AC-power generation, contributing to the development of AC-power industries.

It should be added here that with the growing necessity of long-distance transmission capability as well as with the wide-spread use of motors, 3-phase AC-generators soon dominated the power system market, and eventually the Keage Power Station pioneered the start-up of 3-phase AC-power generation, paving the way for the modernization of Japan.

IV. Phases 2 And 3 Keage Power Station

With the advance of power transmission facilities, the service area of the Keage Power Station gradually broadened,

TABLE 1. DC/AC-GENERATORS INSTALLED IN THE KEAGE POWER STATION

Date	Maker	Type	kW	Volt	Hz	Application
1891, 6	GE(*)	DC	80	500	---	power
1891, 6	GE	DC	80	500	---	power
1891, 6	TH(**)	AC 1(*3)	75	1100	125	light
1891, 12	GE	AC 1	60	2080	125	light
1894. 4	GE	AC 1	60	1040	125	light
1894, 4	GE	AC 1	60	2080	125	light
1894, 8	ST(*4)	AC 2(*5)	60	2000	133	power
1895, 6	TS (*6)	AC 2	60	2000	133	power
1895, 8	GE	DC m(*7)	200	500	---	elect. rail
1895, 9	ST	AC 2	80	2400	133	power
1895, 9	GE	DC m.	75	500	---	power
1895, 12	GE	DC m.	100	500	---	elect. rail
1896, 1	SH (*8)	AC 3(*9)	80	2000	50	power
1896, 4	SH	AC 3	80	2000	50	power/light
1896, 6	GE	AC 3	100	2400	60	weaving
1896, 6	SH	AC 3	80	2000	50	cotton spin.
1896, 9	GE	DC m.	200	500	---	cotton spin.
1896, 6	SH	AC 3	80	200	50	tobacco
1897, 5	GE	AC 3	150	2000	60	cotton spin.

(*)General Electric, USA, (**)Thomson-Houston, USA, (*3)single-phase AC-generator, (*4)Stanley, USA, (*5)2-phase AC-generator, (*6)Tokyo-Shibaura, Japan, (*7) multipolar DC-generator, (*8)Siemens-Halske, Germany, (*9)3-phase AC-generator.

but the adaption of 3-phase AC-generators triggered a drastic expansion of service field. Consequently, the demand for power rose so radically that the existing canal could no longer supply sufficient water to meet the demand [5,8].

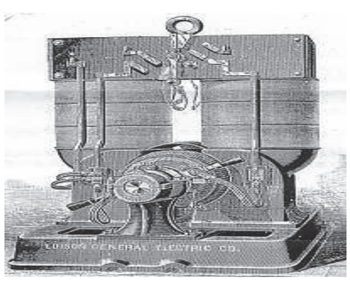

Fig. 4. Edison DC-generator installed in 1981.

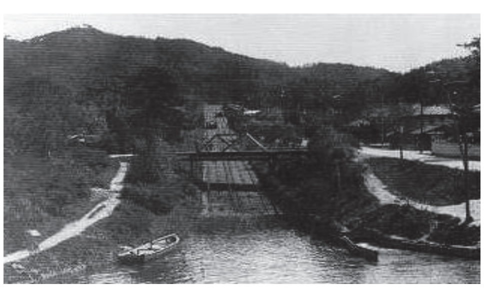

Fig. 5. Incline tracks built in the Keage Power Station.

Fig. 6. Japan's first streetcar in Kyoto.

Thereby, Kikujiro Saigo, the second mayor of Kyoto City, decided to build a second canal independent of the existing one, so that the two canals could be joined together to augment the water supply to the Keage Power Station. The construction work on the second canal was started in October 1908, and was completed in April 1912 [5], resulting in the increase in water intake from 8.3 m^3/s to 23.65 m^3/s [1].

In step with this augmentation of water intake, construction on a second station was started in March 1910 on the southern side of the first station, and was completed in May 1912, provided with five Escher-Wythe horizontal-shaft Francis turbines and five GE 3-phase AC-generators, achieving a capacity of 4,800 kW. To distinguish the existing station from the second one, the former and the latter have since been referred to as '*Phase 1 Keage Power Station*' and '*Phase 2 Keage Power Station*' (see Fig. 7), respectively. When the first two AC-generators installed in the Phase 2 Station were provisionally licensed in February 1912, the Phase 1 Station was decommissioned. Thus, the Keage Power Station was upgraded from the Phase 1 Station with a capacity of 1,760 kW to the Phase 2 Station with a capacity of 4,800 kW [5].

To make the best use of the discharge from the Phase 2 Station, which was augmented by the second canal, a decision was made to construct two additional stations, the Ebisugawa Power Station and the Fushimi Power Station (later renamed the Sumizome Power Station). The former was completed in April 1914, provided with a Boving horizontal-shaft Francis turbine and a Westinghouse 60 Hz 3-phase AC-generator, achieving a capacity of 280 kW; while the latter was completed in May 1914, provided with a Boving horizontal-shaft Francis turbine and a Westinghouse 60 Hz 3-phase AC-generator, achieving a capacity of 1,320 kW [5].

Fig. 7. The Phase 2 Keage Power Station.

Fig. 8. Hitachi AC-generator installed in the Phase 3 Keage Power Station.

Since the total capacity of these three stations reached 6,400 kW, the use of electricity grew year after year, until most of industrial facilities became dependent on electricity. Thus, Kyoto City realized the emergent necessity of expanding inexpensive power generation, and hence decided to construct the Phase 3 Keage Power Station. Construction work started in June 1932, and was completed in January 1936, provided with two Hitachi vertical-shaft Francis turbines and two Hitachi 60 Hz 3-phase AC-generators (see Fig. 8), achieving a capacity of 5,700 kW [5]. Eventually, the Phase 2 Station with a capacity of 4,800 kW was upgraded to the Phase 3 Station with a capacity of 5,700 kW. The capacity of this Keage Power Station has been reduced to 4,500 kW since April 1979, mainly due to the increasing use of water for drinking [8].

Finally, it should be added that

(a) the operating body of the Keage Power Station was transferred from Kyoto City to the Kansai *Haiden* (Power Distribution) Company by the Power Distribution Control Law in April 1942, and then to Kansai Electric Power Co., Inc. by the Electricity Company Reorganization Law in May 1951 [9],

(b) the operation of the station was switched to remote control from the Kojinguchi Control Office in December 1985 [5], and

(c) the present Keage Power Station has been operated by the Kyoto Dispatching and Control Center since June 2006.

V. Technical Significance

A. Construction of the Lake Biwa Canal

Due to the presence of mountains in the path of the Lake Biwa Canal, three tunnels had to be built. Judging from the technical level at that time, tunnel excavation was a major obstacle, since it involved such risks as cave-ins and dynamite accidents, plus problems of scarcity of skilled labor and construction machinery. To overcome the difficulties, a great variety of advanced machines, such as pumps, steam engines, air compressors, etc., were imported. Moreover, to build the 2,440m-long Nagarayama Tunnel, the longest in Japan at that time, a vertical shaft was dug so that lighting could be provided from above and earth and sand could be taken out, steam engines were adopted for hoisting at the vertical shaft, and compressed air was used for digging up soil [1,5].

On the other hand, accurate excavation was also a great obstacle, which was overcome by utilizing the most advanced triangulation method available at that time [5]. In addition, the materials for the construction work had to be domestically made to cultivate the material industry in Kyoto. To this end, a plant for producing bricks was established in Misasagi-mura (presently, Yamashina-ku, Kyoto City) [5].

Consequently, the Lake Biwa Canal enabled numbers of advanced generators to be run at the Keage Power Station in 1891 through 1897.

B. Development of AC-Power Supply

The commercial DC-era began in the early 1880s when Edison demonstrated his 'jumbo' bipolar generator for supplying power to a DC-lighting system. However, a debate over the usage of DC vs. AC arose in the USA in the late 1880s, with DC-power tending to yield to AC-power mainly due to the defects of DC, such as the difficulty of changing the voltage and the lack of long-distance power transmission capability, as mentioned earlier. Thus, DC-power generation proved to be a definite obstacle to the development of electricity supply [6].

In response, the Keage Power Station undertook the installation of Thomson-Houston and GE 125 Hz single-phase AC-generators in 1891 and 1894, expecting the development of AC-power systems [6]. Subsequently, this station installed Stanley and Tokyo-Shibaura 133 Hz 2-phase ac-generators in 1894 and 1895 to meet the power demand for industries of cotton spinning, textile production, etc. [6], as stated earlier.

On the other hand, in 1893 GE built the USA's first commercial 3-phase AC-system, driven by two hydroelectric 250 kW generators, where the power was transmitted 12.1 km at 2.4 kV. Furthermore, in 1896 GE also built a 35.5 km 3-phase transmission line operated at 11 kV to transmit power from Niagara Falls to Buffalo [6].

In this way, with the advance of long-distance power transmission capability as well as with the widespread use of motors, 3-phase AC-generators soon dominated the power system market both in the USA and in Japan [6]. In fact, in Japan the Keage Power Station installed Siemens and GE 3-phase AC-generators in 1896 and 1897, respectively, to meet the growing power demand for spinning, weaving, tobacco, and other industries.

Eventually, the Phase 1 Keage Power Station paved the way for 3-phase AC-power generation, pioneering the development of AC-power industries in Japan [6,7].

VI. Concluding Remarks

This article has overviewed the history of construction and operation of the Keage Power Station, which contributed to the modernization of Japan as described below.

After Japan was opened to the world by USA Commodore Matthew C. Perry in 1854, Western culture and technology steadily prevailed in Japan, including the start-up of electric light and power systems. Specifically, the Tokyo *Dento* (Electric Light) Company began providing service in 1887 using Edison DC-generators. Subsequently, more than 70 electric light and power companies, such as Kobe Dento, Osaka Dento, Kyoto Dento, Nagoya Dento, Shinagawa Dento, etc. [7], started to operate AC-generators all over Japan by the end of the 1890s.

Compared with several of these companies, the Phase 1 Keage Power Station was somewhat slower to start, but it succeeded in lowering electricity prices by adopting the most advanced AC-power systems only a few years later than the West. Thus, the 1890s was an era of revolutionary progress in electric light and power systems both in the West and in Japan [6,7].

In this way, the Phase 1 Keage Power Station pioneered in the start-up of 3-phase AC-power generation, contributing to the modernization of Japan.

Acknowledgement

The authors would like to express their cordial thanks to Mr. M. Noda and Mr. T. Tanioka, Kansai Electric Power Co., for their invariable supports and instructive discussions

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