Featured Articles

Energy Management and Application of Symbiotic Autonomous Decentralization Concept to Water Supply and Sewage

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OVERVIEW: The water supply and sewage sector in Japan is entering a period in which the focus is on operation and maintenance, with the requirement being to maintain safe and reliable services despite aging infrastructure and challenging financial constraints. To achieve this, steps are being taken to consolidate water supply operations by having different utilities work together, and, in the case of sewage, toward coordination with river management based on amendments to the Flood Protection Law, etc. and catchment-wide management based on the Comprehensive Basin-Wide Planning of Sewerage Systems. Accordingly, these moves toward smarter system-wide operation through the interconnection and interoperation of areas that were previously managed independently also has an affinity with the symbiotic autonomous decentralization concept. One example is a trial conducted by Hitachi on the use of water supply operation plans for demand response, with further investigation underway on assisting interoperation between utilities. In the case of sewage, Hitachi is also trialing energy-efficient sewage treatment control as a technology for facilitating regional coordination.

INTRODUCTION

THE water supply and sewage sector in Japan is now entering a period in which facilities built during and after the period of high economic growth are now coming due for replacement, and in which this upgrade work needs to be undertaken in a way that maintains a safe and secure water infrastructure despite constrained finances at a time of falling population. To achieve this, there has been an increasing shift toward initiatives that seek to get a number of water and sewage utilities working together rather than operating independently, or have them collaborate with other sectors.

In the case of water supply, examples include the extensive consolidation that is underway to coordinate some of the activities undertaken by utilities, such as infrastructure sharing and the centralization of management whereby, along with business integration, the utilities pool resources for tasks such as operation and maintenance or water quality testing[1].

In the case of sewage, meanwhile, there are calls for utilities to work with river management agencies in accordance with FY2015 amendments to the law in order to deal with the major rainfall events that have been occurring frequently in recent years[2]. Similarly, under the Comprehensive Basin-Wide Planning of Sewerage Systems being promoted by the Ministry of Land, Infrastructure, Transport and Tourism, there is a move toward comprehensive catchment-wide management of things like water quality and energy consumption in ways that take account of local circumstances[3].

The water supply and sewage sectors are energy consumers. This means that, as part of the social infrastructure of a city, they play an important role in achieving not only energy efficiency but also smart energy use on a city-wide level through measures such as cutting or shifting demand peaks by coordinating their operation with the electric power infrastructure.

The information and control systems used in social infrastructure have grown in sophistication along with the need to provide efficiency and sustainability to individual utilities and the social infrastructure sector. It is also recognized that, as interdependent parts within a larger water cycle, the water supply and sewage infrastructures need to adopt a symbiotic autonomous decentralization approach in order to deal with the increasingly complex challenges they face. This means seeking to create new value at the system-wide level through the interconnection and interoperation of individual systems while having them continue to operate autonomously.

This article presents examples of work on energy management in the water industry based on this concept. In the case of the sewage sector, it also presents an example of energy-efficient control of the sewage treatment process, a technology that facilitates energy management.

APPLICATION OF SYMBIOTIC AUTONOMOUS DECENTRALIZATION CONCEPT TO WATER SUPPLY AND SEWAGE INDUSTRY

The practice in the water supply and sewage industry has been to install separate systems at each plant, whether it be a purification plant, sewage treatment plant, or pumping station. These include the administrative systems for activities such as finance, human resources, and public relations; commercial systems for customer inquiries, metering, and billing; and supervisory control and data acquisition (SCADA) systems used for plant operation and maintenance. In the past, these individual systems have provided their respective functions in an independent system, and the symbiotic autonomous decentralization concept under which new value is created through the interconnection and interoperation of these systems has been studied as a way of solving the problems addressed in the previous section.

Fig. 1 shows this concept in the case of a plant SCADA system.

Each water or sewage utility and river management agency has its own SCADA system for the operation and management of purification plants, sewage treatment plants, pumping stations, and so on. The systems have been operated for their respective purposes as closed systems. Now, however, work is being undertaken to establish platforms that provide integrated access through the interconnection and interoperation of these systems. In Hitachi's symbiotic autonomous decentralization concept, these shared access platforms are called cooperating fields.

These cooperating fields facilitate water industry consolidation in various ways by enabling the interoperation of water utility SCADA systems. Furthermore, having the systems of the sewage utilities in a catchment work together can provide IT support for catchment-wide management. Similarly, interoperation with river management agency systems can provide comprehensive flood control support that takes account of both run-off and river water. Smarter use of electric power, such as demand response (DR), is also possible through the use of cooperating fields for interoperation between the electric power infrastructure and water supply and sewage industry.

The following section presents an example of energy management in the water industry that demonstrates how system technologies create new value through the use of cooperating fields.

ENERGY MANAGEMENT THROUGH INTEROPERATION BETWEEN WATER AND ELECTRIC POWER INFRASTRUCTURE

DR and Water Supply Operation Plan

DR is seen as a way of ensuring security of supply by controlling electric power during times of peak demand (see Fig. 2). Under DR, consumers of electric power receive requests specifying when and by how much to reduce their power consumption from an aggregator (a business that consolidates adjustments in power consumption made by other businesses) who deals directly with the power company to determine the amount and timing of power use reductions (negawatts).

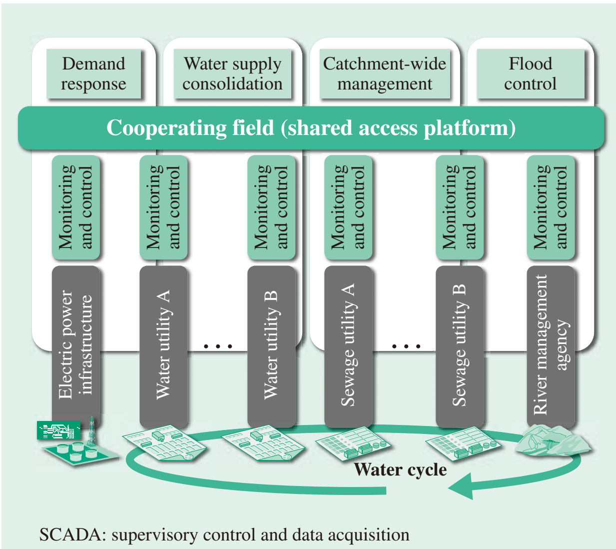

Fig. 1—Application of Symbiotic Autonomous Decentralization Concept to SCADA System for Water Supply and Sewage.
The aim is to create new value through interconnection and interoperation via a shared access platform between electric power infrastructure and the systems involved in the water cycle (water supply, sewage, and waterways).

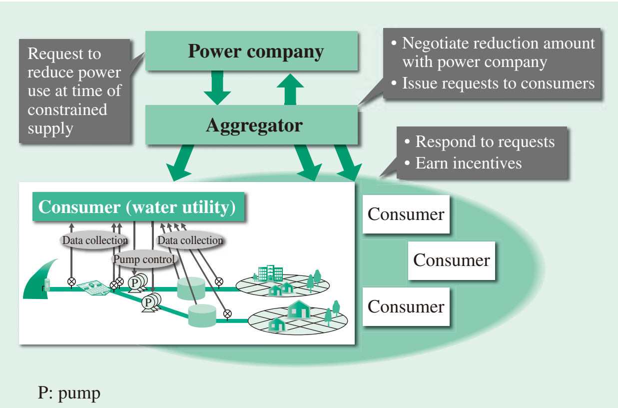

Fig. 2—Overview of Demand Response for Electric Power.
By reducing their power consumption in response to requests issued from power companies via an aggregator, water utilities and other consumers of electric power can earn incentives based on the amount of reduction.

Consumers also receive incentive payments based on their reduction in power use[(4)]. Being major consumers of electric power, water utilities are in a position to participate in such schemes. When they do, because they must prioritize security of water supply, they need to look at how they can participate in DR without compromising this obligation.

The water supply operation planning systems used by the industry are a way to achieve this[(5)] (see Fig. 3). These systems predict the constantly changing daily demand for water and plan the flow rates at which the utility's purification plants and water intake and conveyance pumping stations need to operate. By adding a function for responding to DR requests to reduce power use, the systems can generate plans in such a way that the utility can earn incentive income without compromising security of supply.

Demonstration Project

To verify the potential for using water supply operation planning system technology to incorporate DR into water supply infrastructure and to determine the benefits, the Hitachi City Enterprise Bureau participated as a consumer in the FY2014 Next Generation Energy and Social System Demonstration Project of the New Energy Promotion Council. Because it was a demonstration project, requests from the aggregator were sent via e-mail and operational plans were produced on a personal computer (PC) that was independent of the SCADA system. These operational plans were checked manually and then operators used the SCADA system to manually shut down pumps as required.

The demonstration project was based on fast DR whereby the reduction requests were issued 15 minutes prior to the commencement of DR. Four separate trials were conducted and the reductions in power use were made via six different Hitachi City Enterprise Bureau facilities (18 pumps with a total contracted capacity of 2,901 kW). Fig. 4 shows the results for a DR trial conducted in the summer. Peak demand for electric power was reduced by 54% in response to DR requests between 13:00 and 17:00 and water storage levels of 80% or more were maintained during and after the DR period.

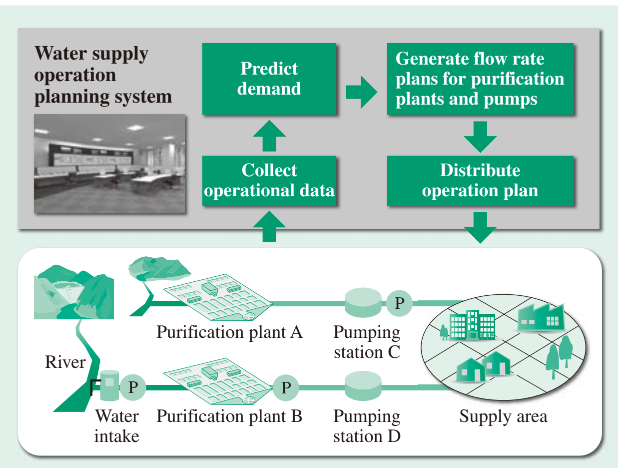

Fig. 3—Overview of Water Supply Operation Planning System.
The system predicts daily water demand and generate and distribute an operating plan for the flow rates at which the water utility's purification plants and pumping stations need to operate.

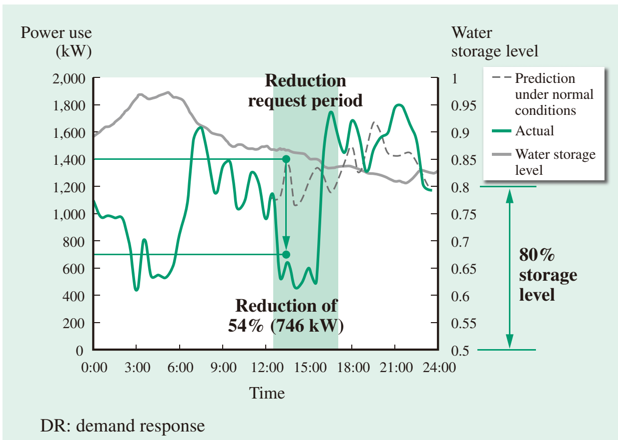

Fig. 4—Results of DR Demonstration Project.
The graph shows the results of a fast DR demonstration project conducted during the summer. This example shows the results for power use reduction requests issued between 13:00 and 17:00, during which time the reduction requests were satisfied while reliably maintaining water storage levels at 80% or more.

Based on this demonstration project, it was concluded that water supply operation systems technology can deliver both security of water supply and reductions in electricity costs through coordination with the electric power infrastructure.

INITIATIVE TOWARD INTEROPERATION BETWEEN UTILITIES

In a new initiative, Hitachi is developing solutions for system-wide optimization through interoperation between water supply and sewage utilities. The following describes one such example, a support tool for coordinating water supply operation that delivers a high level of DR income through coordination across a number of utilities (see Fig. 5).

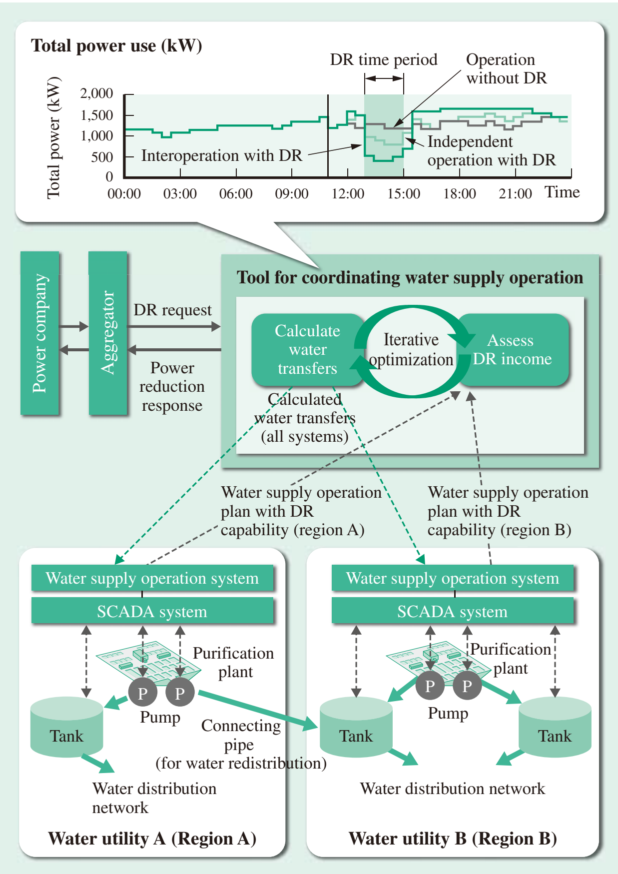

Fig. 5—How Support Tool for Coordinating Water Supply Operation Works and Reductions in Power Use in Response to DR Requests.
The tool utilizes interoperation between each utility's water supply operation system to enable them to maximize DR income by iteratively calculating the DR income for the entire catchment and determining the inter-utility water transfers that will improve this result based on operational blueprints generated for each utility's water supply operation plan, which include a DR function.

The tool is intended for water utilities that are able to transfer water to each other via connecting pipes or other means. It can generate operational plans that provide system-wide optimization (maximize DR income across the entire region) by implementing water supply operation plans with a DR function like that described above over a wider area. These operational plans are generated by solving the mathematical programming problem in a way that treats multiple utilities as a single water conveyance network, including connecting pipes, which means they pose a technological challenge because the larger problem size makes it more difficult to calculate a solution in a short time. Furthermore, the establishment of an integrated system is also typically complicated by the fact that the individual water utilities implement their water supply operation plans as independent business entities.

The support tool for coordinating water supply operation resolves these challenges by interoperating with the water supply operation system of each utility. That is, the support tool iteratively adjusts the boundary conditions (quantity of water transferred via connecting pipes) to progressively improve the overall DR income. The individual utilities then continually solve their respective water supply operation mathematical programming problems (including DR) using these adjusted boundary conditions.

Use of this algorithm shortens the time required to calculate operating plans that maximize (strictly speaking, approximately maximize) the DR income, while preventing the problem size from increasing and keeping the respective water supply operation systems independent of one another.

Fig. 5 shows an example calculation that simulates a water conveyance network covering four cities with interconnecting pipes. The results show that the four city utilities working together achieved a total reduction in electric power use during the DR period that is roughly twice the reduction achieved when the utilities operate independently.

In parallel with this, Hitachi has been developing NEXPERIENCE / Cyber-Proof of Concept (Cyber-PoC)[6] for conducting preliminary cost-benefit analyses of social infrastructure investments. Because the support tool for coordinating water supply operation can be used to make predictive estimates of the energy savings from consolidating the operations of water utilities, there is potential for creating a version of NEXPERIENCE / Cyber-PoC for the water industry.

ENERGY-EFFICIENT CONTROL OF SEWAGE TREATMENT

Prompted by amendments to the Comprehensive Basin-Wide Planning of Sewerage Systems(3), there is growing demand from sewage utilities for advanced control techniques that can save energy and enable interoperation between utilities as well as achieving and maintaining environmental standards for water quality in public basins.

Ibaraki Prefecture and Hitachi have undertaken research trials into “Demonstration of Efficient Nitrification Control with ICT,” which is seen as a core technology for saving energy at the catchment level. The research is being conducted under contract to the National Institute for Land and Infrastructure Management of the Ministry of Land, Infrastructure, Transport and Tourism as part of that ministry’s Breakthrough by Dynamic Approach in Sewage High Technology (B-DASH) project, and has been in progress since FY2014 on water treatment lines at Ibaraki Prefecture’s Kasumigaura Sewage Treatment Plant.

Features of the Control Technique

The technique provides a way to manage the operation of the nitrification process commonly used in biological treatments (in which ammonia is removed by oxidation) by controlling the rate of blower air flow into the biological reactors. It reduces energy use by minimizing excessive blower operation once the target ammonium concentration has been achieved while also providing consistent water quality and more efficient operation and maintenance.

Fig. 6 shows an overview of the control system(7) used in the trials. The system uses a dissolved oxygen (DO) sensor located downstream from the aerobic tank of the biological reactor, ammonium sensors (1) and (2) located respectively upstream from and mid-way through the aerobic tank, and a flow meter. The control system is made up of a feedforward (FF) loop that uses the ammonium concentrations from ammonium sensors (1) and (2) as its input and a feedback (FB) loop that uses ammonium sensor (2).

FF control first predicts the ammonium concentration mid-way through the aerobic tank based on the concentration measured by ammonium sensor (1) and the target effluent ammonium concentration. Next, it uses the newly developed treatment model to determine the blower air flow rate based on the difference between these two values, which represents the ammonium concentration to be treated in the process upstream from the mid-way point.

Similarly, FB control feeds back the difference between the predicted value of ammonium concentration at the mid-way point of the aerobic tank and the concentration measured by ammonium sensor (2) and determines the blower air flow rate.

Using FF control as well as FB control improves the ability of the system to track changes in the incoming sewage while also keeping the treatment process stable with an appropriate air flow rate.

The treatment model used by FF control was implemented using measurements from the two ammonium sensors and actual blower air flow rates. The model is also designed for more efficient operation and maintenance, being auto-calibrated on a daily

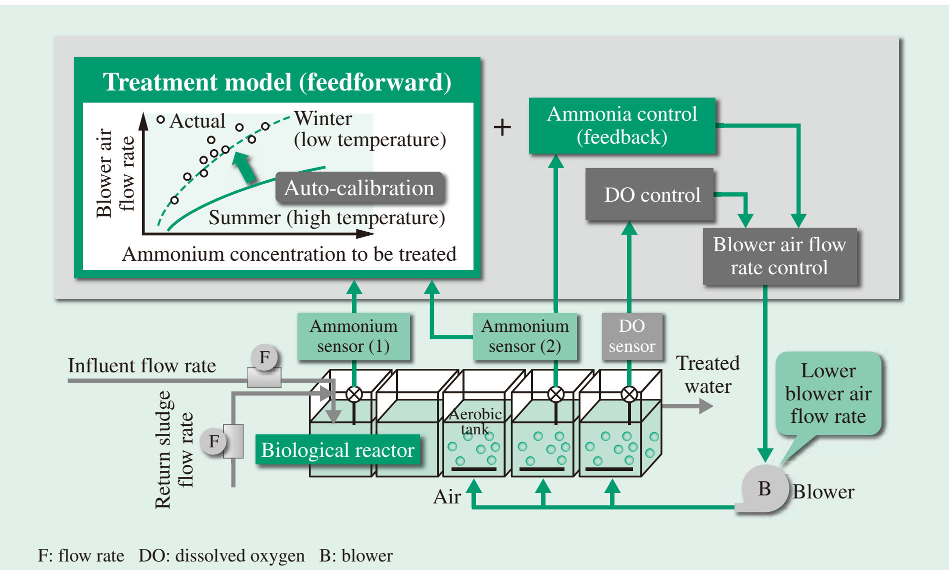

Fig. 6—Overview of Energy-efficient Control of Nitrification. The technique uses two ammonium sensors located respectively mid-way through and upstream from the aerobic tank to maintain water quality and reduce blower use, with a control function that utilizes actual values and values predicted by the treatment model, an auto-calibration function for the treatment model, and a function for displaying the treatment characteristics.

basis using the latest measurements so that it can adapt to changes in the characteristics of the sewage treatment process.

Demonstration Project

A demonstration project was conducted with the No. 5 and No. 6 nitrification/denitrification process reactors at the Kasumigaura Sewage Treatment Plant. The No. 5 reactor was used as the experimental system, and was fitted with the newly developed air flow rate control system, while the No. 6 reactor was used as the reference system, and was operated using the existing constant DO control system (which works by maintaining a constant DO level in the third and final aerobic tank). The target DO setting for the reference system was left at its current level of 2.0 mg/L, while the experimental system was operated so as to target the same degree of nitrification promotion as the existing system, with a mean effluent ammonium concentration of 1.0 mg-N/L or less.

Fig. 7 shows how the aeration flow rates for the two reactors varied over time. This shows that the aeration air flow in the new control system was consistently lower than the reference system. Meanwhile, the effluent ammonium concentrations were 0.3 mg-N/L in the experimental system and 0.1 mg-N/L in the reference system, indicating that both systems achieved the target of maintaining a mean concentration of 1.0 mg-N/L or less to promote nitrification.

The aeration air flow ratio with respect to the new control system was 77.7% that of the reference system. An investigation was conducted into an adjustment method that takes account of the required oxygen amount and diffusion efficiency, with the No. 5 reactor (experimental system) tending to require less aeration air flow than the No. 6 reactor (reference system) for the same concentration of ammonia(8). The investigation found that the adjusted aeration air flow ratio was 85.9%, indicating that the newly developed control system reduced the aeration air flow by 14.1% compared to the previous constant-DO control system.

The demonstration project has continued through FY2015 and proved the long-term stability of the new control system.

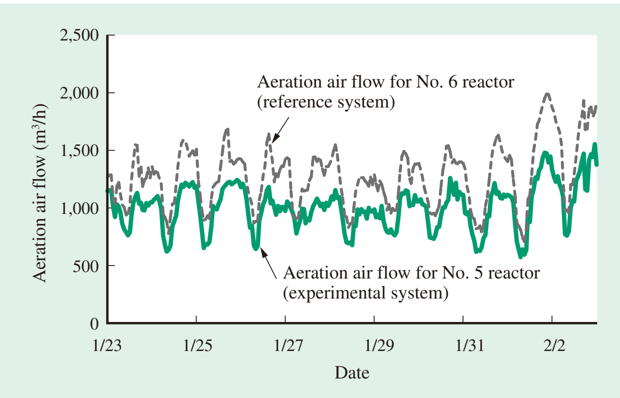

Fig. 7—Aeration Air Flow in Demonstration Project.
The adjusted aeration air flow ratio of 85.9% means that the newly developed control system (experimental system) reduced the aeration air flow by 14.1% compared to the previous constant-DO control system (reference system).

CONCLUSIONS

This article has described work on system-wide optimization of water supply and sewage through the interconnection and interoperation of utilities based on the symbiotic autonomous decentralization concept, including the energy management and energy efficiency benefits that provide examples of the technologies used.

Hitachi intends to continue developing future solutions under this concept to sustain a safe, secure, and comfortable water cycle.

ACKNOWLEDGMENTS

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