Utilization of Renewable Energy in Metropolitan Waterworks: Is Renewable Energy a Key to Solving Energy and Environmental Issues?

T. Tanaka

Facilities Section, Tachikawa Water Supply Management Office, Tama Waterworks Reform Promotion Center, Bureau of Waterworks, Tokyo Metropolitan Government
6-7 Midoricho, Tachikawa City, Tokyo 190-0014 Japan
email: tanaka-toshihiko@waterworks.metro.tokyo.jp

Abstract: In the field of waterworks in urban areas, renewable energy is being utilized through implementing solar power generation at upper parts of facilities and hydraulic power generation using gravity flow of water and excess pressure. As a result, we learned that utilization of renewable energy not only decentralize and diversify energy supply to enhance reliability and environmental performance but also recover its costs sufficiently. This paper proposes a utilization model of renewable energy in metropolitan waterworks by presenting installation, maintenance and management of power generation equipment with renewable energy, their power generation volume, reduction of greenhouse gas emissions, future plans and further utilization methods.

Keywords: renewable energy; solar power generation; hydraulic power generation

1. Introduction

IWA President Kroiss questioned in his keynote lecture (Kroiss, 2015), “Is energy a key issue for urban water management?”, and emphasized the necessity of reliable energy supply and the importance of taking immediate action against climate change. As one of the actions to resolve these key issues, the Bureau of Waterworks, Tokyo Metropolitan Government (hereinafter referred to as “Tokyo Waterworks”), promotes the utilization of renewable energy.

Serving water to 13.04 million people and having the facility capacity of 6.86 million m^3 per day and 26,774 km-long distribution pipes in total (as of the end of March 2015), Tokyo Waterworks has one of the largest scales in the world. The water transmission and distribution pipe network of a city in which population and industries are concentrated in an undulating plain is extremely complex, but we supply tap water with appropriate pressure for end consumers. On the other hand, by its activity, we use around 1 percent (around 800 million kWh per annum) of the total electricity usage in Tokyo, which affects global environment in no small measure. Therefore, we need to make efforts to save energy as one of large-scale waterworks operator.

We have worked for energy saving and environmental countermeasures, such as management of water conservation forest (Nakamura, 2011), water leakage prevention measures (Toki, 2015) and improvement in efficiency of pump equipment (Iwasaki, 2012). As a result, the sand accretion rate of our dam is approximately 3 percent and the leakage rate of water transmission and distribution pipe network is approximately 3 percent, which is at the top level in the world. Therefore, considering cost-effectiveness, there are limitations to further improvement. Instead, in addition to the above-mentioned energy saving, there are more needs to create energy by environmentally friendly power generation. In other words, it is important to create renewable energy that had not been utilized in the past by solar power generation and hydraulic power generation and utilize such energy. These efforts also work for decentralizing and diversifying energy supply and enhancing its reliability.

It is considered that our experience of installing, maintaining and managing a lot of power-generating equipment in urban areas, our past records of utilizing renewable energy in various ways and our plans to promote the utilization in the future provide useful information for other waterworks. This paper proposes the utilization model of renewable energy in metropolitan waterworks.

2. Material and Methods

2.1 Solar Power Generation at Upper Parts of Facilities

In urban areas, it is difficult to find spaces for installing solar panels or to secure sufficient sunlight. In purification plants, Tokyo Waterworks has installed solar panels together with coverlids to prevent foreign matters from being thrown into filter basins (**Figure 1**). In recent years, we install solar panels on the top of distribution reservoirs and buildings (**Figure 2, 3**). It is noted that we give due consideration to neighboring residents by using anti-glare solar panels to reduce reflection of sunlight.

Figure 1 Filter basins

Figure 2 Distribution reservoir

Figure 3 Building

Data of water pressure, flow rate, etc., at each location within the water transmission and distribution pipe network are being collected, transmitted and recorded by telemeters, and some of these data are used for automatic control of transmission and distribution pumps. Therefore, if the telemeters stop functioning due to electric power failure, there might be a concern that it becomes difficult to implement proper water transmission and distribution. To avoid such a consequence, the telemeters that are important for water transmission and distribution are equipped with solar panels and storage batteries (**Figure 4**). In general, the power generation capacity of each equipped solar panel is weak as it is less than 100W, but it is expected to contribute to the stable operation of telemeters at the time of disaster.

We are currently testing a telemeter equipped with solar panels that have 200W or more of power generation capacity, aiming at enabling longer operation of telemeters at the time of power failure and decreasing dependence on commercial electric power source at normal time (**Figure 5**). As the size of solar panels becomes bigger, this test includes study on such issues as safety check, combination with storage battery and control of charge and discharge. In order to install this type of telemeters on public road, it is necessary to find out appropriate spaces and to take aesthetic considerations. Therefore, we have just started our trial at public parks where it is relatively easy to install such telemeters (**Figure 6**).

Figure 4 Telemeter

Figure 5 Test model of telemeters

Figure 6 Sample installation

2.2 Hydraulic Power Generation Using Gravity Flow of Water

In hydraulic power generation, we use gravity flow of raw water from reservoirs down to purification plants (**Figure 7**). Although it requires large-scale equipment in case of high effective head or large flow rate, it is ideal from the viewpoint of power generation capacity. Higashimurayama Purification Plant realizes hydraulic power generation with 1,400kW of power generation capacity by 13.5m of effective head and 13m^3 per second of flow rate (**Figure 8, 9**).

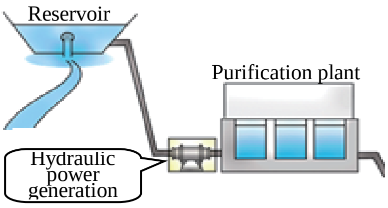

Figure 7 Using gravity flow

Figure 8 Hydraulic turbine

Figure 9 Generator

Himura Purification Plant, one of the small-scale purification plants of Tokyo Waterworks, which is located in a mountain-ringed area, realizes hydraulic power generation with 7kW of power generation capacity by 54m of effective head and 0.023m^3 per second of flow rate (**Figure 10, 11**). To keep the cost low, ready-made hydraulic power equipment was installed and 2 units were connected in series for the adjustment of high effective head and small flow rate. In general, since the volume of water intake is to be adjusted by the volume of water distribution, generated energy also changes its volume accordingly. Therefore, we made up a system to secure constant water intake and generated energy 24 hours a day by taking appropriate volume of water for power generation constantly from the upstream and discharging excess flow back to the downstream after generating. This system can lead to increase capacity factor of power generation equipment. As the river where the plant is located is relatively small-sized, it was rather easy to install the system within legal restraints related to river management. In addition, there still remains 26m or more of effective head after generating, it enables membrane filtration without a pressure pump. In other words, the plant runs hydraulic power generation with its utmost capacity factor by using gravity flow to a maximum extent, while it also purifies water through membrane filtration without additional energy at the same time. Although the plant is small-scale, it could be an ideal model case of purification plants taking advantage of gravity flow and renewable energy.

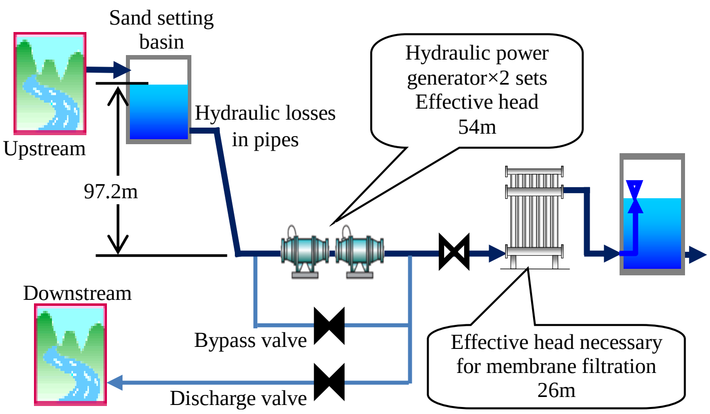

Figure 10 Serial connection of hydraulic generators and discharge

Figure 11 Serial connection of hydraulic generators

2.3 Hydraulic Power Generation Using Excess Pressure

Tokyo Waterworks is promoting minimization of the water transmission and distribution energy by making full use of various energy management systems (Okamura, 2013; Kaneko, 2014), but in the complex water transmission and distribution pipe network, it is nonetheless inevitable that excess pressure arises due to the different distances from pumps and altitudes. The excess pressure becomes unused energy due to the passage of pressure reducing valve and the pressure release at water supply station. Regarding this unused energy as renewable energy, we generate electricity by waterpower (**Figure 12**). Although it is difficult to find out new lands in urban areas, we have installed hydraulic power generation equipment in part of a small space at water supply station by re-arranging pipework in the station (**Figure 13**).

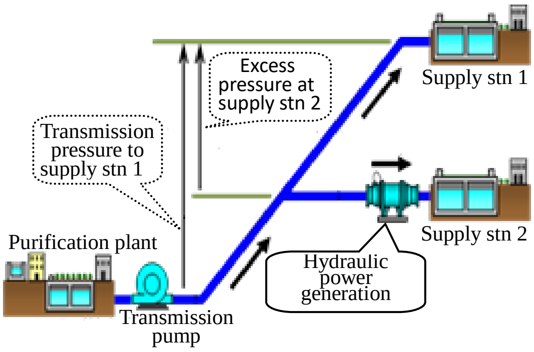

Figure 12 Using excess pressure

Figure13 Hydraulic power generation Equipment at water supply station

At Kohoku Water Supply Station (tentative name), which Tokyo Waterworks is currently constructing newly, high excess pressure is expected to arise. Therefore, in tandem with hydraulic power generation equipment, it is planned to install directly-connected water distribution pump (**Figure 14, 15**). Under this system, excess pressure that has been abandoned as unused energy before is used for power generation or booster by switching in accordance with water demand, and it is called the Hybrid Energy Saving System (Taniguchi, 2013; Matsuda, 2015).

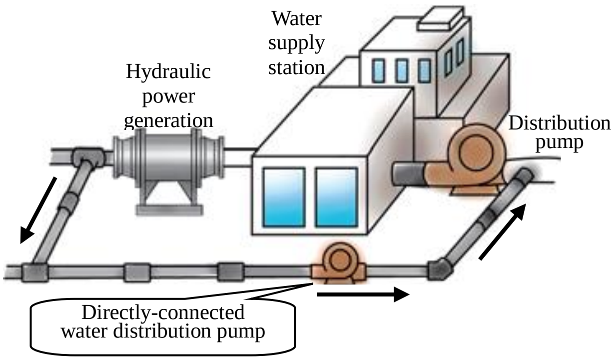

Figure 14 Hybrid energy saving system

Figure 15 Sample installation of directly-connected water distribution pump

3. Results and Discussion

3.1 Effects and Challenges of Solar Power Generation Equipment

The table below shows annual volume (from 1 April 2014 to 31 March 2015) of generated energy and reduction of greenhouse effect gas (CO2) emissions against power generation capacity of solar power generation equipment (**Table 1**). In calculating the volume of reduction of CO2 emissions, emission conversion factor

0.382t-CO2 per thousand kWh (Bureau of Environment, Tokyo Metropolitan Government, 2012) is used.

Table 1 List of solar power generation equipment

Name of Facility (P.P.: Purification Plant) (S.S.: Supply Station)	operation launched	Generation Capacity (kW)	1/Apr/2014-31/Mar/2015 Generated power (kWh/annum)	CO$_2$ reduction (t-CO$_2$/annum)	Installation location
Higashimurayama P.P.	1995	70	70,000	27	Distribution reservoir
Ogouchi Rearvoir	1999	125	70,000	28	Ground
Takatsuki P.P.	2004	20	20,000	6	Cover lids of filter basin
Asaka P.P.	2005	1,200	810,000	310	Cover lids of filter basin
Misono P.P.	2005	400	360,000	138	Cover lids of filter basin
Ozaku P.P.	2005	280	220,000	84	Cover lids of filter basin
Higashimurayama P.P.	2007	1,200	850,000	324	Cover lids of filter basin
Nagasawa P.P.	2007	200	170,000	64	Cover lids of filter basin
Kanamachi P.P.	2007	800	560,000	213	Cover lids of filter basin
Misato P.P.	2007	1,080	150,000	58	Cover lids of filter basin
Ozaku P.P.	2010	180	220,000	83	Distribution reservoir
Kinuta P.P.	2011	80	110,000	40	Distribution reservoir
Narahara S.S.	2015	250	200,000	75	Distribution reservoir
Kanamachi P.P.	2015	517	70,000	26	Distribution reservoir, building
Total		6,402	3,880,000	1,476	

As for solar power generation equipment, although there were some unfortunate cases that required minor repairs of lighting damage, no other major problems occurred and maintenance and management are easy. Accumulated total generation capacity of solar power generation equipment is 6,402kW. As solar power generation is possible only in daytime and dependent on weather, capacity factor remains relatively low as expected. However, as long as spaces for installation are secured, solar power generation has less trouble and can provide generated energy in a stable manner on a long-term basis. In particular, such water supply facilities as purification plants and water supply stations can get sunlight easily in urban areas as they have large spaces including upper parts of facilities. We are planning to increase energy generation by increasing accumulated total of generation capacity up to 8,000kW by the end of March 2020 and to 10,000kW by the end of March 2025. However, it is noted that increase in power sources with fluctuating output such as solar power generation may require arrangement of measures against output fluctuation.

The fact that peak time of solar power generation coincides with that of power demand in urban areas works beneficially for peak shaving or peak-cut, of which Nagasawa Purification Plant shows a good example. It is a medium-scale purification plant with the facility capacity of 200 thousand m^3 per day, and solar panels installed on the upper part of filter basins provide most, or sometimes more than 100 percent, of total electricity consumed by the plant during hours with good sunlight condition. This is partly because water intake and distribution are being managed by gravity flow, but solar power generation usually takes up 15 percent (annual average) of total electricity consumption.

Although Japan does not suffer electric power failure so much in a global sense, there are still risks of power failure. It is confirmed that when power failure happened several times, telemeters installed with solar panels and storage batteries functioned properly without any trouble and enhanced their reliability. Such installation appeared promising as decentralized electric power sources applicable not only to telemeters but also to other water supply equipment. From now on, we are studying to install solar panels and storage batteries as back-up power supply with broadly spread equipment such as industrial measuring instruments, automatic water quality meters and electric anti-corrosion equipment and verify their effects.

3.2 Effects and Challenges of Hydraulic Power Generation Equipment

The table below shows annual volume (from 1 April 2014 to 31 March 2015) of generated energy and reduction of greenhouse effect gas (CO2) emissions against power generation capacity of hydraulic power generation equipment (**Table 2**).

Table 2 List of hydraulic power generation equipment

Name of Facility (P.P.: Purification Plant) (S.S.: Supply Station)	operation launched	Generation Capacity (kW)	1/Apr/2014-31/Mar/2015		Installation location
			Generated power (kWh/annum)	CO_2 reduction ($t\text{-}CO_2$/annum)	
Higashimurayama P.P.	2001	1,400	Not counted due to repairing		Conveyance pipe of Raw water
Minamisenjyu S.S.	2005	95	690,000	265	Inlet pipe of distribution reservoir
Kameido S.S.	2008	90	280,000	107	Inlet pipe of distribution reservoir
Yagumo S.S.	2010	300	880,000	336	Inlet pipe of distribution reservoir
Kasai S.S.	2013	340	1,270,000	486	Inlet pipe of distribution reservoir
Himura P.P.	2015	7	Not counted due to recent launch		Inflow pipe of Raw water
Total		2,232	3,120,000	1,194	

As for hydraulic power generation using gravity flow, it is operated by using raw water which contains some amount of foreign matters and particles and thus, abrasion, erosion and corrosion of the parts tend to occur to a certain extent. For example, hydraulic power generation equipment at Higashimurayama Purification Plant went under overhaul and repair for the first time after 14 years from its installation. Especially, parts for shaft seal were found damaged seriously. As it could be caused by usage of raw water as shaft seal water, alteration was made in order to use purified water. This improvement can be expected to reduce mechanical failure.

With regard to hydraulic power generation using excess pressure, since the equipment uses purified water that does not contain foreign matters or particles, there were no major troubles occurred and it is easy to maintain and manage. Generation capacity of hydraulic power generation equipment is 2,232kW cumulatively and suitable places where hydraulic power generation can be conducted are limited, while it can operate 24 hours a day in most cases and thus, capacity factor is relatively high. Therefore, like solar power generation equipment, as long as spaces for installation are secured, it has less trouble and can provide generated energy in a stable manner on a long-term basis. From now on, we will examine the installation of hydraulic power generation equipment at the facilities requiring pressure reduction and pressure release.

Pertaining hybrid energy saving system, it can operate appropriately in response to water demand by using excess pressure to a maximum extent and thus, it is expected to produce a great effect on energy saving. According to a number of simulations, energy saving effect increases when directly-connected water distribution pump being operated. On the other hand, as retention time of water at water supply stations becomes longer, study on reduction of water distribution energy considering water quality is ongoing (Masuko *et al.*, 2011).

3.3 Challenges and Utilization Model of Renewable Energy

There are three forms of utilization of generated renewable energy; namely, self-consumption, self-consumption plus surplus power selling and full amount selling. In any case, support of public system is indispensable in order to recover construction costs and maintenance costs as well as to promote introduction of renewable energy. However, as public systems often change (for example, from the Excess Electricity Purchasing Schedule to Feed-in Tariff), we always need to select the most advantageous form to utilize renewable energy. Power generation equipment of Tokyo Waterworks started to respond to self-consumption at the beginning, gradually responded to self-consumption plus surplus power selling, and nowadays respond to full amount selling.

According to the standards set by Tokyo Waterworks, solar power generation equipment has 20 years of lifetime, while hydraulic power generation equipment has 22 years. Considering trial calculation so far and actual performance of power generation, it is highly possible to recover costs for construction and maintenance within their lifetime by appropriating reduced electricity costs by self-consumption and power selling profits though under the support of public systems. In particular, payback period of hydraulic power generation equipment is as short as 10 years. As for solar power generation, payback period varies depending on installation conditions and time of installation. This is because the price of solar panel decreases year after year, while purchase price of generated electricity under the Feed-in Tariff scheme goes down. It is necessary to observe price change and system trend closely when planning construction of power generation equipment in the future.

From the viewpoint of decentralization and diversification of energy supply for the important facilities, Higashimurayama Purification Plant shows an excellent example. The plant is a large-scale purification plant with the facility capacity of 1.265 million m^3 per day and the average power generation is approximately 5 million kWh per annum before the overhaul and repair of hydraulic power generation equipment. It is equivalent to 20 percent (annual average) of total electricity usage within the plant and it has recorded even 25 percent (annual average) (**Figure 16**). In this case, renewable energy consisting of solar power generation and hydraulic power generation covered nearly 30 percent of energy mix. This shows well-balanced energy mix combining several sources of electricity supply, which enhances reliability of energy supply. However, the ratio of renewable energy out of the total amount of energy consumption of Tokyo Waterworks as a whole is merely about 1 to 2 percent. We are making its effort to increase the share of renewable energy at other facilities by considering energy mix.

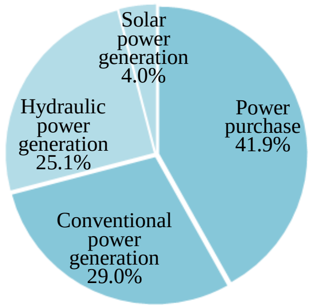

Figure 16 Energy mix of Higashimurayama

In Tokyo Waterworks, many facilities are facing the time of renewal. Taking the opportunity of the renewal, expansion and new construction of the facilities, we plan to optimize the facility placement and take full advantage of gravity flow for water intake, purification, transmission and distribution (Tokyo Waterworks, 2016). In addition, from our past research results and experience, we plan to place the solar panels and hydraulic power generation equipment appropriately and promote this as the utilization model of renewable energy (**Figure 17**).

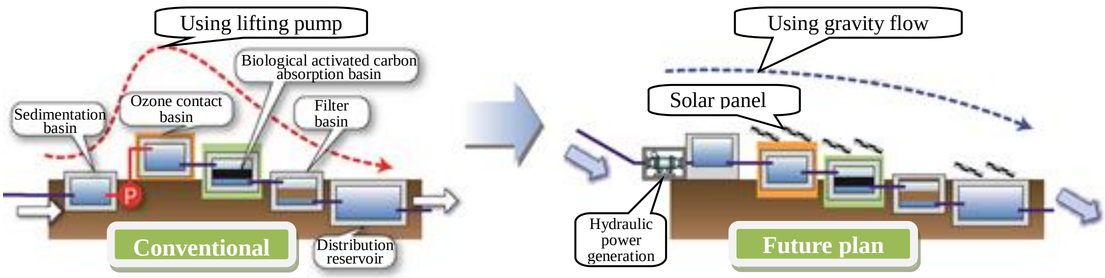

Figure 17 Utilization model of renewable energy

4. Conclusions

In response to the question, "Is energy a key issue for urban water management?", our answer is "Yes" and this paper shows one of the actions to resolve the issue. As for our own question, "Is renewable energy a key to solving energy and environmental Issues?", our answer is "Yes", too, and we launched Tokyo Waterworks Innovation Project (Tokyo Waterworks, 2016) in 2016. Under this project, in addition to solar power generation and hydraulic power generation, production and utilization of hydrogen are raised as one of its measures, which proposes production of hydrogen, by renewable energy. Empirical research on utilization of hydrogen generated by water purification plant facilities which has been exhausted, i.e. by-product hydrogen generated in the process of production of chlorine for chlorination, has been already planned. In this research, energy supply in ordinary time and utilization in emergency will be examined. Technology of production and storage of hydrogen would be potential measures for fluctuation of output of power generation by renewable energy. It is understood that through production of water and hydrogen, waterworks and energy supply will get closer. We are committed to progress of waterworks system and to sharing information inside and outside the country.

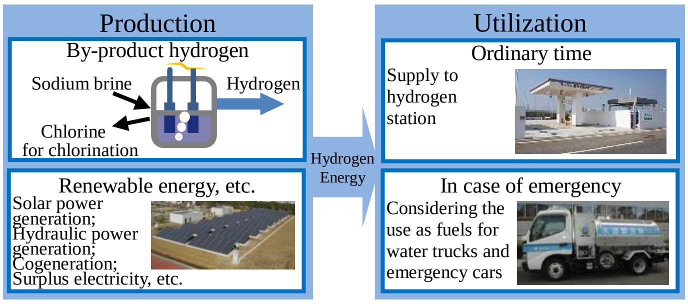

Figure 18 Image of hydrogen production and utilization

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