Stabilization of Power Source with Self-sustained Power Generation Facilities in Water Purification Plants

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1. Introduction

The Japanese Islands are located in an area under which plates constituting earth surface spread against each other, subject to earthquakes. According to the observation data during 2000 to 2009, 20% of all earthquakes with M 6.0 or more have occurred around Japan.[I]

Japan is under constant threat of large-scale earthquake attacks, such as the 2016 Kumamoto Earthquake most recently, and has faced repeated destruction of city infrastructure. Although there has not been any large earthquake directly hitting Tokyo for nearly 100 years since the Great Kanto Earthquake in 1923, the Japanese Government's Headquarters of Earthquake Research Promotion has computed the probability of an earthquake attacking Tokyo with seismic intensity 6-lower[II] or higher at 47%. Earthquake disaster countermeasures are an important and urgent issue for Tokyo.

When the Great Hanshin-Awaji Earthquake occurred in 1995, suspension of water purification facilities and water failure caused by power outage as well as breakdown of conduits and facilities were reported[III], and securing independent electric power source emerged as an important issue.

Moreover, in the aftermath of the Great East Japan Earthquake in 2011, scheduled blackouts were executed for 2 weeks in turns among wide-range areas of the east Japan including neighborhood of Tokyo mostly because of the damage to power stations. Although Tokyo was not directly attacked by the earthquake or tsunami, power supply to some water facilities was also stopped and consequently there were about 9,000 water failures and turbid water was supplied in 256,000 cases. The fear that power outage caused by a disaster also damages water supply has become reality.

Currently, Bureau of Waterworks, Tokyo Metropolitan Government (BWTMG) serves 13 million people, the biggest in Japan, with the water distribution amount to 4.6 million m^3 per day. Additionally, 80% of its raw water is taken from places at an altitude as low as 5m or lower, with power consumption for water purification and pumping reaching approximately 800 million kWh per year as a total of all sites. This power is equivalent to 1% of the power consumption in entire Tokyo.

In this way, BWTMG must cope with natural disasters including earthquake and able to respond surely while regularly consuming enormous amount of electric power. It is an important mission of water supply utilities to secure electric power necessary for the water supply and continue supplying water to disaster areas. This is also necessary for firefighting activities, rescue operation of victims, and numerous inhabitants who are obliged to continue living in stricken areas after the disaster.

[I] *White Paper on Disaster Management 2010* (Cabinet Office)

[II] People cannot keep standing and less earthquake-resistant wooden houses collapse (Japan Meteorological Agency seismic intensity scale)

[III] *Hanshin Awaji Daishinsai to Suido (The Great Hanshin-Awaji Earthquake and Waterworks)* (March 1997, Japan Water Research Center)

Outline of the Waterworks Bureau, Tokyo Metropolitan Government
(as of the end of March, 2016)

Start supplying water	Dec.1, 1890
Service area*	1,239km^2
Population served*	13,173,000
Number of service connections*	7,340,000 cases
Volume of water resources	6.30 million m^3/day
Water purification capacity	6.86 million m^3/day
Total length of distribution pipes	26,915 km
Number of employees	3,543
Total distribution amount per year**	1,530.3 million m^3
Average distribution amount per day**	4,181,000 m^3
Maximum distribution amount per day (2015.7.14)**	4,604,000 m^3

* : as of October 1st, 2015 **: through the year 2015

While BWTMG has been tackling the reinforcement of facilities and conduits against earthquakes, securing power supply is also important in continuing water supply at the time of disaster.

The author is going to treat of the matter of "preparing continuous power generation facilities in major water purification plants."

2. Policy of Preparing In-house Power Generation Facilities

As described above, power outage in city water facilities would give enormous impact on the water supply activities. Since 1995, BWTMG has been aiming at preparing city water facilities for the power outage so that they can supply 2.8 million m^3 per day during the power outage, considering the decline of water demand. However, BWTMG has judged that further reinforcement is necessary since Great East Japan Earthquake and changed the goal of the preparation in 2012.

Currently, the target performance of water supply plants is not set based on "the amount of water supply," which had been conventionally used, but defined "being able to fulfil the capacity of each water purification plant even while commercial power supply[IV] is discontinued." Self-supply of power is being advanced by implementing in-house generation facilities, including emergency generators, planning to complete in 2023, in major water purification plants of the BWTMG.

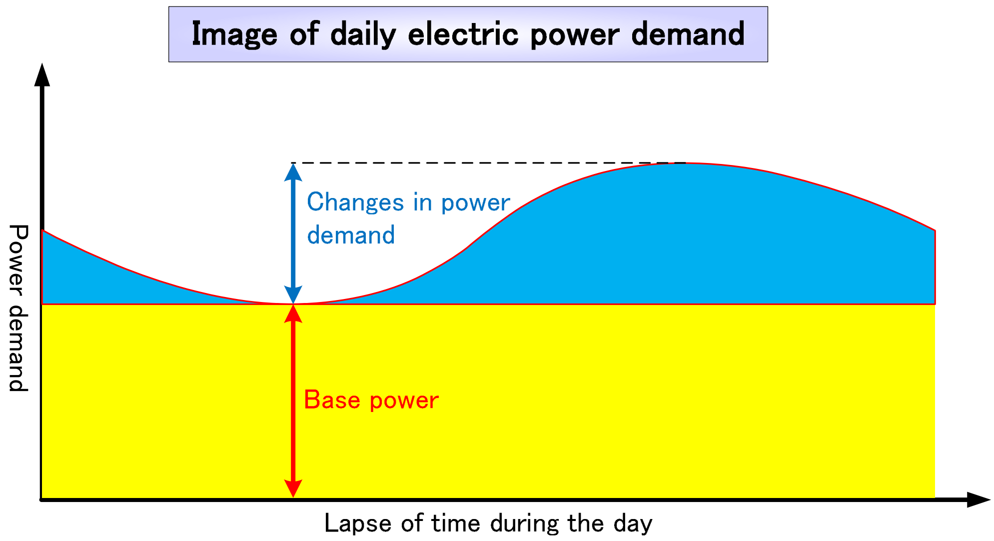
When a disaster takes place, a water supply utility must cope with the cases where a part of important water purification plants or piping are not usable. If such a situation occurs, intact facilities must work to their full capacity to back up others. If the disaster response is operated along a scenario assuming power consumption at normal condition, electric power to back up other facilities might run short. Therefore the target is set at the amount of power generation enough to accommodate maximum capacity of each water purification plant.

3. Status of Installation and Operation of Continuous In-house Power Generation Facilities

[IV] Power supplied by power utilities

(1) About the Continuous Power Generation Facilities

There are two kinds of in-house power generation facilities in water purification plants: continuous and emergency. The two kinds are not so different except the performance of reduction for air pollution by emission gas, etc.



However, their intended purpose is entirely different. While emergency generators have been installed assuming the operation while commercial power supply is discontinued, continuous generators in plants of BWTMG are basically intended to work continuously to supply base power[V] and rely on commercial power for fluctuation of power demand.

In the case of power outage, the emergency generator supplies the fluctuation part of power.

As explained in detail in the subsequent sections, when a continuous generator is adopted, unlike emergency generators, it can be also utilized as a stable heat source. This heat is utilized for processing sludge[VI], thereby attempting to make effective use of energy.

(2) Status of the Installation and Operation of Continuous in-House Power Generation Facilities

BWTMG has water purification plants with water purification capacity 6.86 million m^3/day in total. Among them, continuous power generation facilities are installed in large plants, because a large amount of base electric power is necessary and waste heat can be continuously used for processing sludge.

Already the power generation facilities equivalent for 33,820 kW (for processing and supplying 2.935 million m^3 water per day) have been installed in 4 water purification plants (Higashi-Murayama, Kanamachi, Asaka, Misono). Currently power generation capacity of 20,000 kW (equivalent for 1.35 million m^3/day) is being implemented in Misato plant, considering future reinforcement of water purification capacity.

[V] The minimum electric power regularly consumed to operate the facility.

[VI] Solid component such as soil or sand separated by coagulation and sedimentation from the raw water during water treatment.

Plan and Status of the Implementation of Power Generation Facilities
in Major Water Purification Plants

Water Purification Plants (Capacity: thousand m^3/day)	Continuous Generation (kW)	Emergency Generation (kW)
Higashi Murayama (1,265)	3,200	4,000
Kanamachi (1,500)	10,000	*6,400*
Misato (1,100)	*About 20,000*	6,400
Asaka (1,700)	17,200	*6,800*
Misono (300)	3,420	*Under consideration*

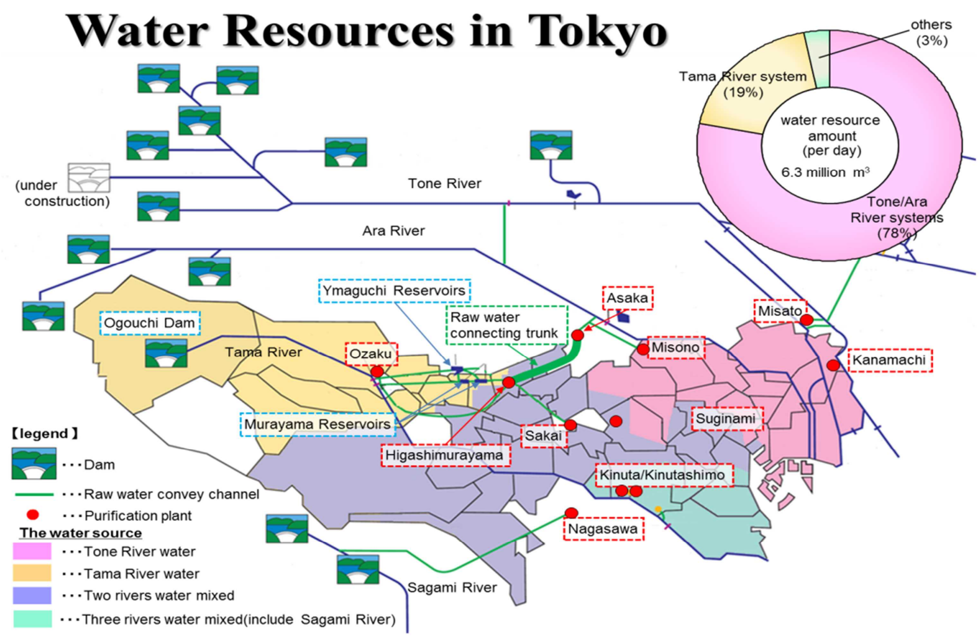
Italics: Under construction or planning

Meanwhile, emergency power generation facility is built up in facilities such as water supply stations (service reservoir + distribution pump facility) where daily power demand fluctuates extensively and there is no heat demand, because the advantage of continuous power generator cannot be utilized.

(3) Capacity of the Power Generator Facilities

Electric power required in water purification plants of BWTMG differs extensively from each other depending on processing method and site condition.

Source of Tokyo tap water is roughly classified into Tonegawa and Arakawa system, which constitutes 80%, and Tamagawa system, which constitutes 20%. The former does not have an excellent water quality and has come to need continuous measures against odorant. Consequently advanced water treatment has been applied to a part of water supplied from Tonegawa and Arakawa system since 1994. This treatment is done by processing with ozone made by processing atmospheric oxygen with high-voltage discharge and by additional processing with biological activated carbon. All water from this water system has been purified with advanced water treatment since April 2014. Because treatment procedure was increased in a limited space of plant, it was obliged to build a multi-layered structure and pump up the raw water to make the water flow bypassing up and down. Consequently, more electric power is needed to process water taken from Tonegawa-Arakawa system than water from Tamagawa system.



Among other things, bigger factor is the site condition of water purification plant. For example, Higashi-Murayama Water Purification Plant is located at a high altitude and therefore it can utilize gravity flow to supply water. However, because most other plants take water at a low altitude, pumping to urban area is required and need electric power for that.

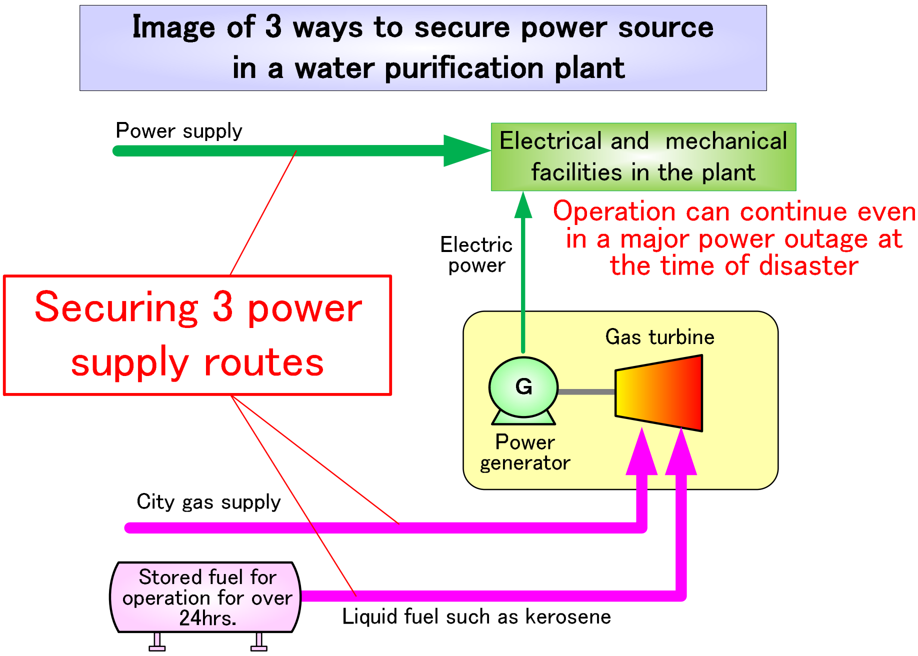
Because of the above, the electric power necessary for purifying and supplying $1m^3$ of raw water differs extensively from each other. The generation capacity (continuous+emergency) is defined based on that.

(4) Secure of Fuel

These continuous power generation facilities mostly use gas turbine as the prime mover, usually taking fuel from city gas supply network. The gas supply pipe line used here is classified intermediate-pressure pipe, which is considerably resistant to disasters and expected to stably supply fuel. Although there has been no gas leak from intermediate-pressure pipes during Great Hanshin-Awaji Earthquake in 1995, either[VII], it does not assure 100% stable supply in case of disaster, like other lifelines do not. BWTMG prepares for discontinuation of gas supply, installing these turbines so that they can run on liquid fuels like kerosene.

Thanks to these efforts, water purification plants with continuous power generation facilities installed can secure three ways to obtain power: commercial power supply, in-house power generation with city gas, and in-house power generation with stored fuel.

However, BWTMG does not think that this is enough. During the Great East Japan Earthquake and its aftermath, most of the commercial logistics networks failed to work properly and consequently lots of damaged areas suffered serious fuel shortage.



It is the situation where a major power outage occurs and supply of city gas is also discontinued that the stored fuel is used. It is not assured at all that fuel supply like during the regular condition can be given within 24 hours. From these discussions, BWTMG aims at fuel storage enough to

VII According to Website of Tokyo Gas Co., Ltd.

accommodate the operation for 72 hours and as described in the subsequent section, it is planned to reinforce fuel tanks, etc. in an extensive renewal work.

(5) Utilization of Waste Heat (Cogeneration) and Reduction of burden to Environment

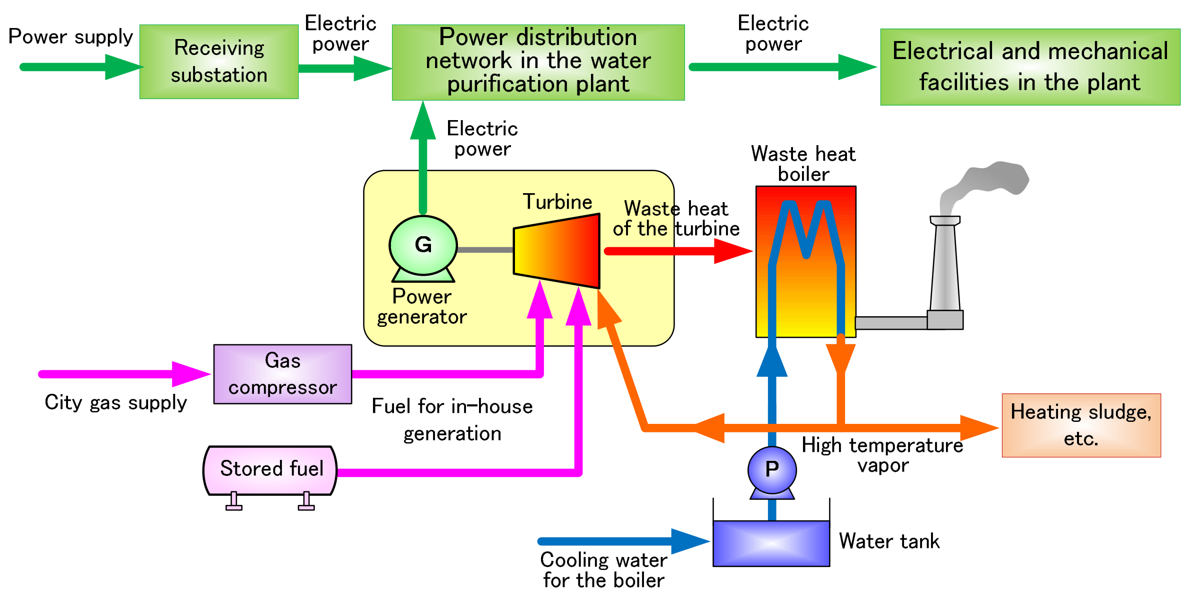
When a power generation facility is operated, high temperature exhaust gas is generated. The system where waste heat as well as the electric power is collected and used is called cogeneration. BWTMG utilize waste heat by collecting it with a boiler, thereby utilizing the generator as a heat source.

The heat collected by the system is utilized to heat the sludge generated in the water purification process and to dry the cake (dehydrated sludge). This system has improved the efficiency of drying sludge and shortened the dehydration time. Additionally, the waste heat is recycled as energy to generate electric power.

Generally, energy efficiency of ordinary thermal power generation is about 40%, but when the waste heat is utilized by cogeneration, the combined efficiency of the whole system is improved to 60 to 70%.

Additionally, power generation using city gas as fuel emits less CO_2 and NO_x compared to the one using petroleum or coal, and generates no SO_x. Therefore it could safely be said that it is an environment-friendly power supply method.

Conceptual diagram of cogeneration system (Kanamachi's case)



(6) Cost Comparison about the Implementation of Continuous Power Generation

As the continuous in-house generator is implanted, BWTMG was enabled to shorten of dehydration time and improve efficiency of facility operation by utilizing waste heat as described above. Additionally, reduction of the time of dehydration also contributes to reduce maintenance cost and power cost.

Comparing construction, maintenance, and operational cost for base electric power between in-house continuous generation and past commercial power supply, continuous power generation is expected to cost more than commercial power supply by 2 to 3%, because it needs more devices. Although in-house continuous power generation costs slightly more than commercial power supply, it enables to significantly reduce the danger of large-scale water failure by improving reliability by duplicated fuel sourcing, as described above, and reducing the risk of long-distance power transmission with in-house generation.

4. Future Issues

(1) Installation of Large Capacity Fuel Storage Tank

As described above, BWTMG aims at reinforcing fuel storage tanks so that they can accommodate fuel enough to operate 72 hours. However, there are already a number of structures constructed in water purification plants, and numerous piping and cables are buried underground. Currently it is no easy task constructing a large tank in plants. Therefore it is specified that at least the amount equivalent for 24 hours shall be allocated and the capacity shall be as much as possible according to the situation of plants. Additionally, because liquid fuels such as kerosene is regarded hazardous material in Japanese law, there is a strict constraint in storing them in large amount.

Majority of the water purification plants were built during the high economic growth period during 1960s and their renewal date is going to come before long. Because most of constructions in the facilities are drastically restructured, BWTMG is going to construct large-capacity tanks then.

(2) Development of Human Resources by Training Personnel to Obtain License for Operation Management

Japanese Electricity Business Act specifies that maintenance and operation of continuous in-house generator shall be done under supervision of licensed Chief Engineer of Boiler and Turbine. To acquire the license, the personnel must have operational experience for 6 years or more, if he or she is the bachelor of mechanical engineering. However, because technical personnel of BWTMG often reassigned at a shorter cycle, BWTMG needs to continuously forward the plan to train personnel for the qualification according to the reassignment schedule.

5. Conclusion

As described in the introduction, Japan is always exposed to the risk of natural disasters and measures against it are an urgent challenge for those who manage city life lines. As described above, BWTMG has advanced implementation of independent continuous power generation facilities. Owing to this effort, two power sources of commercial power and in-house power generation have been secured.

As for the power generation fuel, both city gas and fuel stored in the plant are enabled, thereby improving the reliability of securing electric power. Although the cost of supplying power increases slightly, it was enabled to operate the water purification plants in order to continue the water supply even if the power supply is discontinued by disasters such as earthquakes.

Additionally, the waste heat is effectively recycled by implementing cogeneration in continuous power generation facilities to improve the combined energy efficiency and contribute to the reduction of burden to the environment in emission of CO_2, NO_x, and SO_x.

BWTMG is advancing implementation of emergency power generator also in raw water transmission facilities in the water source and urban water supply stations. BWTMG is going to continue the effort of securing operation continuity of the overall water system in case of disasters and power outage.