Social System Demonstration of Dynamic Pricing in the Kitakyushu Smart Community Creation Project

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ABSTRACT

The "Kitakyushu Smart Community Creation Project" being conducted in the Yahatahigashida region of Fukuoka, Kitakyushu, celebrated its fourth year since inception. This project utilizes a regional energy management system based on a "cluster energy management system" and aims to reduce CO_2 emissions by at least 50% compared to that of typical urban areas. As part of this project, the first public demonstration of dynamic pricing in Japan was conducted in 2012. The price of electric power during peak hours was varied in five stages, from 15 to 150 yen/kWh, and an average reduction in demand of 9 to 13% was confirmed.

1. Introduction

In April 2010, "Kitakyushu Smart Community Creation Project" was selected as one of the four regions (Yokohama city, Toyota city, Keihanna Science City and Kitakyushu city) of the "Next-Generation Energy and Social Systems Demonstration Project" by the Ministry of Economy, Trade and Industry. This is an effort to establish smart grid and achieve its overseas expansion as mentioned in national growth strategy, "Environment and Energy Giant Country Strategy by Green Innovation."

The implementing body of this project is the Kitakyushu Smart Community Creation Committee" comprised of over 60 companies and organizations including Kitakyushu city, Nippon Steel & Sumitomo Metal Corporation, IBM Japan Ltd., Yasukawa Electric Corporation and Fuji Electric Co., Ltd. The committee drew up the master plan, which consists of 32 tasks (worth the total of 16.3 billion yen in 5 years from FY2010) and these tasks are being promoted. With this demonstration, Fuji Electric is demonstrating pioneering technological development such as advanced regional energy management systems (CEMSs: cluster energy management systems), smart meters and smart storage systems and is planning to broadly deploy the know-how in establishing and operating smart community as a social infrastructure in the domestic and overseas energy infrastructure business as a differentiated item.

This paper mainly describes the results of dynamic pricing demonstration, which was conducted in FY2012 for the first time in Japan.

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2. Kitakyushu Smart Community Creation Project

2.1 Overview of project

The target of this project is the Higashida region (approx. 120 ha) of Yahata-higashi ward in the city of Kitakyushu, Japan (see Fig. 1). The objective of this project is to obtain a 20% energy saving effect and reduce CO_2 emissions by 50% or more compared to the typical block in the city. This is accomplished by expanding the introduction of new energy resources, introducing energy-saving system to buildings, efficiently using energy with CEMS which is installed in Smart Community Center called "Community Setsuden-sho" as a core, and by streamlining social system such as the transportation system. Furthermore, the aim is to strengthen the competitiveness of the environmental energy industry by broadly deploying technology and knowhow, which were developed through this project, in Japan and overseas and advancing promotion of the related industries and international standardization.

In addition, the demonstration region is a special

Fig.1 Higashida Region, Yahata-higashi Ward, Kitakyushu City

supply area where power is supplied over a self-owned line from cogeneration power station in Yawatal Works of Nippon Steel & Sumitomo Metal Corporation. One of the characteristics of this region is that it is possible to change the power rate unit price by changing the actual power contract in cooperation with the Kitakyushu Higashida Maeda Chiku Denryoku Jukyu Kumiai of the relevant region.

2.2 Global view of demonstration project

This project is establishing an energy management system (EMS) centering on the Community Setsuden-sho, and the basic stance is to build a new energy system that "utility customers participate in," where conventional utility consumers become production consumers, or what is called, "prosumers." The idea is to achieve "demand side management" to manage energy that people use for themselves, by means of citizens (who are the prosumers) and utility providers through "thinking" and "participating" in addition to the existing energy suppliers. The following five concrete results from such demand side management are considered.

(1) Energy saving

Promote energy saving with "visualization" by providing information such as power usage and the regional supply and demand situation via a smart meter onto the user's in-home display (tablet terminal), and utility customer EMS, which is introduced partly.

(2) Load leveling

Although regional power supply load differs depending on the type of utility customer, achieve load leveling in the whole region by utilizing information technology and storage batteries, and combining various types of utility customers to cut and shift peak demand.

(3) Optimized use of renewable energy

Build a mechanism to utilize electric power of renewable energy wisely without suppressing output by having a reverse power flow as much as possible in preparation for a society introducing large-volume of renewable energy.

(4) Independent operation system at the time of disaster

It is important for smart grid to interconnect with main electric power system and have a mutually cooperative relationship. Meanwhile, because the system is connected to the large-scale electric power system, smart grid system becomes unavailable in the event that a major power outage occurs at the time of a disaster. In this project, a system is established to enable independent operation within the minimum required range even at the time of a disaster.

(5) Utilization of smart grid platform for social infrastructure

Create new business including various types of social infrastructure such as transportation and security/safety (watching service, on-demand type community bus, data aggregation etc.) in order to improve citizens' convenience by utilizing information communication infrastructure such as smart meters that is made available through this project.

2.3 Demonstration of regional energy management

CEMS, which is the core of the demonstration project, is installed in the Community Setsuden-sho, and shares information with home energy management system (HEMS), building and energy management system (BEMS), factory energy management system (FEMS), store energy management system (SEMS) and smart meter that correspond to demand response. In addition, CEMS performs information sharing with cogeneration in the Higashida region, distributed power generation such as solar power generation, wind generation and fuel cells as well as community installation type storage battery systems, and control generators and storage batteries according to the electric power generation amount and quantity demanded. At the same time, it leads utility customers to energy saving and peak shift by means of dynamic pricing where energy unit price per time period is varied. Utility customers who installed BEMS and HEMS can control the load of equipment within the building, EV charging equipment, or home electric appliances in the household using this dynamic pricing information.

2.4 Demonstration system for regional energy management

Figure 2 shows the overall structure of the demonstration system.

The demonstration system comprises utility customer EMS (BEMS, HEMS, FEMS, SEMS etc.), which operates energy optimally on the utility customer side such as at home, in the company or plant; distributed power generation that supplies energy in the region; community installation type storage system; and CEMS that performs optimal and comprehensive control of these systems.

In addition, for all utility customers, a smart meter and an in-home display are installed to display various types of energy information from the smart meters and CEMS.

(1) CEMS

CEMS, which is installed in the Community Setsuden-sho, forecasts energy supply and demand of the entire region, draws up an operation plan for cogeneration and storage systems, and also transmits dynamic pricing information to smart meters and utility customer EMS (see Fig. 3).

(2) Community installation type storage system

Community installation type storage system shares information bidirectionally with CEMS, levels the load in regional grid and provides emergency reserve power, and controls the quality of grid power in ways such as by suppressing instantaneous frequency fluctuations and controlling voltage by reactive power.

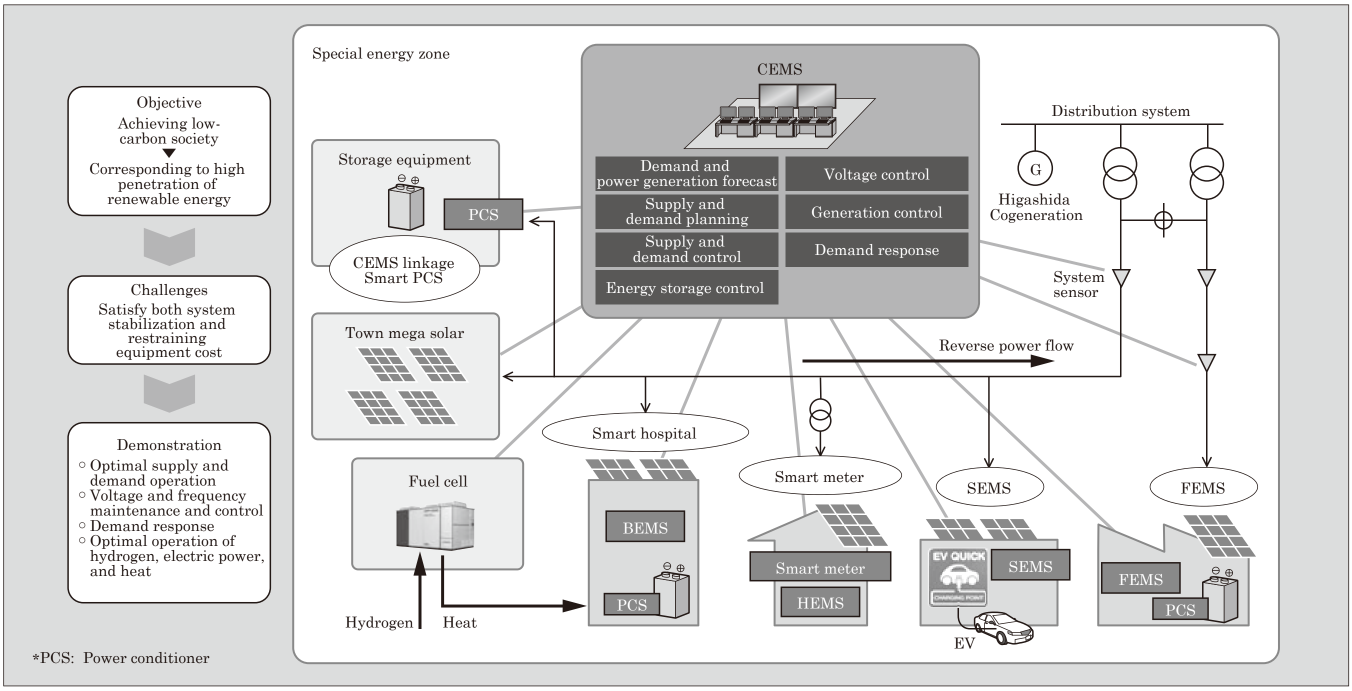

Fig.2 Overall structure of demonstration system

Fig.3 CEMS installed in the Community Setsuden-sho

Fig.4 Storage system for 300 kW

In addition, by having an interconnection with solar power and fuel cells that are installed in the region, it achieves an independent operation function to maintain power supply to essential loads at the time of a large-scale disaster such as the Great East Japan Earthquake. Figure 4 shows a 300 kW storage system

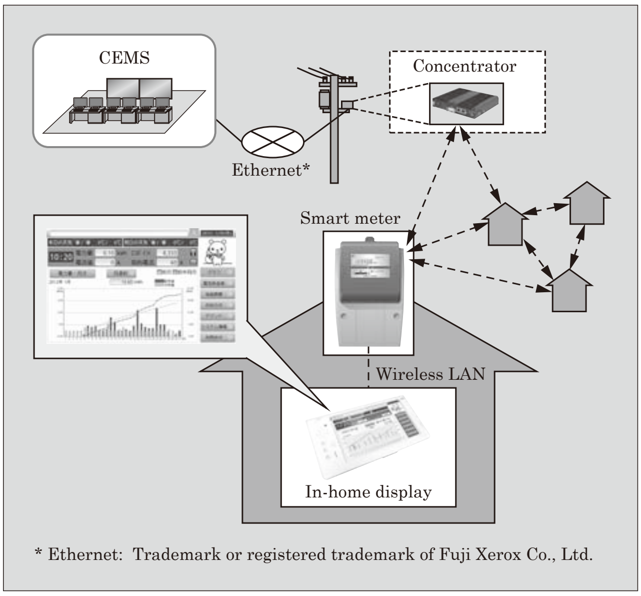

Fig.5 System configuration of smart meter

as an example of a community installation type storage system.

(3) Smart meter

Figure 5 shows the system configuration of a smart meter. The smart meter performs bidirectional communication via the CEMS and the concentrator.

A mesh type wireless communication method is introduced for the communication between the smart meter and the concentrator in consideration of introducing the system to all the utility customers and corresponding flexibly to the future expansion of scale. This allows reducing the pull-in cost of communication network to each door, changing the communication route with a multi-hop function, and corresponding flexibly to meter extension.

Dynamic pricing information from the CEMS is displayed in the in-home display through the smart meter via wireless LAN. The in-home display also displays energy supply and demand situation of the whole region as well as the energy usage situation of individual utility customer, and provides information for utility customers to be able to participate in regional energy supply and demand by the judgment of each user. The smart meter itself holds electric energy data of each 30 minute for 44 days. Smart meters have obtained certification of the Japan Electric Meters Inspection Corporation (JEMIC) and it can be used for power rate negotiations.

Smart meters are installed in 225 households for low-voltage use and 50 offices for high-voltage use as of March 2013 and is used for most utility customers in the district.

(4) Utility customer EMS

Utility customer EMS draws up an optimal plan for energy concerning to the equipment installed in the utility customer site and sends its planning information to CEMS. By using information from CEMS (power rate table), it changes the plan, and corresponds to dynamic pricing by consuming various energies based on the plan.

As of March 2013, HEMS was introduced to 10 households, and BEMS and FEMS were introduced to 8 locations including tenant office buildings, industrial buildings, a corporate dormitory for single employees, a hospital, a factory, city museum and commercial facility.

3. Demand Response System Design

Demand response in this demonstration is implemented by combining two methods: dynamic pricing (DP) and incentive program (IP).

Dynamic pricing is a system to change the power rate unit price corresponding to the peak time period and obtain a reaction from utility customers with the power rate unit price as a trigger. There are the following three types of dynamic pricing system.

(1) Basic pricing

This pricing is set at the beginning of the fiscal year, and the unit price pattern for each seasonal time period is determined based on the past record of power demand, etc. This becomes the basis of the relevant fiscal year, and is notified to utility customers.

(2) Real time pricing

This pricing system sets and notifies the unit price of the next day based on the renewable energy electric power generation amount and supply & demand forecast based on the weather forecast of the next day, by means of multiplying the predetermined coefficient to the basic rate unit price.

(3) Critical peak pricing

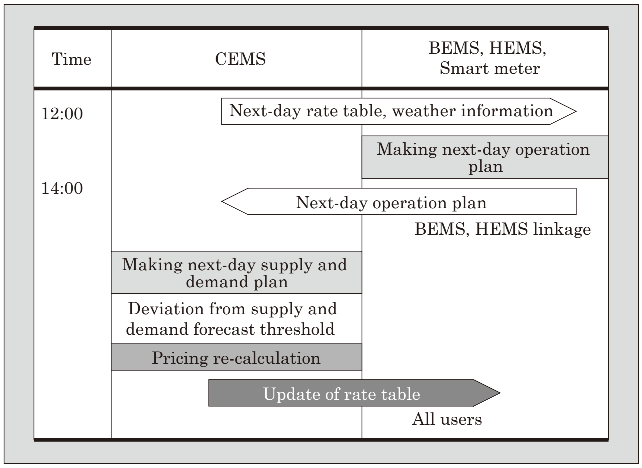

Fig.6 Implementation example of dynamic pricing

This pricing system notifies the unit price based on the predetermined unit price pattern for emergencies if an unexpected situational change (substantial change in the renewable energy electric power generation amount and electric power demand) occurred by the day before.

Figure 6 shows an implementation example of dynamic pricing. CEMS performs demand forecast for the next day and delivers the next day power rate table to utility customer EMS and smart meters every day. Based on this forecast, an operation plan for the next day at a utility customer EMS is generated and sent to CEMS. Based on this information, power rate table for the next day is determined.

4. Dynamic Pricing Social Demonstration

4.1 Dynamic pricing demonstration design

Starting FY2012, the demonstration test of demand response by dynamic pricing to change the electric power rate unit price per period is being conducted. Although the demonstration test is implemented for both general households and offices, this paper reports the results of the demonstration for general households.

The demonstration is conducted by dividing the participants into a controlled group (without implementing demand response), and treatment group (with implementation of demand response) based on random sampling of general households. This follows Randomized Controlled Trial (RCT) as described in the guideline of the US Department of Energy. By comparing the controlled group and treatment group, it is possible to analyze the effect of dynamic pricing application.

The basis of dynamic pricing is critical peak pricing where the power rate is set higher in the limited demand peak time zone on the day when electric power supply and demand become tight such as during the winter and summer. In this test, the critical peak pricing to change the rate level of the peak time period in

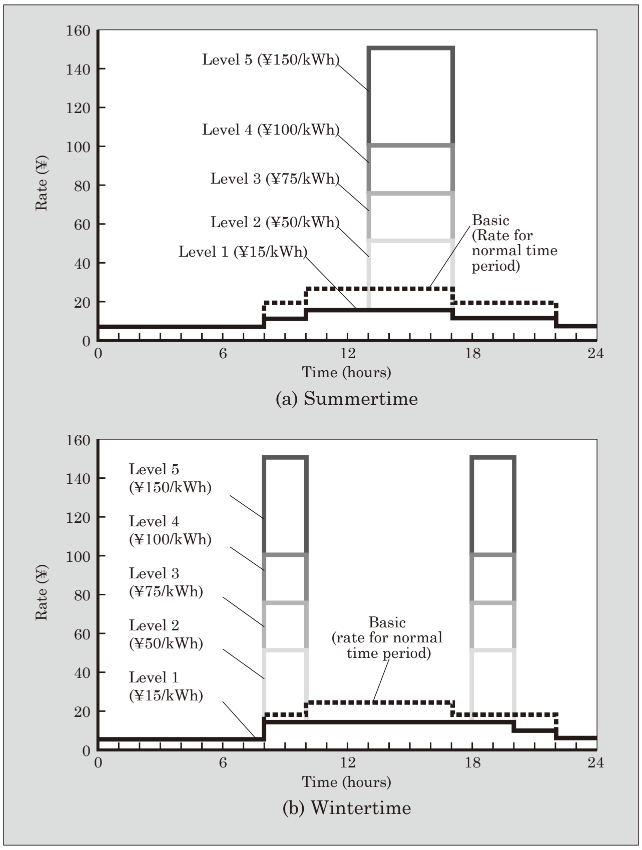

Fig.7 Rate system of dynamic pricing

five stages is implemented in order to obtain the relationship between the price rate level and demand reduction effect.

Figure 7 shows the electric power rate system (in summer and winter) at the demonstration test. In the controlled group, a rate per usual time period called “Basic” is applied. On the other hand, in the treatment group, a different rate per time period other than Basic is applied and the rate from Level 1 (¥15/kWh) to Level 5 (¥150/kWh) at the peak time period was applied. The peak time period is set as 13:00 to 17:00 during the daytime in the summer, and 8:00 to 10:00 in the morning and 18:00 to 20:00 in the evening during winter.

Levels 2 to 5 were implemented randomly on weekdays with the highest temperature forecast of 30 °C or higher for the summertime test (June to September) and on the weekdays with the lowest temperature forecast of 5 °C or below for the wintertime test (December to March), respectively.

4.2 Result of dynamic pricing demonstration test

(1) Summertime test results

Table 1 shows the number of demand response days that were implemented during the summer. In June, there was no day with the highest temperature forecast of 30 °C or higher, and therefore demand response was not implemented. However from July to September, the test was conducted for 40 days in total,

Table 1 Number of demand response implementation days (summertime)

Demand response	Rate level	June	July	August	September
None	Level 1	30	16	11	25
Implementation	Level 2	0	4	4	2
	Level 3	0	4	5	1
	Level 4	0	4	5	1
	Level 5	0	3	6	1

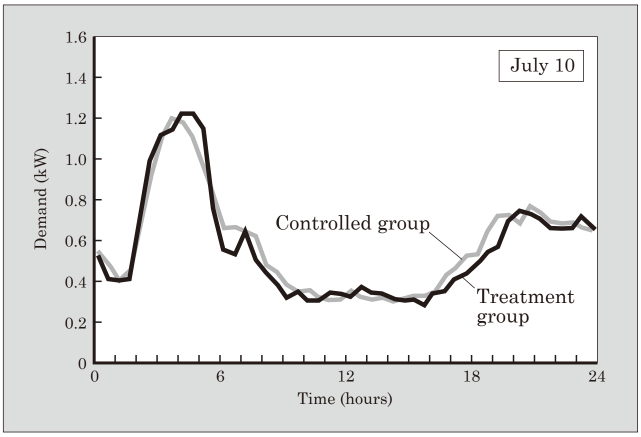

Fig.8 Comparison of demand curve with no demand response

10 days each for levels 2 to 5. Figure 8 shows a comparison of the demand curve (average value) between the controlled group and treatment group on July 10, when demand response was not conducted. The demand of both groups was almost consistent and there was no significant difference. This shows that the grouping by random sampling was appropriately performed.

On the other hand, Fig. 9 shows a comparison of the demand curve between two groups on August 20 when demand response of Level 5 was performed for the treatment group. It is confirmed that in the peak time period where the power rate price becomes higher, demand from the treatment group is decreased.

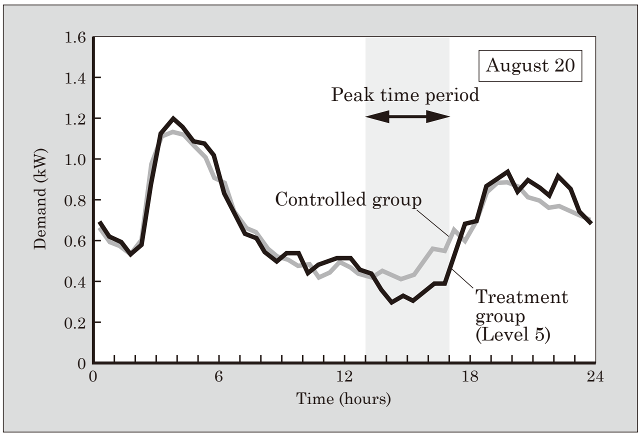

Fig.9 Comparison of demand curve at implementation of demand response

Such change trend of the demand curve can be found in all levels from 2 to 5, and it was possible to confirm the demand reduction effect due to demand response at general households. Next, the relationship between demand response and temperature was analyzed. Figure 10 shows a scatter diagram of the demand from the treatment group at 16:00 against the highest temperature of the day (July to September). As for Level 1, for which demand response was not implemented, there was a correlation between demand and the highest temperature. There was a trend showing that as the highest temperature rises, the demand increases. This implies that the main demand factor during the summertime is air conditioning.

On the other hand, for levels 2 to 5 for which demand response was implemented, although there was a correlation between demand and the highest temperature in Level 4, there was no statistically significant correlation found from other levels. It can be considered that factors other than the highest temperature influenced the demand.

As for the demand reduction effect and the level of demand response, the analysis was conducted by research members centered on Prof. Ida of Kyoto University using the econometrics analysis method with which the treatment group and controlled group were compared. Figure 11 shows the analysis result of the demand reduction rate at the peak time period of each level. The demand reduction rate becomes about 9 to 13% according to each level, and there is a tendency to show the higher effect in the higher level, indicating the effectiveness of the demand response. The analysis result shows the demand response is effective.

(2) Wintertime test results

Table 2 shows the number of demand response days that were performed during wintertime. During December to February, demand response for 10 days or 11 days was performed for each level of 2 to 5, for 42 days in total during the period. Although there was a few days when the temperature was at 5 °C or below in March, demand response was not performed.

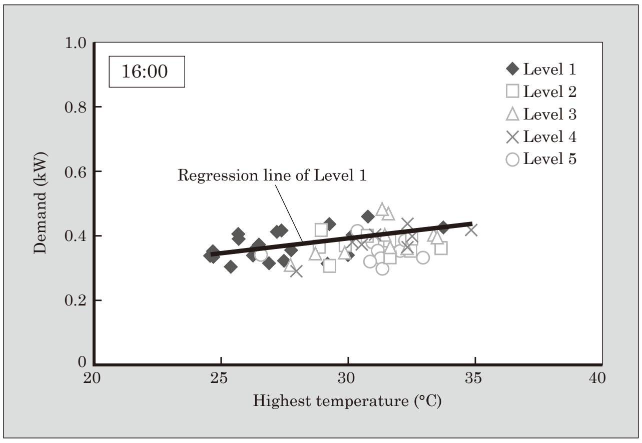

Fig.10 Relationship between the highest temperature of the day and demand at 16:00

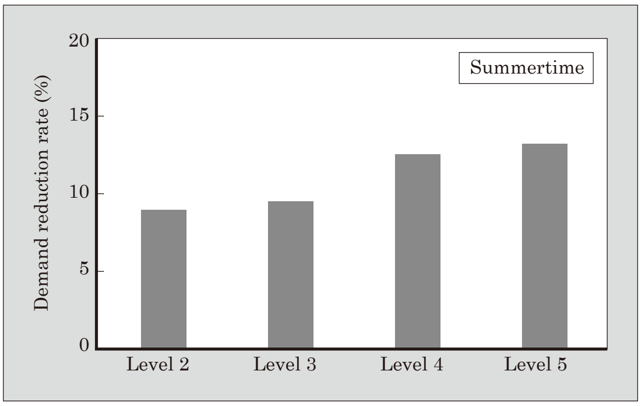

Fig.11 Demand reduction rate (summertime)

Table 2 Number of demand response implementation days (wintertime)

Demand response	Rate level	December	January	February	March
None	Level 1	18	14	16	31
Implementation	Level 2	3	4	3	0
	Level 3	4	3	4	0
	Level 4	3	5	3	0
	Level 5	3	5	2	0

In the wintertime test, the demand curve of the treatment group and control group was also almost consistent when demand response was not performed.

On the other hand, Fig. 12 shows a comparison of the demand curve between two groups on January 28 when demand response for Level 5 was performed with the treatment group. It was possible to confirm that the demand from the treatment group became less during the two peaks of time periods in the morning and evening where the power rate price becomes higher. In addition, there was a behavior of increasing demand after 20:00 when demand response was finished and it was indicated that there was a possibility of shifting the time of electric power use. Such change trend of the demand curve could be found in all levels from 2 to 5, and it was possible to confirm the demand reduction

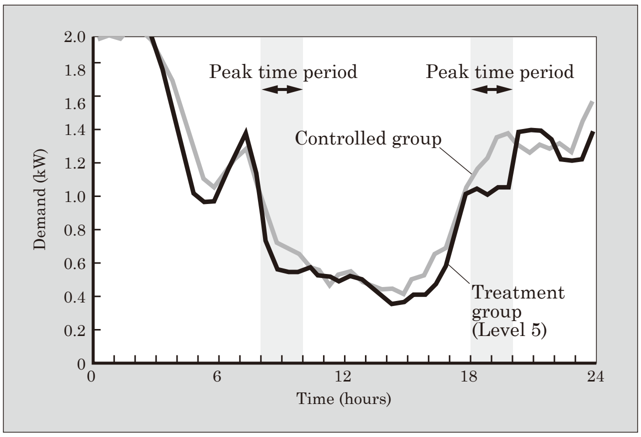

Fig.12 Comparison of demand curve (January 28, Level 5)

effect by demand response in wintertime results, the same as the summertime test.

Figure 13 shows a scatter diagram of demand of the treatment group at 9:00 against the lowest temperature of the day. As for Level 1, for which demand response was not implemented, there was a correlation between demand and the lowest temperature. There was a tendency that the demand increased as the lowest temperature dropped. This implies that the main demand factor during the wintertime is heating appliances. On the other hand, for levels 2 to 5 for which demand response was implemented, no statistically significant correlation was found between demand and the lowest temperature; and it was considered that factors other than the lowest temperature influenced the demand.

Figure 14 shows the demand reduction rate of each level (total of peak time period in the morning and evening) that was analyzed by the research member of Prof. Ida of Kyoto University. The demand reduction rate is about 9 to 12% and it is possible to obtain a demand reduction effect at the same level as for the summertime.

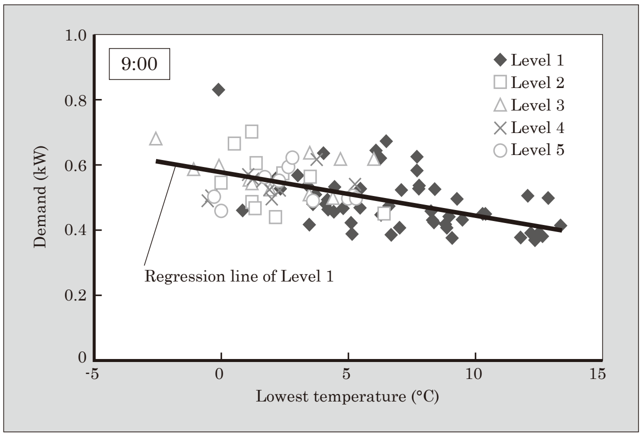

Fig.13 Relationship between the lowest temperature of the day and demand at 9:00

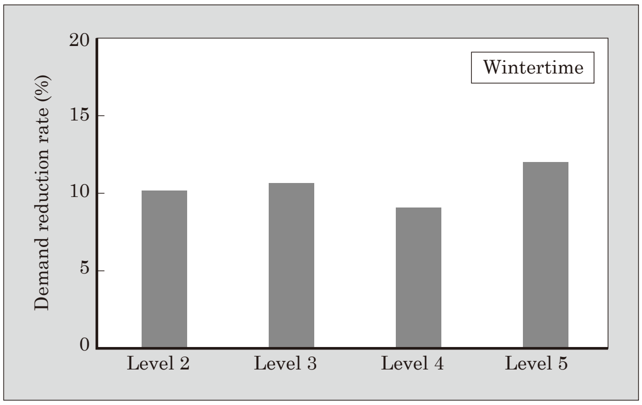

Fig.14 Demand reduction rate (wintertime)

5. Deploying Result of Dynamic Pricing Demonstration Test

From the dynamic pricing demonstration test this time, it was found that the higher the power rate level reaches, the larger the peak cut effect becomes. However, the growth of the effect shows a gradual decreasing trend. In order to deploy the mechanism of demand response including the results of this time in Japan and overseas, the following mechanism is considered necessary.

(1) Review of demand response system

Although the demand response system is currently at the demonstration level, the need for such system is increasing as a result of the Great East Japan Earthquake and the subsequent suspension of nuclear power plants. In the future, in order to continuously establish the system as a social infrastructure, cooperation of providers and utility customers will be necessary. It would be ideal to disseminate a demand response system in which the original idea of the providers is utilized under a clear energy policy established at the national level.

(2) Standardization of demand response

The task for standardization of demand response is promoted by the "Demand Response Task Force" of "Smart House/Building Standardization and Business Promotion Study Group" in Japan Smart Community Alliance (JSCA) centered on the Ministry of Economy, Trade and Industry. The promotion task for standardization is underway based on the Open Automated Demand Response (OpenADR) that is reviewed by Energy Interoperation (EI) 1.0. EI is established by International Consortium OASIS that promotes international open standard as a standard for mutual operation of system between energy companies. OpenADR is a telecommunications standard of demand response and OpenADR alliance (headquarters: Palo Alto, California, USA) develops authentication programs and serves as certification authority. It carries out activities in anticipation of OpenADR compliant systems and future dissemination of the products.

It is necessary for Japan to deploy the demand response service business with OpenADR as a telecommunications standard immediately.

(3) Ensuring security and privacy protection

It is difficult to achieve demand response without gaining reliability related to security and privacy protection. In the United States, partial introduction is initiated in some states and it is pointed out there is a concern that individual's life patterns are disclosed when electric power usage data is leaked. In addition, if there is external intrusion to smart meters and a management system that manages these smart meters, the impact on society is huge; therefore, it is necessary to build a demand response network with high security. In 2011, the US Department of Energy announced “2011 Road map for ensuring cyber security in energy supply system” and indicated strategic framework for the next 10 years in order to develop a safe energy supply system.

6. Postscript

This paper mainly described the results of dynamic pricing demonstration, which was conducted in FY2012 in Kitakyushu, Japan. Fuji Electric will conduct various reviews and demonstrations on demand response systems during the demonstration period until FY2014. We will contribute to the realization of new social systems that can be deployed in various regions in Japan and overseas.