Power Supply and Demand Control Technologies for Smart Cities

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One of the missions of smart cities is to contribute to the environment and reduce social costs by using energy more efficiently and utilizing more renewable and distributed energy. This is reflected in the increasing use of renewable energy and in energy consumers becoming "prosumers," i.e., people who not only consume but also generate and sell power. However, several factors related to this trend are causing both the supply and demand sides of electrical power to fluctuate and complicate the control of the balance between the two sides. While supply and demand balance is controlled mainly with generators in conventional power systems, more effective and economical control is needed for future systems. We believe that it will be important to also optimally control the amount of energy that is needed for people to manage their daily lives at home and at work. Demand response (DR) is a technology that is receiving attention in light of this need. This article introduces R&D initiatives at Fujitsu Laboratories, including development of a Demand Response Automation Server (DRAS) conforming to OpenADR, which is advancing as a standard for DR, and a building-demand simulation technology that optimizes control of the balance between supply and demand for electric power using DR technology.

1. Introduction

The Great East Japan Earthquake of 2011 led to the expectation of dramatic changes to electrical power systems in Japan and of the creation of smart cities supporting a more efficient and stable power distribution environment. One possible change on the power supply side is a shift from large-scale, concentrated power generation, such as conventional nuclear power generation, to diversified types of power generation including renewable energy, co-generation, and various distributed power sources. On the demand side, users are expected to become "prosumers." That is, rather than simply consuming power, many households will also produce power by, for example, using solar panels or emergency household generators and then sell the power they do not use. These changes, however, will complicate the control of the balance between power supply and demand. A promising approach to addressing these challenges is demand response (DR) technology, which not only reduces the peak load in smart cities but also helps balance power supply and demand.

As a specific measure to directly handle the power outages after the Great East Japan Earthquake, Fujitsu Laboratories developed a power demand estimation function that uses power demand data gathered online at 30-minute intervals from offices all over Japan[1] and has been using it within Fujitsu as a real service since August 2011. Another technology is being developed to provide cloud-based integrated control of the charging of office PC batteries and thereby reduce the peak load in the overall power demand in offices.[2] This paper reports our latest research and development activities related to DR technology, including the development of the DR Automation Server (DRAS) and a means for optimizing the control of demand for power on the basis of human activity in households and businesses. The later incorporates techniques for analysis, modeling, and prediction of enterprise and regional power demands.

2. Current state of DR technology

DR technology is used to balance the supply of and demand for power on a regional basis when there is a supply shortage. The basic concept of DR technology is illustrated in **Figure 1**. It works by requesting consumers to reduce power use rather than increase power generation capacity. This enables power companies to avoid investing in excessive power generation facilities to meet peak power demands. Consumers that cooperate can receive payments from the power company. New businesses related to DR technology are expected in the future.

Europe and America are leading the implementation of DR technology. In the U.S., peak demand curtailment ("negawatts") through DR technology grew from 30 to 66 GW between 2006 and 2012,[3] and DR services in various forms are being offered. These services can be broadly classified into two types: those based on monetary compensation and those based on time-based pricing. Those of the first type can be controlled systematically while those of the second type cannot because they involve consumers responding on their own initiative.[4]

Currently, most DR services based on monetary compensation are provided via systems used by a power company to send requests by telephone or e-mail to large-scale consumers pre-registered for the DR service asking them to reduce power use. If such services were expanded to include medium- and small-scale consumers and the general public, it would be difficult for power companies to communicate directly with such a large number of consumers and to manage the available DR resources at customers' premises. This has led to the appearance of DR aggregators, who gather the demand curtailments of many consumers and make the entire quantity available to a power company as a resource during electricity distribution operations. Such "negawatt aggregation" requires sophisticated data analysis and complex equipment coordination. Through collaboration with DR aggregators who have expertise in these techniques, power companies hope to achieve both cost effectiveness and supply reliability.

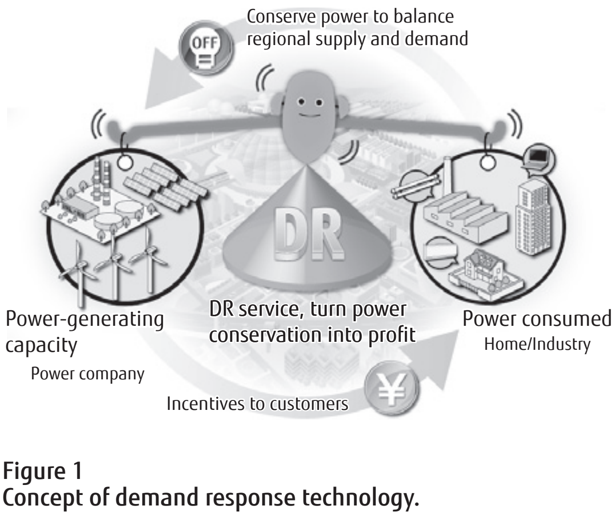
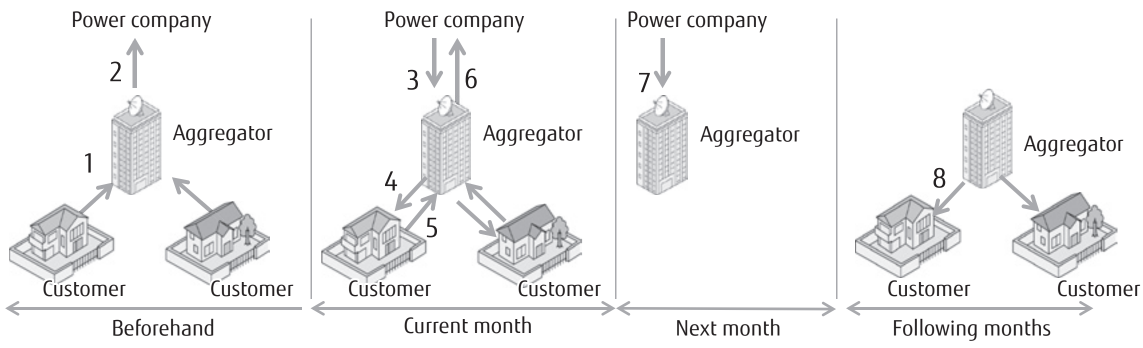


Figure 1
Concept of demand response technology.

An example of negawatt aggregation is the Capacity Bidding Program offered by the Pacific Gas and Electric Company (PG&E) in California, which is illustrated in **Figure 2**.[5] Each customer enters into a contract with an aggregator specifying the conditions under which they can reduce their consumption of electricity, and the aggregator enters into a DR program agreement with a power company on the basis of these contracts. The aggregator may send DR event notifications to customers when it receives a power restriction request from the power company and reports the amount of power reduction achieved to the power company. The power company makes a payment to the aggregator in accordance with these achievements, and the aggregator then compensates the customers in accordance with their contracts.

3. DR standards (OpenADR) and DR Automation Server

Automated Demand Response (ADR) is a key technology in expanding DR services as it connects servers at power companies or DR aggregators directly to energy management systems in buildings and houses. Standardization is the key to interconnecting devices from various vendors and reducing the cost of such solutions. The most recognized standard for ADR is Open Automated Demand Response (OpenADR). The OpenADR 1.0 specification was proposed by the Lawrence Berkeley National Laboratory in the U.S., and the OpenADR 2.0 international standard specification is now being finalized by the OpenADR Alliance, with participation from over 100 companies. The OpenADR 2.0a specification for simple device control was published in August 2012, and the 2.0b specification, covering a larger variety of services, was published in July 2013.



1. Contract for conservable amount (negawatts)
2. Agree on options such as timing of DR event notifications (previous or same day) and the period and quantity for DR events.
3. Power company sends power restriction request to aggregator.
4. Customers notified of DR event start time, duration, reduction amounts, etc.
5. Data regarding reductions
6. Data regarding reductions
7. Compensation paid to aggregator
8. Payments to customers based on contracts

Figure 2
Example of negawatt aggregation—Capacity Bidding Program at PG&E.

Fujitsu Laboratories quickly recognized the importance of ADR and began development of a prototype based on OpenADR. Fujitsu officially joined the OpenADR Alliance in October 2012 and was the first Japanese enterprise to exhibit a DRAS prototype conforming to OpenADR 2.0a at Grid-Interop 2012 in December 2012. Grid-Interop 2012 is the largest event related to smart grids in the U.S. Fujitsu also demonstrated its compatibility with products from U.S. household device manufacturers. In August 2013, Fujitsu's DR client (VEN: Virtual End Node) software became one of the first in the world to receive certification of compliance with OpenADR 2.0b. In October 2013, Fujitsu's DR server (VTN: Virtual Top Node) software became the first among Japanese companies to receive 2.0b VTN certification.

A DRAS is used by a DR aggregator to send and receive signals to control the DR service (DR events) between a power company and its customers. For example, when it receives a request to restrict power usage from the power company, it sends power conservation commands to smart appliances in the homes and to the energy management systems in the buildings and factories of DR service subscribers.

The configuration of the developed test system is shown in **Figure 3**. Tests confirmed its ability to control home devices such as a heating/cooling thermostat and smart plugs conforming to the ZigBee Smart Energy Profile, which is standard in the U.S., through a Universal Devices home gateway supporting OpenADR2.0a.

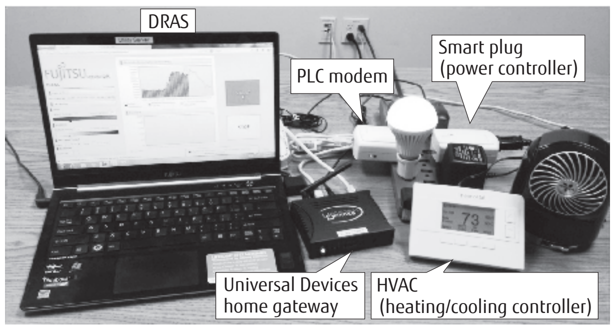


Figure 3
DRAS test system.

The OpenADR Alliance is also studying fast DR as a future direction for ADR technology. It is expected to handle instabilities in power supply due to an increase in the use of renewable energy by controlling supply and demand within seconds or minutes. Reformation of the electrical power system is also being discussed in Japan, including issues such as liberalizing the power retail business and separating power generation and power distribution into different businesses. The business environment surrounding energy systems is changing, and ADR standardization is being studied in Japan as part of these changes under the leadership of the Ministry of Economy, Trade and Industry.

4. Demand control and simulation technology

In addition to conforming to international standards, a DRAS must also optimize management of DR resources at each consumer. Developing a demand control mechanism based on the models of physical energy estimation and human activity is an important part of achieving this.

In the work reported here, a building-demand simulator was developed to link the Spot Oriented Agent Role Simulator (SOARS),[6] which is a social behavior simulator developed at the Tokyo Institute of Technology, and EnergyPlus,[7] which is a simulator incorporating energy consumption models at the building level developed by the U.S. Department of Energy. The EnergyPlus simulator takes inputs including the building structure, weather information, heating, cooling, and lighting equipment, and usage scenario (occupancy rates) and computes the energy consumption. SOARS is able to simulate human activity by defining mobile elements such as people as "agents" and locations as "spots" and then regulating the movement of agents between spots and the interactions among agents at spots.

An overview of the developed building-demand simulator is shown in **Figure 4**. A simulation of energy consumption in a building is implemented by simulating the activities of employees, including aspects such as arriving and leaving from work and attending meetings. The results are used to automatically generate occupancy rates for the building, which are the inputs to EnergyPlus that are used to compute the energy consumption of the building.

The building-demand simulator can be used to, for example, evaluate the effects on employee comfort if a building manager implements DR service energy control. As a specific example, a DR scenario was formulated to optimize energy-use restrictions through DR requests and to maximize comfort in terms of room temperature, and an air conditioning control plan was drafted.[8]

Two DR policies were simulated: "floor optimization" (the temperature is set individually for each floor) and "building-wide setting" (one temperature is set for the entire building). The simulations were done under the following conditions.

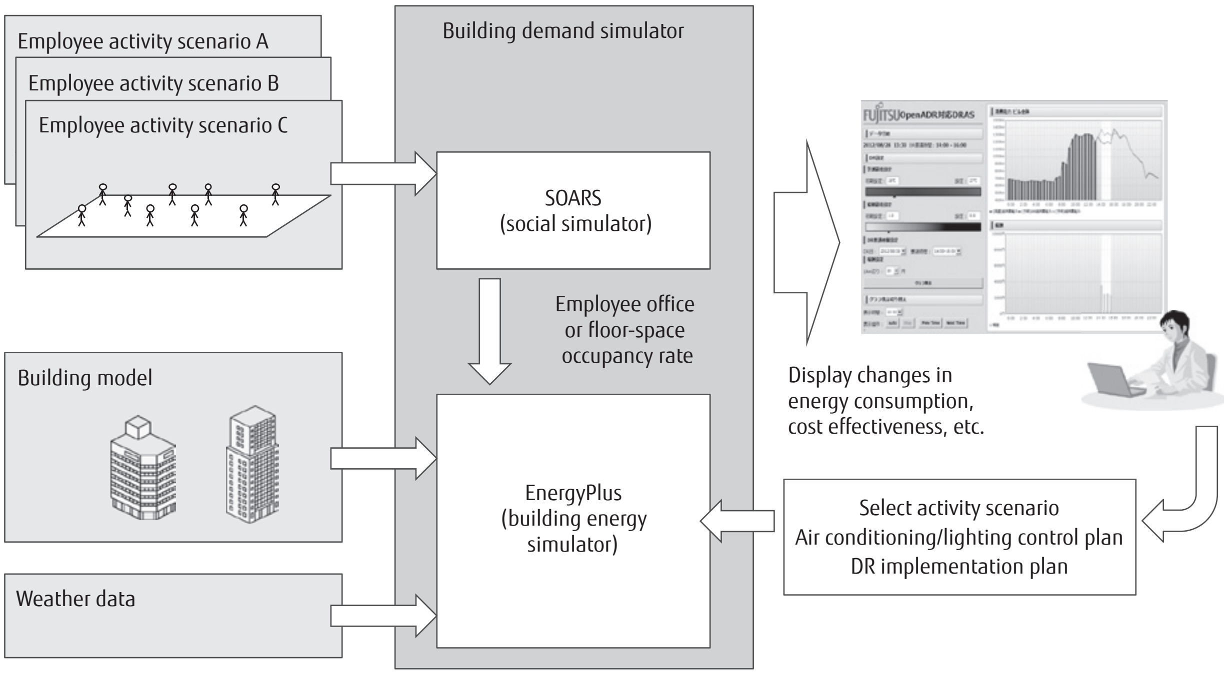


Figure 4
Building demand simulator overview.

- Building: Fujitsu Laboratories (Kawasaki City)
- Data collection period: from 10:00 to 17:00 weekdays during July and August 2011, when outside daytime temperatures were 29°C or greater
- Demand reduction targets: 5, 10, 15, 20 (kWh)

The level of comfort in offices was converted into an index using the model proposed by Tawada et al.[9] The increases and decreases in energy used for air conditioning were estimated using multiple linear regression, with external temperature and room temperature by zone as explanatory variables.[10] The results are plotted in **Figure 5** and show that the floor optimization policy maintained a higher level of comfort for each target.

Such energy usage simulations can be used by building facilities managers to estimate the effects of policy measures and by DR aggregators to estimate the potential load curtailment, enabling them to control the balance of supply and demand more effectively.

5. Conclusion

Demand response technology is essential for implementing economical and stable electrical power systems in smart cities and is important for saving the environment and reducing social costs. For this technology to be used effectively, techniques are needed for analyzing, modeling, predicting, simulating, and optimizing the control of energy demand. We intend to refine these techniques through verification and testing. We also plan to apply them for use as solutions in other application domains.

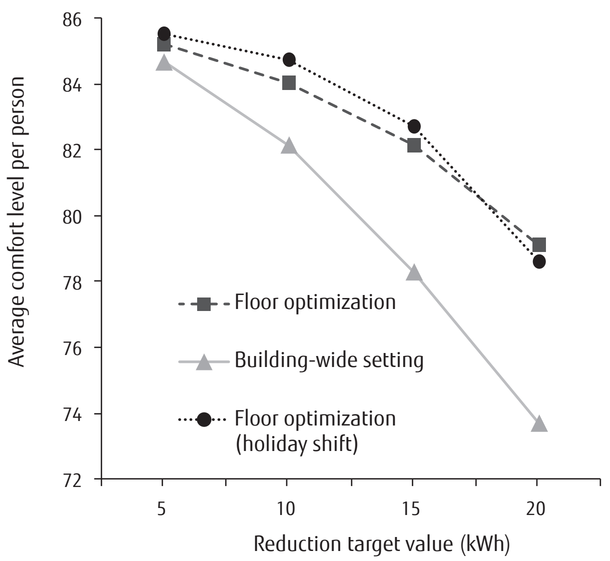


Figure 5
Example results for two DR policies.

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