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Energy Management System (EMS)

Fuji Electric

Innovating Energy Technology

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Energy Management System (EMS)

Efficient use of energy is becoming more and more important to prevent global warming, respond to a tight electric power supply and demand situation, and cope with increases in energy price. Efficient use of energy, particularly building of energy management systems (EMSs), is promoted in various sectors such as industrial, household and retail distribution sectors.

Fuji Electric develops products based on its unique control technologies and contributes to improvements in social and industrial infrastructure by releasing these products on the market. This special edition introduces, centering on a cluster energy management system (CEMS) that manage regional energy and a utility customer EMS for each sector, our efforts toward EMS by utilizing Fuji Electric's control technologies and the latest technologies that support EMS.

Cover Photo:

CEMS installed in the Community Setsuden-sho in Higashida district of Yahata-Higashi ward in the city of Kitakyushu, Japan; smart meter; ECOMAX controller; 300-kW storage system

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Energy Management System (EMS): Current Status and Future Outlook

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1. Introduction

Energy self-sufficiency in Japan is as low as 4%, and most of its energy comes from fossil fuels such as petroleum and liquefied natural gas (LNG). Improving energy self-sufficiency and securing energy security have been longstanding challenges after the first oil crisis. In addition, recently, energy consumption has been rapidly increasing against the background of economic growth of newly developing countries including China and global environmental issues are becoming more serious in addition to the issue of stable acquisition of energy .

As one of the countermeasures to these issues, proactive utilization of clean renewable energy is promoted as a policy, and the "Feed-in Tariff Scheme for renewable energy" has been in place since 2012.

Meanwhile, an urgent challenge is economic reform, and strategic efforts are necessary to realize an economic system that allows sustainable development. If we can achieve a clean, economical and stable next-generation energy system ahead of the world, it will serve as a big pillar, and help us to ensure the above-mentioned energy safety, strengthen international competitiveness and promote regional regeneration by utilizing regional resources[1].

The "Next Generation Energy and Social Systems Demonstration Project" initiated in 2010 by the Ministry of Economy, Trade and Industry promotes the advanced demonstrations of a smart grid[*1] in four regions (Yokohama city, Toyota city, Keihanna Science City, and Kitakyushu city) with a view to achieving the next-generation energy system. In this project, regional renewable energy is used in highly efficient and stable. Moreover, technological and social demonstrations and evaluations are performed for demand side management, in which customers also participate in regional energy demand and supply operation by having an energy saving system on the customers' side such as BEMS[*2], HEMS[*3], and smart meters[*4]. In addition, an examination is underway on how to deploy the results of the demonstrations and evaluations to overseas energy infrastructure and infrastructure for restoration from the Great East Japan Earthquake.

The next-generation energy system provides customers with various energy menu options. In order for customers to use these options wisely, diffusion of energy management systems (EMS[*5]) becomes an important condition.

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***1: Smart grid**

This is an electric power distribution system to share information between energy providers and utility customers by using technology such as a smart meter, and operate a large-scale electric power system and regional power grid in cooperation. With this system, it is possible to introduce renewable energy in large quantities and utilize the energy efficiently.

***2: BEMS**

Abbreviation of building and energy management system. This is a system to perform energy management of air conditioning, lighting and power for industrial buildings. It is possible to remotely control energy equipment and load by sharing information with building facility management systems in a large-scale building.

***3: HEMS**

Abbreviation of home energy management system. This system is used to visualize energy supply and demand at home, along with diffusion of technology such as hot-water supply systems and air conditioning systems by using solar power generation for households and nighttime electric power and fuel cells for households. There are various forms of HEMS, including those that monitor and control energy by installing a home terminal at each house, provide an energy management service by using a personal computer and a smartphone, and convert home electrical appliances into intelligent devices.

***4: Smart meter**

This is a watt-hour meter with a bi-directional communication function. With this meter, it is possible to remotely read the meter of electric energy, measure voltage and current, remotely change the contract electric energy, and remotely stop and release stop of power supply.

***5: EMS**

Abbreviation of energy management system. This is a system to visualize energy such as electricity, heat and gas and optimally operate facilities. According to the management target, the system includes BEMS, CEMS, FEMS, HEMS and REMS.

This paper describes CEMS[*6] for performing regional energy management, utility customer EMS for each field, as well as each type of technology that comprises EMS.

2. Energy Management System (EMS) Technology

2.1 Global image of EMS

Figure 1 shows a global image of EMS that Fuji Electric considers.

In 2011, Fuji Electric commercialized and released the "EnergyGATE Series" as package products of CEMS to perform regional energy management in smart community[*7] and EMS to visualize customers' energy in each type of field such as in factories and stores, and promote energy saving.

In addition, Fuji Electric provides retail EMS (REMS[*8]) and factory EMS (FEMS[*9]) to achieve more advanced energy management in the field of distribution stores and industrial fields based on the know-how of energy-saving, manufacturing and facility operation that Fuji Electric has been accumulating with customers.

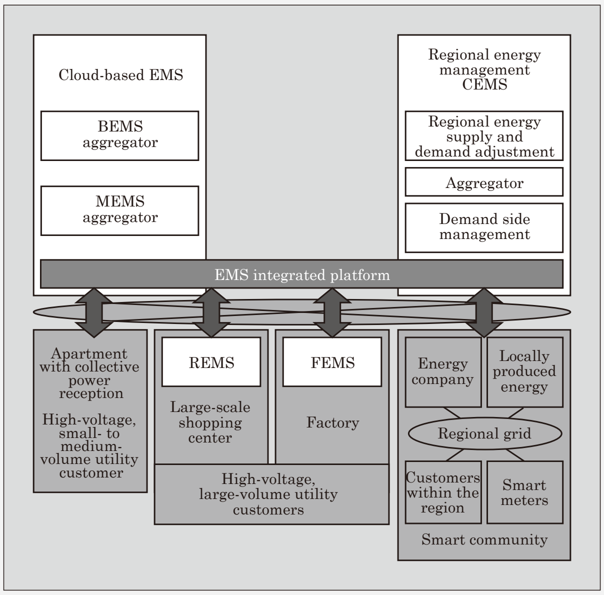

Fig.1 Global image of EMS

Furthermore, for high-voltage, small-volume utility customers such as elementary and junior high schools, small-scale stores and apartments with collective power reception, it is difficult to recover the cost if EMS equipment is introduced individually. Accordingly, the investment cost of EMS facilities is suppressed by providing an EMS service in a cloud[*10] environment.

2.2 Development road map for EMS

In Japan, the Act on the Rational Use of Energy (Energy Saving Act) has been revised several times since it was enacted in 1979. In 1997, Japan ratified the Kyoto Protocol with the aim of preventing global warming, and revised the act in a manner that enforces the regulations further, and has been promoting the introduction of renewable energy as a policy.

In addition, while economic society is developing globally, Japan expanded its electricity liberalization in stages from 1995 in order to meet a request for market liberalization. Meanwhile, Japan is actively corresponding to international standards in order to secure international competitiveness in the domestic industrial fields and expand markets.

Furthermore, consumption of petroleum and LNG is growing and their prices are increasing rapidly due to unstable social conditions in oil-producing countries in the Middle East and business expansion in emerging countries in Southeast Asia that has been seen since around 2000.

Fuji Electric has been providing various products and solutions related to energy-saving to customers since the first oil shock in 1973. In addition, Fuji Electric has been developing advanced EMS products by anticipating the surrounding environmental changes and development of information processing technologies. Figure 2 shows the development road map of Fuji Electric EMS as well as main technology and components. The next section explains the development background of main ele-

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***6: CEMS**

Abbreviation of cluster energy management system. This is a system to optimize regional energy supply and demand. It is possible to perform direct or indirect control of load on the customers' side by sharing information with smart meters and energy saving systems of the customer.

***7: Smart community**

This stands for low-carbon, stable and economical social infrastructure by harmonizing with the natural environment. This infrastructure aims at having sustainable growth of the overall community in ways such as efficient use of energy, cyclic use of energy and environmental conservation.

***8: REMS**

Abbreviation of retail energy management system. This is a system to visualize energy supply and demand in the field of retail distribution and optimally operate facilities. It is necessary to implement energy saving in retail stores after securing safety and sanitation management of foods and amenities of users as the top priority.

***9: FEMS**

Abbreviation of factory energy management system. This is a system to perform advanced factory operation focusing on cost reduction of the product life cycle by linking with product management and supply chain management. It is possible to correspond to the regulations of energy-management-designated factories based on the revision of the Energy Saving Act in 1998.

***10: Cloud**

Abbreviation of cloud computing. This is a technology to store data on dispersed servers and computers via a network and use the software resources within them.

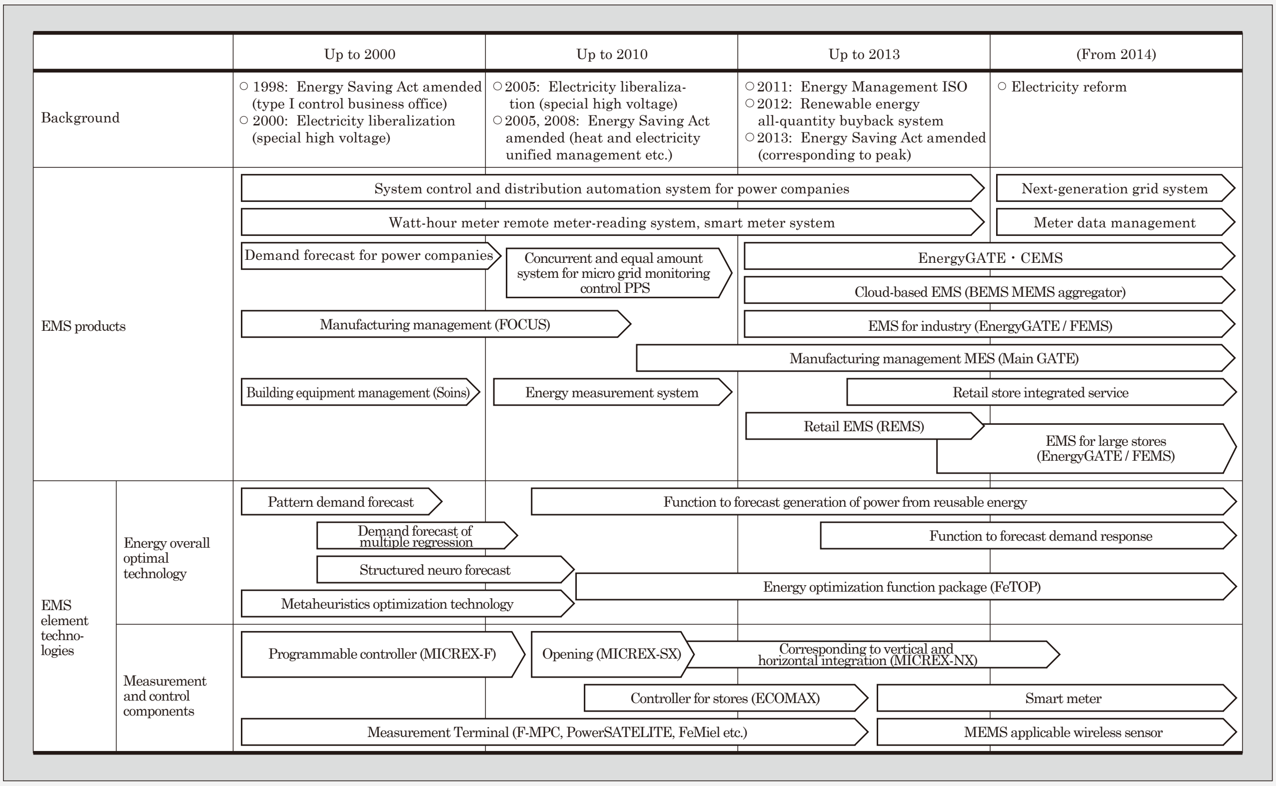

Fig.2 Development road map for EMS and main technologies and components

ment technologies that constitute EMS and EMS products.

(1) Measurement and control components

A measurement and control components, which constitute EMS, is used to measure and control energy use status of load equipment at a site. In 1985, Fuji Electric launched the programmer controller “MICREX-F” and provided a manufacturing and facility management system to monitor and measure the state of building and plant equipment, advance facility operation such as auto control, and labor saving. Furthermore, Fuji Electric develops a higher performance series such as the open interface “MICREX-SX” and “MICREX-NX” enabling easy data sharing with each type of system within the customers’ premises in order to correspond to user needs and progress in information processing technologies.

After the revision of the Energy Saving Act in 1995, continuous energy saving became compulsory for small and medium-sized establishments in addition to large establishments, and as a result, the needs for simplified energy measurement systems have expanded. Fuji Electric responded to this trend and released energy measurement system with low-cost measurement terminals such as “F-MPC” and “PowerSATELITE.”

Furthermore, in order to simplify the installation of measurement terminals on site, Fuji Electric developed a self-power supply system measurement sensor that applies wireless tags and smart meters that allow obtaining meter-reading information within a building.

(2) Energy overall optimal technology

Through several amendments of the Energy Saving Act, the main individual energy-saving policies have been already implemented. Thus operational improvement of overall energy equipment and manufacturing plans are needed to achieve further energy-saving. In addition, operation of utility customers’ energy equipment is becoming more complicated owing to the increase of choices available to procure energy as a result of electricity liberalization and promotion of use of unstable renewable energy.

Fuji Electric released the optimization package “FeTOP” in 2003 to draw up overall optimal operation planning of complicated energy equipment. FeTOP is used to automate planning by using advanced information processing technology such as structured neural network and metaheuristics optimization technique. It is possible to minimize energy equipment cost such as electricity, heat and power, and environmental impact. It is possible to apply this package to a wide range of optimization processes including not only overall optimization of energy, but also water system control and power generation amount forecasts for renewable energy.

(3) EMS products

To achieve clean, stable, low-cost energy supply and demand, sharing information between energy suppliers and utility customers and achieving energy distribution control in a coordinated manner become a big challenge. In order to do so, promoting the introduction of EMS to utility customers and introducing CEMS to link these to energy providers and each type of energy service provider bidirectionally becomes a mandatory requirement.

Fuji Electric integrated energy measurement and control technology, energy optimization technology, information processing technology and the like, which have been provided to individual customers, and released the energy management system package "EnergyGATE" in 2011.

Figure 3 shows the software configuration of EnergyGate.

This package is targeted at both energy providers and utility customers. The characteristic of this package is its configuration where each piece of software for energy providers and utility customers are implemented on a common integrated EMS platform and provided.

The integrated EMS platform is provided with high-speed program cooperation service "Fuji Service Bus," which links EMS service software distributed in each server, and high-speed data sharing service "Field Connector," which controls data reference from each piece of software and control commands. With these functions, it is possible for EMS that is installed by energy providers and utility customers to achieve seamless and high-speed service software linking and data sharing[2] (refer to "A Framework for Optimal Planning Systems on the EMS Platform" on page 186).

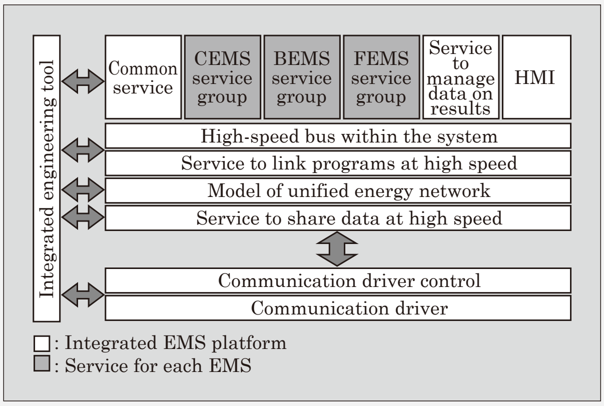

Fig.3 Software configuration of "EnergyGATE"

3. EMS Structure for Each Field

3.1 Regional energy management system

Since 2010, Fuji Electric has been promoting demonstration and evaluation of CEMS to perform regional supply and demand control in "Kitakyushu Smart Community Creation Project,"[*11] which was selected as one of the four regions of the "Next Generation Energy and Social Systems Demonstration Project" by the Ministry of Economy, Trade and Industry. This CEMS is equipped with advanced regional energy management functions such as a renewable energy power generation forecast that is linked with meteorological data, and an optimal supply and demand planning function to utilize regional renewable energy effectively in a concerned region (refer to "Supply and Demand Control System for Power Systems with Distributed Power Supplies" on page 191, and "Photovoltaic Power Generation Forecasting Technology for Supporting Energy Management Systems" on page 196).

In addition, Fuji Electric is conducting a real-scale demonstration of dynamic pricing[*12] to create utility customers' peak shift reaction by sharing information bidirectionally with smart meters, which are installed for all utility customers within the demonstration region, and utility customer EMS, a product that each participating company is demonstrating.

During the demonstration period until the end of FY2014, Fuji Electric is planning to evaluate each type of pioneering technology and social system in aspects such as their ability to maintain power quality of a grid when renewable energy is introduced in large quantity, use of hydrogen by utilizing characteristics of the region adjacent to the factory, and heat management, in addition to the above-mentioned Dynamic Pricing.

Along with the demonstration project, Fuji Electric is proceeding with a review of business models toward continuation of CEMS business after it has completed demonstrations and domestic and overseas deployment of demonstration results. A large amount of information on energy usage situations of utility customers is gathered in CEMS. As for reviewing the commercialization, it is positioned

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***11: Kitakyushu Smart Community Creation Project**

This project is selected as one of the projects in "Next Generation Energy and Social Systems Demonstration Project" promoted by the Ministry of Economy, Trade and Industry from 2010. This project is being carried out at the Higashida district of Yahata-higashi ward in the city of Kitakyushu, Japan (120 ha) until 2014. One of the characteristics is that the Higashida district is conducting demonstration of real-scale dynamic pricing in the power supply region with a private line by Higashida Co-generation Corporation in corporation with the Power Supply and Demand Union in the same district.

***12: Dynamic Pricing**

This is a system to change power rates per time period according to the change in supply and demand state. This system promotes power saving of utility customers by increasing the power rate during the time period when supply and demand are expected to be high.

in terms of the Data Aggregator business and securing profitability is evaluated. At this point, Fuji Electric is considering adding a CEMS operator to its regional energy management service business to optimize regional energy supply and demand and utilize large amounts of utility customers' information to expand each type of service menu with approval from utility customers.

Figure 4 shows an overview of service cooperation of CEMS as a data aggregator. It is possible to develop the utility customer energy usage information gathered by CEMS in services other than energy such as watching elderly people, transportation, and attracting customers to commercial buildings in addition to EMS services such as visualization of energy and energy saving (refer to "Social System Demonstration of Dynamic Pricing in the Kitakyushu Smart Community Creation Project" on page 152).

3.2 FEMS

Fuji Electric has been providing manufacturing management packages centering on the "MainGATE Series" to various types of industry and has been accumulating know-how related to the operation of various types of manufacturing equipment such as batch, line and continuous processes. The characteristics of FEMS for industrial fields are that it utilizes that know-how and realizes optimal operation of factory utility equipment that is linked to the manufacturing plan of the factory.

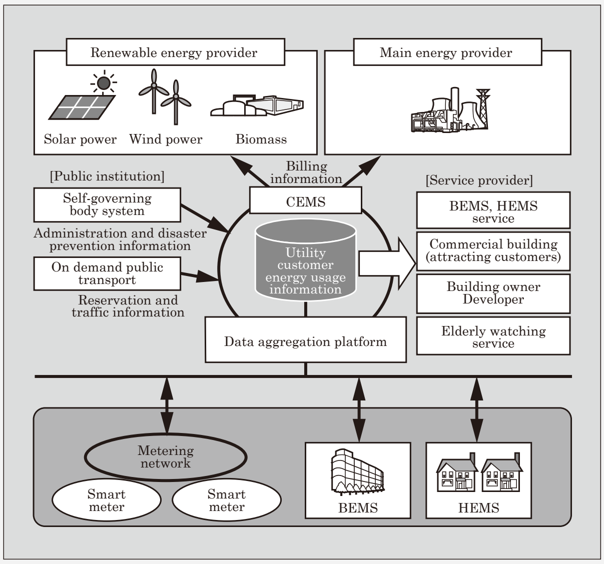

Fig.4 Conceptual image of service cooperation of CEMS as a data aggregator.

A large-scale iron foundry possesses an energy center and supplies energy such as gas, heat, and electricity related to iron manufacturing. Fuji Electric used the latest metaheuristics optimization technology by interlocking energy supply with the iron manufacturing process and developed an iron and steel EMS to draw up the optimal operation plan (refer to "'Steel EMS Package' Optimizing Energy Management at Steelworks" on page 165).

In addition, in the paper manufacturing industry, in which a large amount of heat consumption is the main constituent of the energy used, an increasing number of customers are implementing cogeneration[*13] when replacing deteriorated equipment after the Great East Japan earthquake, with the aim of securing power supply in the event of a disaster. Fuji Electric developed a heat management system to allow optimum operation of cogeneration systems and boilers to correspond to heat demand (refer to "Energy Optimization System for Cogeneration Plant of Paper Factory" on page 160).

3.3 Cloud-based EMS for buildings and apartments

High-voltage, small-scale users (contracted power of 50 kW or more but below 500 kW) consume a small amount of energy and it is difficult to recover the cost for introducing EMS equipment individually. By providing an EMS service such as visualization and energy saving in a cloud environment to small-volume utility customers, it is possible to control the cost for capital investment in EMS.

Figure 5 shows an overview of cloud-based EMS. Fuji Electric installs an energy-related information display terminal on the small-scale user side and provides an EMS service such as visualization of energy and energy-saving via communication network from an external EMS aggregator. Improvement of equipment operation by visualizing energy on the utility customer side is expected to bring an energy saving effect of about 10%.

In addition, the relevant energy information is aggregated and distributed regularly to the owner of the target facility and self-governing body that manages elementary and junior high schools.

Fuji Electric initiated the BEMS aggregator business for elementary and junior high schools

***13: Cogeneration**

This is a system where power generation equipment is installed on the utility customer side such as in the factory and building and utilizes the generated heat. By using LNG as fuel, a reduction in CO_2 of about 30% is expected compared to commercial power. Although introduction reached its peak due to a sudden increase in fuel price, enterprises are paying attention to it again as an autonomous power supply at the time of a large-scale disaster, and because of an incentive provided to peak-cut cooperation at the time when the power supply and demand situation gets tight.

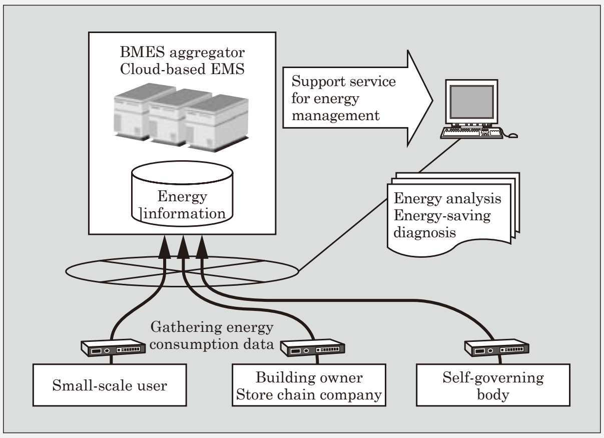

Fig.5 Overview of cloud-based EMS

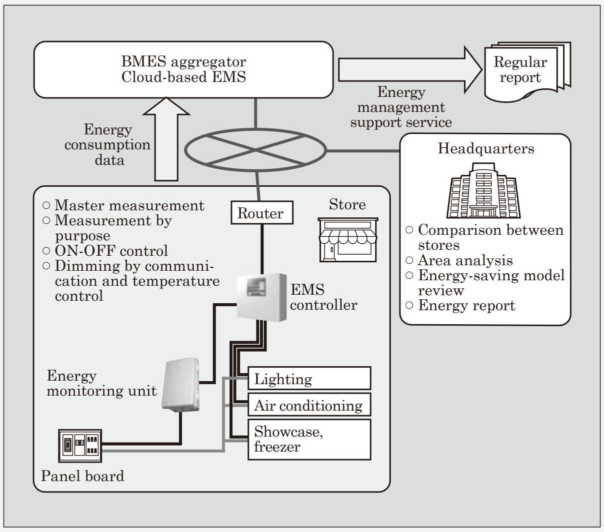

Fig.6 Example of REMS

and commercial buildings in 2012, and the mansion EMS (MEMS) aggregator[*14] business for high-voltage batch power receiving apartments in 2013 (refer to "Energy Management Support Service with Cloud-Based EMS" on page 176).

3.4 REMS

Energy-saving of distribution stores such as convenience stores and supermarkets is required to be compatible with unique factors such as maintaining amenity of in-store environment including air-conditioning and lighting as well as temperature control of refrigerated and freezer showcases for food.

Fuji Electric offers the line-up of store construction method "Ecolo Unit" considering the environment and cold chain devices such as refrigerated and freezer showcases. In addition, Fuji Electric has developed "ECOMAX Controller," which monitors energy in a store and automatically controls lighting and the temperature of display cases and air conditioning to support energy saving of the whole store.

Furthermore, Fuji Electric has built REMS which collects energy consumption data gathered from each store with cloud-based EMS by using BEMS aggregator, sends energy-saving guidance to each store, and sends energy management support information to a chain store headquarters. Figure 6 shows an example structure of REMS.

In addition, Fuji Electric developed and is conducting demonstrations and evaluations of EMS to perform dynamic pricing in the facility for large-scale shopping centers comprised of multiple tenants (refer to "The 'ECOMAX Controller' Realizes an EMS for Use in Stores" on page 181 and "EMS for Large-Scale Commercial Facility" on page 170).

4. Postscript

This paper describes CEMS for performing regional energy management, utility customer EMS, as well as technologies that constitute EMS.

EMS package of Fuji Electric, "Energy GATE" is considered to be providing an important solution for making the energy supply side and utility customers smart. Fuji Electric will continue making efforts to provide advanced energy services corresponding to new energy systems and the trend of standardization in anticipation of an expansion overseas.

Reference

(1) "Strategic Market Creation Plan". Prime Minister of Japan and His Cabinet. http://www.kantei.go.jp/jp/singi/keizaisaisei/pdf/rm_en.pdf, (accessed Jul. 16, 2013).
(2) Horiguchi, H. et al. Integrated Energy Management System Platform. FUJI ELECTRIC REVIEW. 2011, vol.57, no.4, p.146-151.

***14: Aggregator**

This is a system to provide each type of energy service such as visualization and energy procurement at low cost by arranging medium- to small-volume utility customers under the environment of electricity liberalization. It can solve the issue of medium- to small-volume utility customers having weak price negotiation power and thus is difficult to find merits to reduce individual energy cost.

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

OGA Eiji * KABASAWA Akihiro ⁑

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.

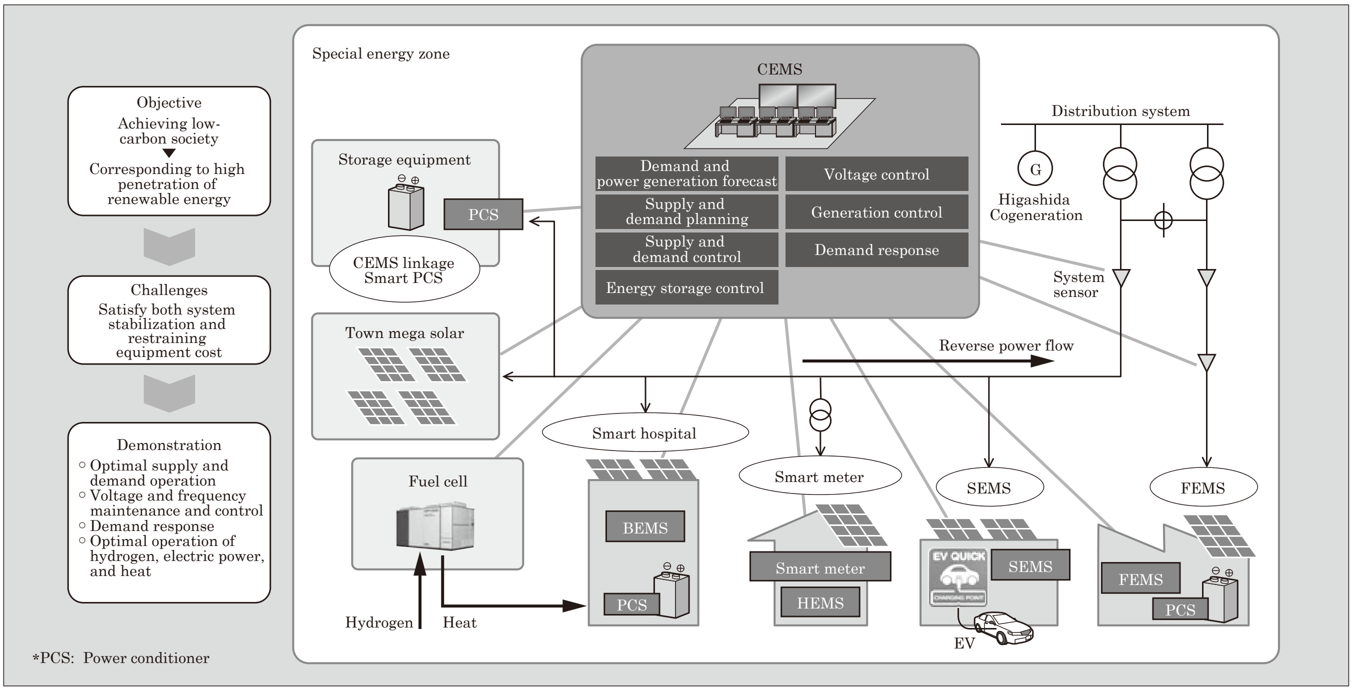

Fig.2 Overall structure of demonstration system

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 as an example of a community installation type storage system.

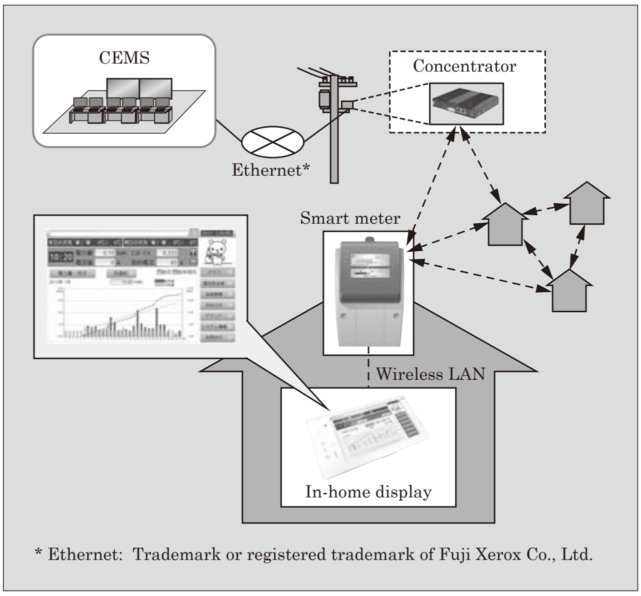

Fig.5 System configuration of smart meter

(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

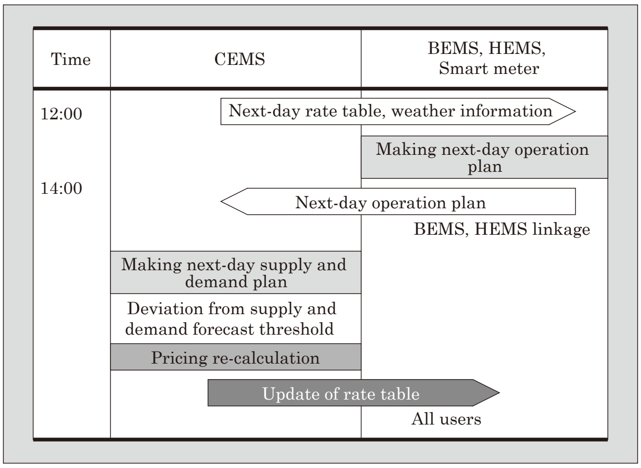

Fig.6 Implementation example of dynamic pricing

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

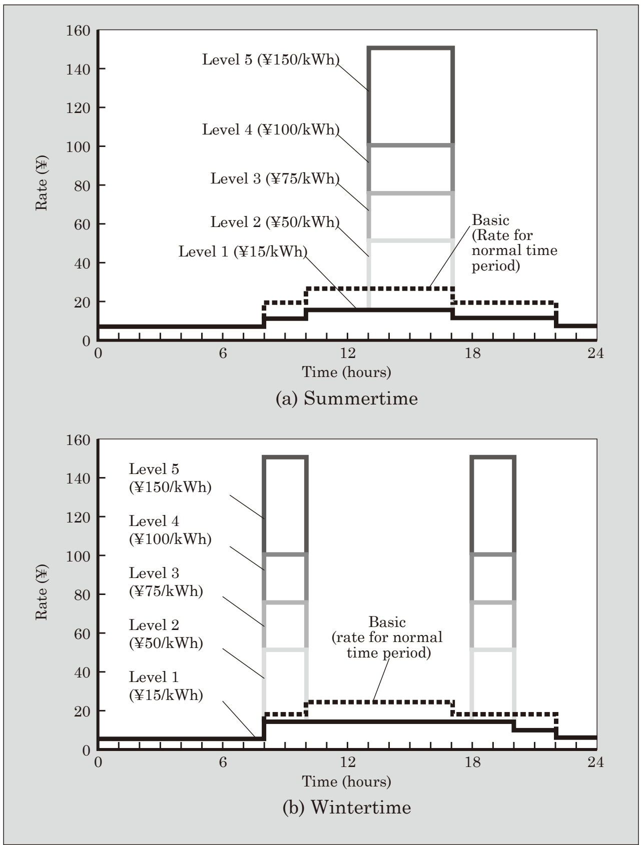

Fig.7 Rate system of dynamic pricing

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

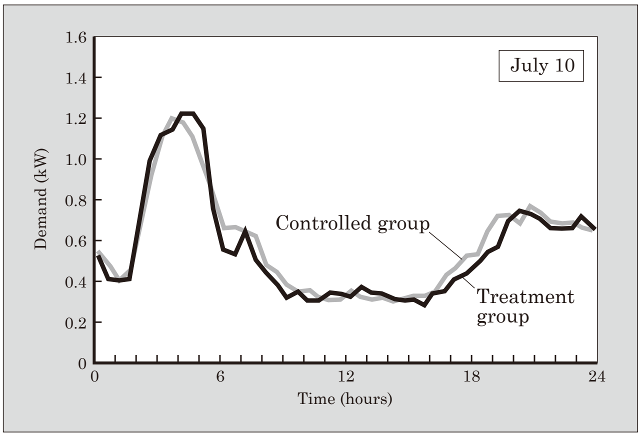

Fig.8 Comparison of demand curve with no demand response

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.

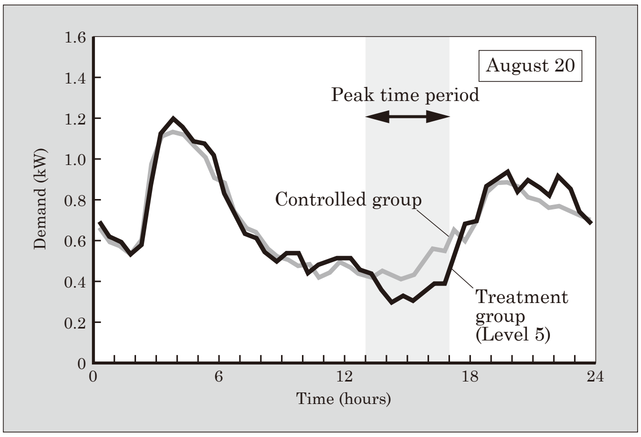

Fig.9 Comparison of demand curve at implementation of demand response

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.

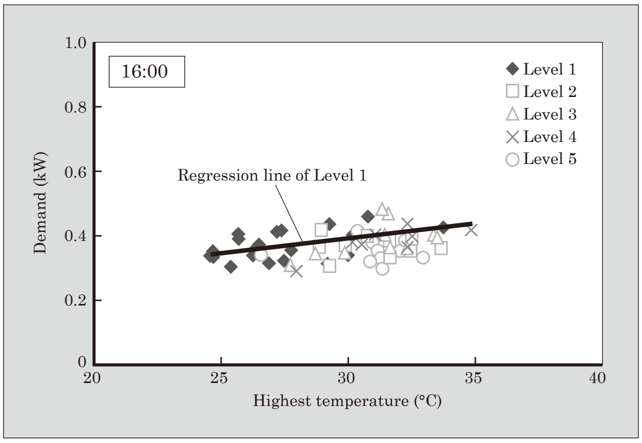

Fig.10 Relationship between the highest temperature of the day and demand at 16:00

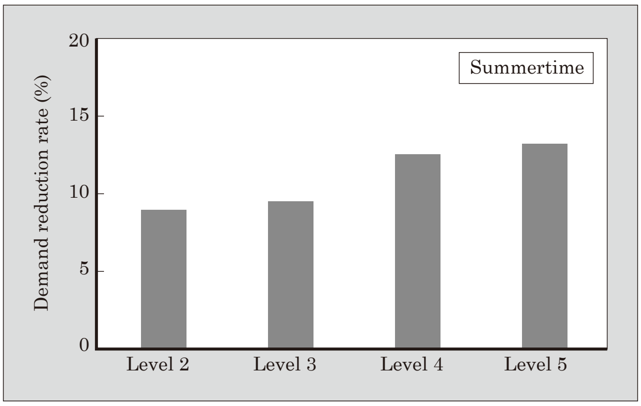

Fig.11 Demand reduction rate (summertime)

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

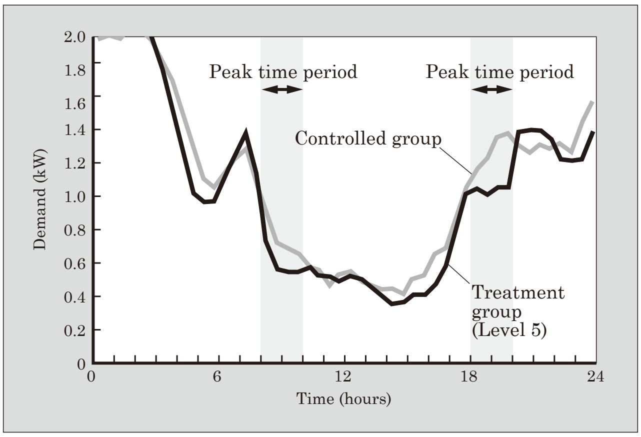

Fig.12 Comparison of demand curve (January 28, Level 5)

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.

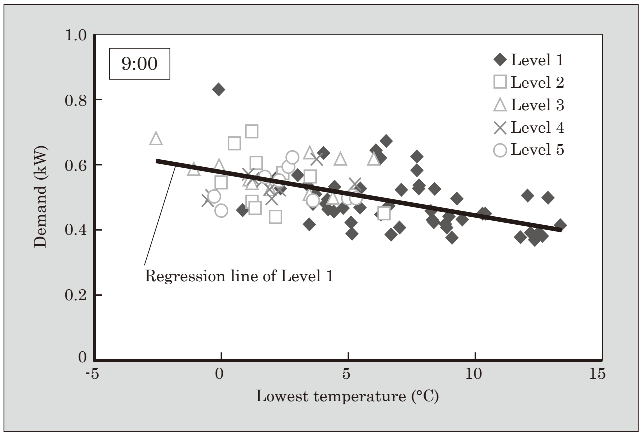

Fig.13 Relationship between the lowest temperature of the day and demand at 9:00

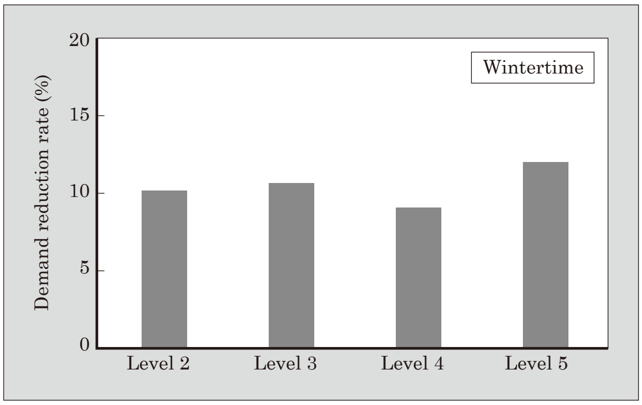

Fig.14 Demand reduction rate (wintertime)

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.

Energy Optimization System for Cogeneration Plant of Paper Factory

TATTA Naoto * KANEHIRA Yoshiji ⁑

ABSTRACT

A cogeneration plant provides steam and electric power required for paper factories. Fuji Electric has developed and delivered an energy optimization system for the cogeneration plant of a paper factory. The system is capable of monitoring the state of various facilities, including power/steam loads and the amount of steam produced by an exhaust-heat recovery boiler, which fluctuate greatly in the factory. The system can thus optimize the operation in real time according to the supply-demand balance of power and steam. Since the system automatically optimizes loads so that contracted electricity limits are never exceeded at times of excessive steam loads, while also ensuring that there is no inverse power flow during times of steam shortages, the cost of installing the system can be confirmed to be recovered in one year.

1 Introduction

Cogeneration facilities first went on the market in the 1980s. With growing electric demand, cogeneration facilities are introduced at the time of renewing equipment such as boilers or converting energy sources from heavy oil to natural gas, intending to attain energy-saving and cost-saving. They are in wide use at plants, industrial facilities, etc. Although the introduction of cogeneration facilities slowed down because of the recent steep rise in the price of crude oil, the number of utility customers introducing cogeneration facilities has been on the increase since the Great East Japan Earthquake as they think it important to ensure electric power for themselves.

We proposed a cogeneration system for a paper-making factory, and accepted an order to develop and deliver the system. This paper provides an overview of the system that optimizes energy-saving operation of the cogeneration facility.

2. Cogeneration Facility

2.1 Overview of the cogeneration facility

An overview of the cogeneration facility of the paper-making factory to which our energy optimization system was delivered is shown in Fig. 1. This facility consists of a gas turbine, generators, an exhaust gas boiler, a steam turbine, a waste heat recovery boiler, and an auxiliary boiler, etc. The exhaust gas boiler is designed to enable reheating.

The electric power required for the factory (electric load of the factory) is provided by the electric power received from the electric power company and the electric power generated by the combination of the gas turbine generator and steam turbine generator which are installed inside the factory. The steam consumed in the factory (steam load of the factory) is provided by exhaust steam from the steam turbine and steam from the waste heat recovery boiler and the auxiliary boiler.

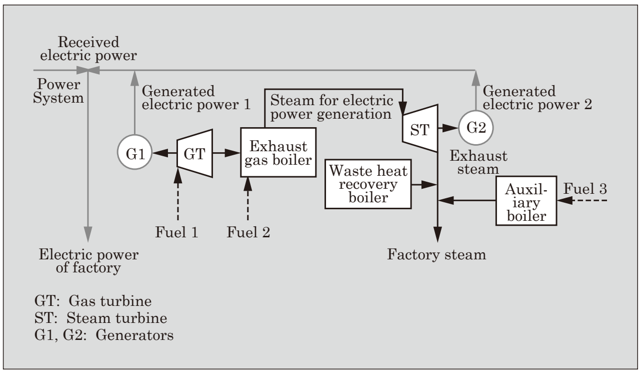

Fig.1 Overview of the cogeneration facility

2.2 Operation of the cogeneration facility

The electric and steam loads of the factory significantly vary depending on the operating state of the factory or the season, and the volume of steam generated by the waste heat recovery boiler varies as well. What is most required for the cogeneration facility is the ability to supply the proper volumes of electric power and steam in response to greatly varying electric power and steam needs of the factory just enough without delay.

The cogeneration facility is operated in the following three patterns depending on the steam load of the factory and the supplying state of steam:

(1) During normal operation

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When the operation of the factory is at normal state, each of electric power supply and the volume of generated steam are in balance with the factory's electric load and steam load respectively, and steam supply is automatically regulated by operating the gas turbine with maximum load and bringing the steam turbine into backpressure mode.

As the electric load of the factory slightly decreases, received electric power is monitored to avoid unnecessary electric power generation so as to minimize reverse power flow.

(2) When steam is excessive

The steam load of the factory is decreased if the operation level of the factory is relatively low, and steam becomes excessive when the waste heat recovery boiler is in operation. In these situations, excessive steam will be inevitably released. To reduce the volume of steam to be released, the steam turbine will be placed in output operation mode, which keeps the volume of exhaust steam from the steam turbine constant, and operated with pressure controlled by a steam release valve. The factory will be monitored to prevent demand over*1 because the amount of electric power generated decreases.

(3) When steam is insufficient

Even though the operation of the factory is at a normal level, the waste heat recovery boiler may stop operation and the factory may fall short of steam, just for a short period. In this case, the auxiliary boiler will be operated to make up for insufficient steam. The steam turbine will be operated in backpressure operation mode. The factory will be monitored to prevent a reverse power flow because the amount of electric power generated increases.

3. Energy Optimization System

3.1 Configuration of the energy optimization system

The configuration of the energy optimization system introduced this time is shown in Fig. 2, and its functions are described in Table 1.

This system collects data about the operating state of the cogeneration facility through an existing PLC for data collection. The manufacturing and energy analysis assisting package of Fuji Electric Co., Ltd., "MainGATE[(1)]," is introduced and used to accumulate and analyze data.

On the operation console for the energy optimization system, three optimum operation mode switches (optimization during normal operation, optimization when steam is excessive, and optimization when steam is insufficient) are provided, and they can be turned on and off any time. The screen of the operation console displays the state of the cogeneration facility, current values and other data, enabling to grasp the operating state of this energy optimization system at a glance. In addition, all parameters for tuning can be set and changed on the screen and are easy to adjust. Output from this energy optimization system is input directly into the remote control console for the existing gas turbine and steam turbine, and flow rate controller of the auxiliary boiler.

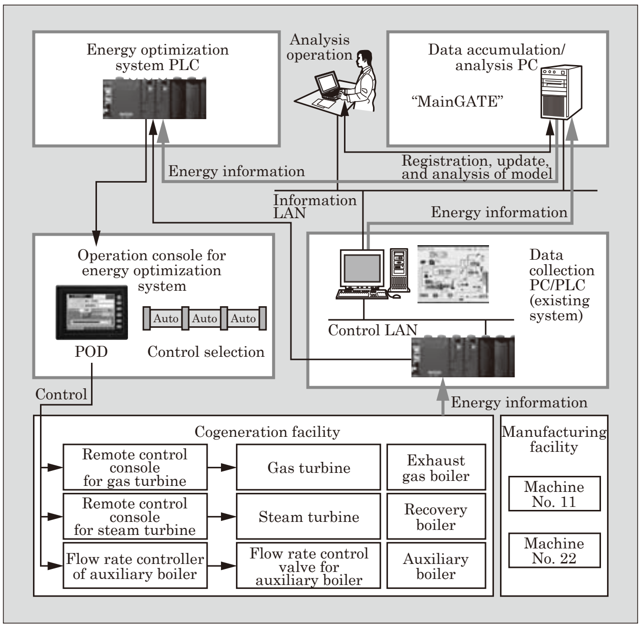

Fig.2 Configuration of energy optimization system

Table 1 Functions of energy optimization system

Unit	Function
Data accumulation/ analysis PC	Accumulates and displays data to promote visualization.
	Estimates the characteristics of the boiler and turbine by using collected data.
PLC of energy optimization system	Optimizes the state of the cogeneration facility during normal operation. (Input load increase and decrease signals, etc. into the remote control console for the existing gas turbine.)
	Optimizes the state of the cogeneration facility when steam is excessive. (Input load increase and decrease signals, etc. into the remote control console for the existing steam turbine.)
	Optimizes the state of the cogeneration facility when steam is insufficient. (Input setting values, etc. into the flow rate controller for the auxiliary boiler.)
Operation console for energy optimization system	Activates and deactivates the automatic operation of the energy optimization system. In automatic control, displays necessary information on the POD. Inputs constants and setting values of parameters with the POD.

3.2 Features of the energy optimization system

Optimum operation means preventing demand over or reverse power flow, reducing the volume of steam released to zero, selecting more inexpensive

*1: Demand over: Exceeding the upper limit of the contracted power reception amount.

fuel, and reducing the volume of fuel consumption. However, optimum operation is, in fact, difficult to achieve in manual mode because constant monitoring is required and there is difference in performance among operators. Great energy saving and operation efficiency can be expected by employing automatic operation using the energy optimization system.

This energy optimization system is characterized by the software and hardware functions described below. The system is intended to implement automatic operation in real time with adequate consideration given to safety, and it realizes optimum operation by making the most of the measurement and control devices for the existing gas turbine and steam turbine.

(1) Functional features of software

An existing control system has been prepared for controlling each of the existing gas turbine, steam turbine and exhaust gas boilers.

This energy optimization system is positioned as a set point control (SPC) system that gives these control systems setting values. From the viewpoint of making use of the existing measurement and control devices and ensuring safety, the energy optimization system was designed as a speed type SPC that gives differences from current set values, not a position type SPC designed to give setting values to lower-order control systems. Thus, even if an error occurs to this energy optimization system, the cogeneration facility can continue operating safely by separating this energy optimization system.

A heuristic approach is used for the algorithm and is capable of bringing values to optimum ones with the appropriate process values from the existing measurement and control devices. Tools, such as the energy optimization assisting package "FeTOP,"(2) are used to conduct simulations while verifying the effectiveness of the algorithm.

(2) Functional features of hardware

The existing gas turbine and steam turbine are equipped with a remote control console, which, in combination with a dedicated controller, makes it easy for the operator to operate the turbines. These operation consoles were made available with this energy optimization system by modifying them to become capable of receiving pulse signals from the system. In addition, since the energy optimization system can be used with existing systems, the cogeneration facility can be operated and used in the same manner as before using the existing control device and remote control console when this energy optimization system is not used. This energy optimization system realizes energy saving and is designed to deactivate functions and promptly switch the cogeneration facility to operation by the operator in case of emergency.

4. Effect of Introduction

The scale and payback period of the energy optimization system can be estimated by making a trial calculation of the effect of introduction. A trial calculation of the effect before introduction is extremely important for an optimization system like this energy optimization system because it significantly affects the decision of whether or not to introduce the system. It is also necessary to verify the actual effect of the system after introduction.

4.1 Trail calculation of the effect of introduction

Fuji Electric has a standardized procedure for making a trial calculation of the effect when using FeTOP, and the same procedure was applied to this energy optimization system (see Fig. 3).

We made optimization calculations using an optimization model of the cogeneration facility and trial calculations of the effect of introduction under various conditions based on time-series data obtained from the customer, which indicated the operating state of the cogeneration facility. Time-series data was easily collected from this cogeneration facility with the aid of the data collection system "BEST" of Fuji Electric. Thus, we could make trial calculations effectively and efficiently in a relatively short period.

Based on the results of the trial calculations, we revealed problems in each of the three operation patterns shown below and solutions to them.

(1) During normal operation

A reverse power flow occurs when the gas turbine is operated with maximum load if the electric load of the factory is decreasing. The load of the gas turbine is required to reduce to prevent a reverse power flow, but it is difficult to set and operate the gas turbine in manual mode while monitoring received electric power at all times. For this reason, the gas turbine load was reduced, and as a result, the factory was operated in a state with excessive received electric power than required.

Received electric power can be reduced by predicting the electric load in real time and operating the gas

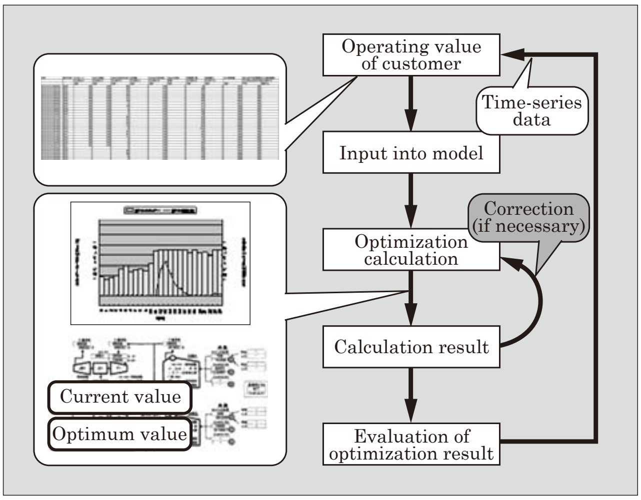

Fig.3 Procedure for trial calculation of introduction effect

turbine with limit load that does not cause a reverse power flow.

(2) When steam is excessive

It is desirable that the exhaust gas boiler be operated with minimum load to reduce the volume of steam released. This operation requires the output setting value of the steam turbine placed in output operation mode to be set while monitoring the pressure fluctuation of the exhaust gas boiler and other data.

However, the set output value tends to be slightly higher because it is difficult to operate the exhaust gas boiler in manual mode while constantly monitoring the pressure fluctuation of the boiler, etc., and the boiler has been operated in such a manner that the volume of steam released could not be reduced.

The fuel cost of the exhaust gas boiler can be cut down by safely operating it in automatic operation mode with load close to minimum load and reducing the volume of steam released.

(3) When steam is insufficient

The volume of steam from the auxiliary boiler is desired to minimize in view of energy saving. To achieve it, the load of the exhaust gas boiler should be maximized, but it is subjected to flow rate fluctuation at all times because the steam turbine is set in backpressure control mode. Maximizing the load of the exhaust gas boiler in this state involves a high risk and requires constant monitoring. However, constant monitoring operation is difficult to perform in manual mode, and the auxiliary boiler has been operated with a higher load.

The fuel cost of the auxiliary boiler can be reduced by safely operating the exhaust gas boiler in automatic operation mode with load close to the maximum.

Based on these operation modes and solutions, we converted loss in each operation mode into an amount of money and calculated how much could be saved annually.

When we added up the results of the trial calculations of the effect of introduction, it was estimated that the factory would be able to reduce its unit consumption rate in terms of LNG to approximately 1.5 Nm^3/t of paper. This indicates that the cost invested in the introduction of the energy optimization system could be recovered in only two years.

4.2 Actual effects of the introduction of the energy optimization system

We have confirmed that more than 3.0 Nm^3/t of paper in the unit consumption rate in terms of LNG can be reduced annually on average when the calculated results of all patterns are summed up. This value is about twice the effect estimated from the trial calculation before introduction, which is equal to recovering the cost incurred by the introduction of the system in one year. The following three probable reasons are considered:

(a) When steam is excessive, the amount of generated electric power is decreased because of the suppression of the production of steam, and demand over is consequently apt to occur. In the past, the facility was operated with a higher amount of electric power generated than the necessary level to avoid this state. This energy optimization system succeeded in cutting down fuel costs by expanding functions during normal operation and operating the gas turbine in automatic operation mode with limit load that does not cause demand over. This effect was identified in adjustment operation after the introduction of the system.

(b) When steam is insufficient, the amount of electric power generated is increased because the production of steam increases, and as a result, a reverse power flow tends to occur. In the past, the facility was operated with a lower amount of generated electric power than the necessary level to avoid this state. This energy optimization system successfully reduced received electric power by using functions during normal operation as they were and operating the gas turbine in automatic operation mode with limit load that does not cause a reverse power flow. This effect was also confirmed in adjustment operation after the introduction of the system.

(c) The energy data analysis function of the energy optimization system made it possible to perform parameter tuning in order to bring the cogeneration facility close to the optimum operating state promptly and safely, resulting in extended optimum operation time and an expanded effect.

5. Postscript

This paper described the energy optimization system introduced to cogeneration facility of a paper-making factory. This system was adjusted and delivered to the factory in November 2012 and has been operating in good condition since then.

With regard to production plants in other fields consuming much electric power and steam, their cogeneration facilities are similar in their configurations composed of turbine, generator and boiler as well as load patterns, although their quantities and capacities are different. Thus, the effects described herein can apply to the cogeneration facilities of production plants in various fields.

With the steady realization of the smart community concept, plants having a cogeneration facility will also be required to promote more advanced energy management, such as harmonization with nearby residents and peak saving of energy, as community members. We will further study energy-saving operation through the effective use of this energy optimization system, as well as new energy management systems.

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“Steel EMS Package” Optimizing Energy Management at Steelworks

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ABSTRACT

With the installation of an “energy center” and the central management of various types of large quantities of energy at a steelworks, a comprehensive approach to energy savings, increased operational efficiency of labor saving and motive power equipment, and environmental management is being promoted.

Focusing on supply-demand forecasting and optimization, which is a basic function of an energy center, Fuji Electric has developed a “Steel EMS Package” for improving energy management and operational efficiency, which are complexly intertwined within a steelworks. This package forecasts the energy fluctuation for several hours in advance or makes daily or monthly forecasts, and optimally operates the energy production equipment so as to contribute to energy saving throughout the steelworks.

1. Introduction

In the steel industry, which accounts for 10% or more of the aggregate energy amount consumed in Japan, “energy saving measures” is regarded as the most important issue for resolving energy and environmental problems.

In steelworks, it is essential “to operate in the most efficient way to reduce total cost of the utilizing energy in order to work stably 24 hours a day, 365 days a year,” and “to monitor and control energy appropriately.” An “energy center” was established for the purpose of performing integrated management of various types and large amounts of energy and comprehensively controlling energy saving, labor-saving, rationalization, environmental management, etc.

In this energy center, which Fuji Electric has been building ahead of the world together with customers, “Steel EMS Package” that optimizes energy management was developed.

2. Energy Center

2.1 Purpose of energy center

The energy center has the following four purposes.

(1) Stable supply of energy

The energy required for production fluctuates greatly depending on the production state. As a result, it is necessary to constantly monitor fluctuating energy demand and control it appropriately.

(2) Energy saving

The important role is to keep a balance between supply and demand in the purchased energy (gas, oxygen, electric power etc.) and by-product energy (by-product gas, steam, electric power etc.), which are intertwined in a complicated way, reducing unnecessary energy through the most effective operation.

(3) Labor saving and rationalization

Integrated management of monitoring and operating energy facility and automated operation of energy systems are required.

(4) Environmental management

Recently, environmental problems have been becoming more serious and it is necessary for steelworks, where a large amount of energy is consumed, to address CO_2 reduction positively in ways such as introducing environmentally friendly facilities.

2.2 Basic function of energy center

Rotating the PDCA cycle of five functions (production and operation plan, results and facility monitoring, analysis and diagnosis, supply and demand forecast, and optimization) greatly helps the Energy Center to achieve its purposes as shown in Fig. 1.

(1) Production and operation plan

Draw up an energy allocation scheme that brings the best energy saving plan based on the production plan and operation plan of the facilities, while supplying energy stably.

(2) Results and facility monitoring

Operators check the operational condition and review energy allocation based on the differences between the production plan and results, and operation plan of the facility and results.

(3) Analysis and diagnosis

Grasp energy usage and generation amount per factory and product and review energy-saving further.

(4) Supply and demand forecast

Automatically judge the differences from the production plan and operation plan of the facilities based

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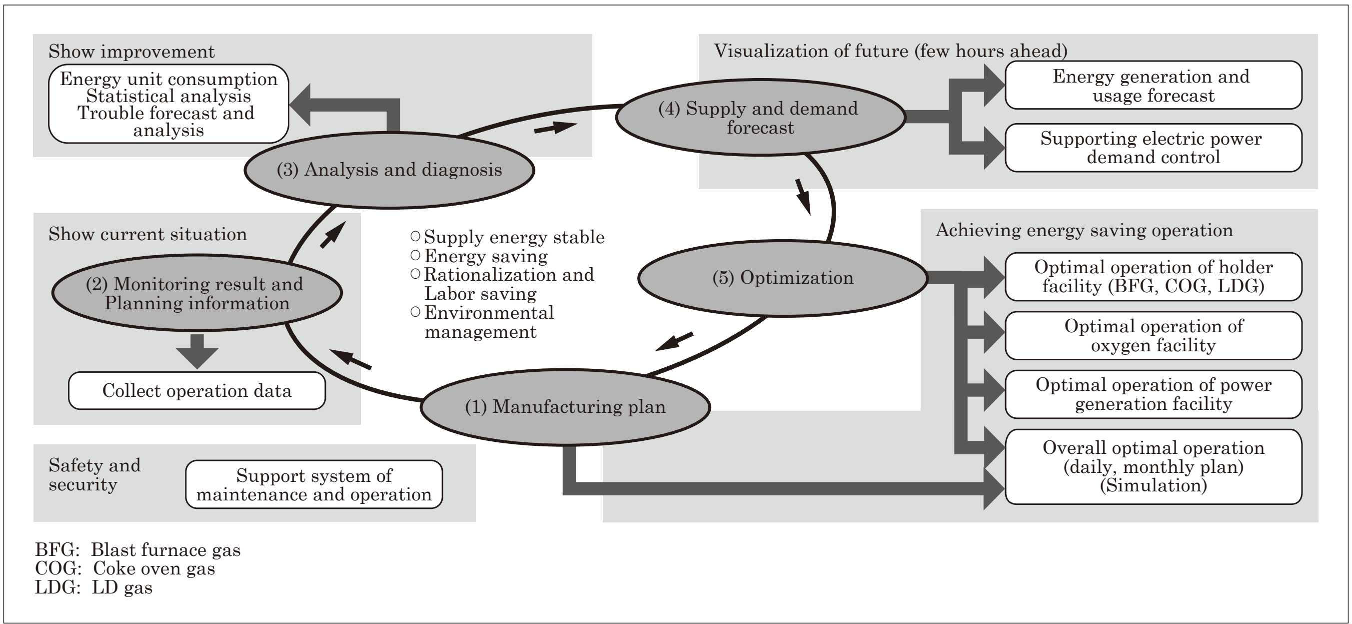

Fig.1 Basic function of Energy Center

on the results information, and forecast energy fluctuation daily, monthly, or several hours in advance by using the results of energy usage and generation amount per factory and product.

(5) Optimization

Draw up the optimal operation plan for energy production facilities based on forecast data of energy.

3. Steel EMS Package

The Energy Center has been built with a method that connects its basic functions one by one to meet customers' needs. However, the iron and Steel EMS Package strengthens further the function of "Supply and demand forecast" and "Optimization (Holder facility, oxygen facility, and power generation facility and whole plant)," which are the most important functions, and operates each function on the integrated EMS platform[1]. It is possible to build a system according to the customers' needs by installing only the required packages. It allows installing each function in an easier way than before and providing a more flexible and appropriate system (see Fig. 2).

The Steel EMS Package can further improve operational efficiency of the energy that is used in the intricately intertwined steelworks and reduce total energy cost to the utmost extent.

The integrated EMS platform was developed to focus on the energy supply chain of each field such as electric power, industry and retail distribution, not only iron and steel, to provide EMS functions that meet various needs on site promptly and at low price.

4. Visualization of Future via Supply and Demand Forecast

A supply and demand forecast is one of the important basic functions in the steel EMS. Energy fluctuation (by-product gas generation rate, load amount, electric power load, steam load etc.) is estimated based on the results data from the distributed control system (DCS) and production and operation plan data from the manufacturing execution system (MES).

Visualization of energy fluctuation enables operators to operate a system with appropriately anticipated behavior and in energy-saving manner.

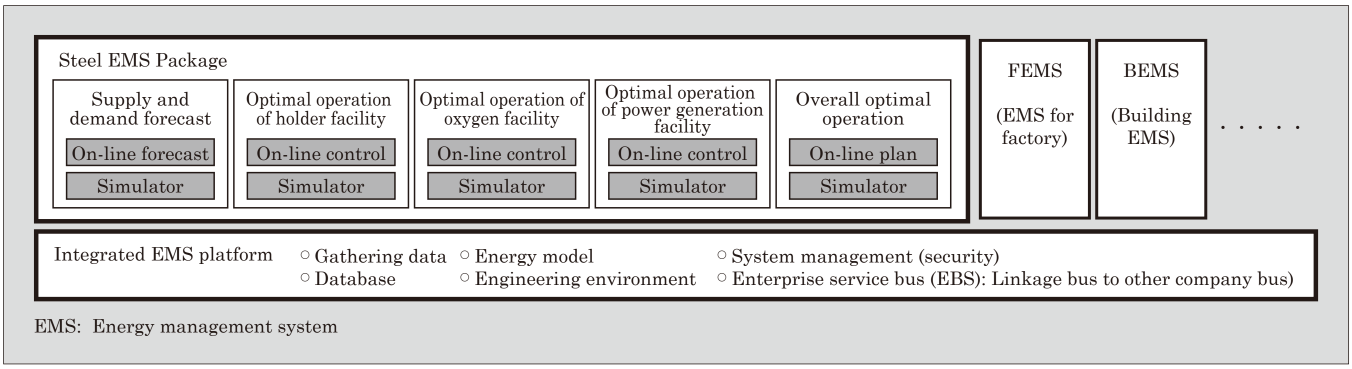

Fig.2 "Steel EMS package"

4.1 Forecast function

(1) Energy generation and usage forecast function

(a) Energy forecast from production and operation plan

When there is a difference between the operation state on site and production and operation plan, it is possible to obtain a highly accurate energy forecast value by correcting the plan automatically.

(b) Creation of energy consumption rate*1

Automatically create an energy consumption rate required for the forecast from results data.

(2) Electric power demand management support function

Operators monitor electrical power consumption of each factory within the steelworks, output an alarm if the value is about to exceed the contract value, and request each factory for production adjustment.

In addition, operators monitor the amount of received electricity from a power company and provide guidance for production adjustment of the factory according to the output adjustment and priority of the power generation facility. Operators make a request for production adjustment to the relevant factory according to the guidance.

4.2 Forecast method

(1) Forecast method based on operation plan

An energy supply and demand forecast per factory and type of energy is performed based on the operation plan of MES and energy consumption rate. In addition, the operation state of the site is compared with operation plan of MES, and a correction to the operation plan is made according to the difference.

(2) Forecast method based on production plan

Energy supply and demand forecast per product is performed based on the production plan of MES and energy consumption rate. In addition, the operation state of the site is compared with operation plan of MES, and a correction to the production plan is made according to the difference.

5. Achieving Energy Saving Operation via Optimization

Optimization is the most important basic function in the iron and Steel EMS Package. By applying optimization to steelworks, energy saving operation is realized. Energy cost of steelworks is minimized by using the particle swarm optimization (PSO) method[(2)], which is the latest metaheuristic optimization technology, based on the forecast data (data per factory and energy) obtained from supply and demand forecast.

The targets of optimal operation are holder facility, oxygen facility and power generation facility, which have particularly large energy saving effect in the steelworks, and in addition to these, optimal operation of the entire steelworks (daily, monthly plan) (see Fig. 3).

It is possible to automatically extract optimum operation patterns in operation facility using the PSO method and obtain the optimum solution when there is change in the operation method or when operation outside the scope of design, which is not feasible if created with logic, is conducted. The operation outside the scope of design is adopted when mathematical expressions are not available, when the formula becomes complicated, when the numerical formula changes depending on the conditions, and when verification is not yet performed.

5.1 Optimal operation of holder facility

In steelworks, by-product gas, which is generated in large quantities, is stored and used as energy source. Among by-product gas, blast furnace gas (BFG) that is generated from a blast furnace and coke over gas (COG) that is generated from a coke oven is used as fuel for power generation; and LD gas (LDG), which is generated from a LD is used as fuel for hot-blast stove and sintering furnace. Optimal operation improves gas recovery efficiency by specifying usage destination of each by-product gas and minimizing gas dissipation rate.

It is possible to achieve further energy saving because purchase fuel of a power plant can be reduced depending on the portion of increased gas recovery. From the effect trial calculation, a 90% reduction of the dissipation amount is expected.

(1) Optimal operation of COG, BFG holder

Making the optimal operation plan based on the occurrence forecast and usage forecast of COG or BFG, which is obtained from the forecast method based on the operation plan as described in Section 4.2 (1), the delivery amount is determined so that the dissipation amount is minimized.

It is possible to predict up to three hours ahead of the time at intervals of five minutes.

(2) Optimal operation of LDG holder

Making the optimal operation plan based on the LDG generation forecast and usage forecast, which is obtained from the forecast method based on the production plan as described in Section 4.2 (2), the delivery amount is determined so that fluctuation in dissipation amount and delivery amount is minimized. It is possible to predict up to three hours ahead of the time at intervals of one minute. Figure 4 shows a screen example of optimal operation for holder facilities.

5.2 Optimal operation of oxygen facility

In the oxygen facility, oxygen is taken out from

*1: Energy consumption rate: This value indicates energy efficiency. This represents the amount of energy, such as electricity and heat (fuel), required for unit production of the product (steel). It is generally used as an index to show the energy-saving state.

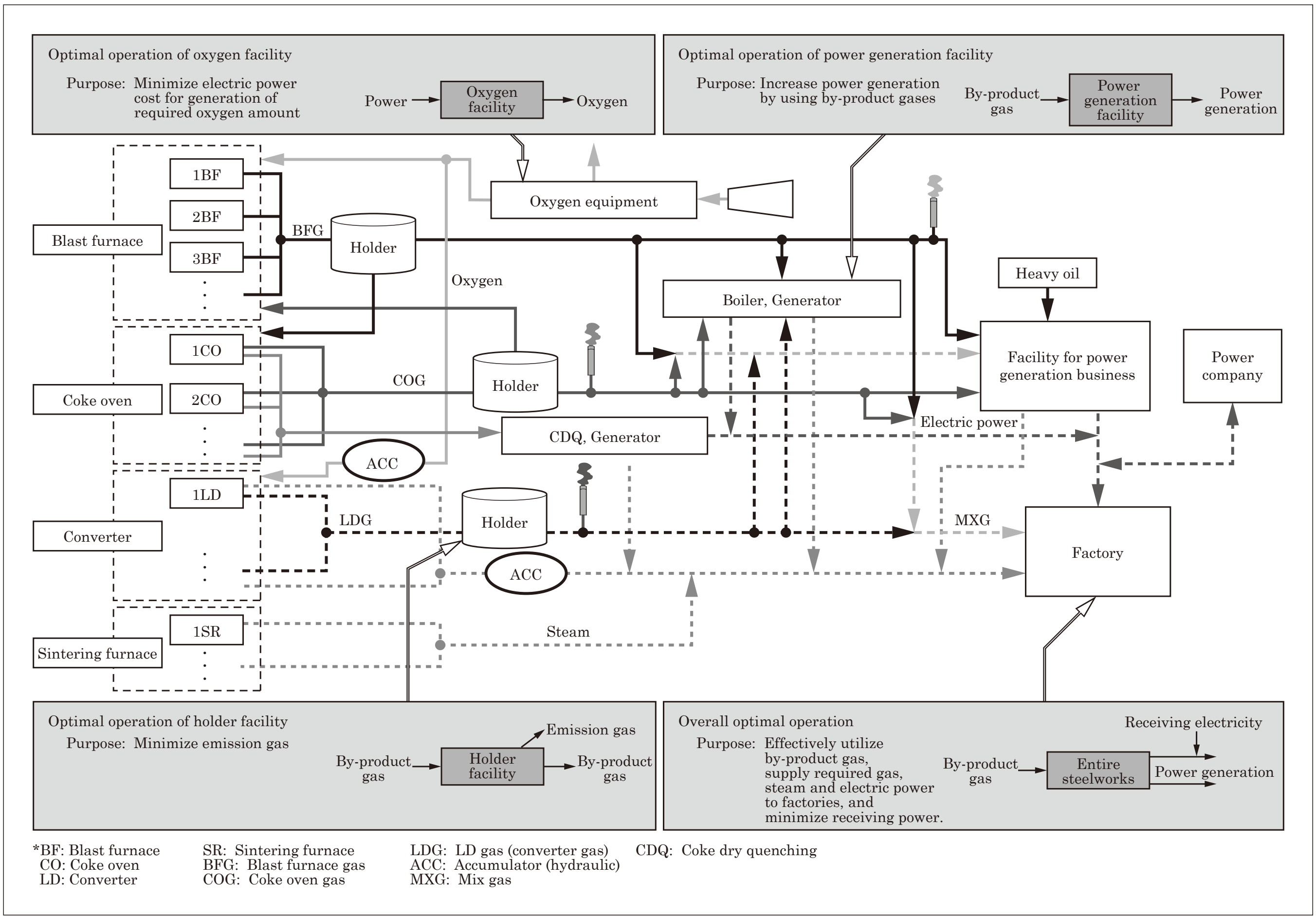

Fig.3 Energy saving optimal operation of steelworks

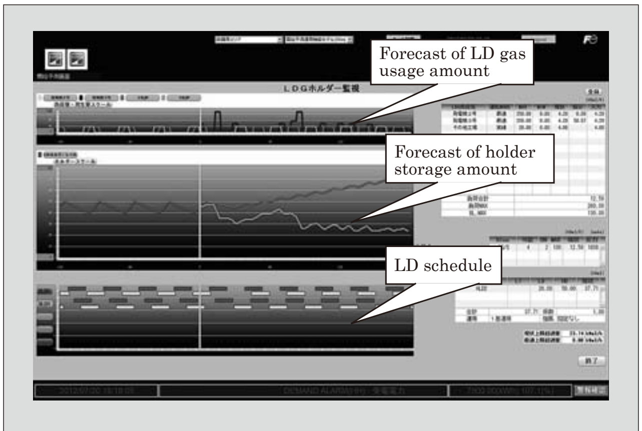

Fig.4 Screen example of optimal operation for holder facility

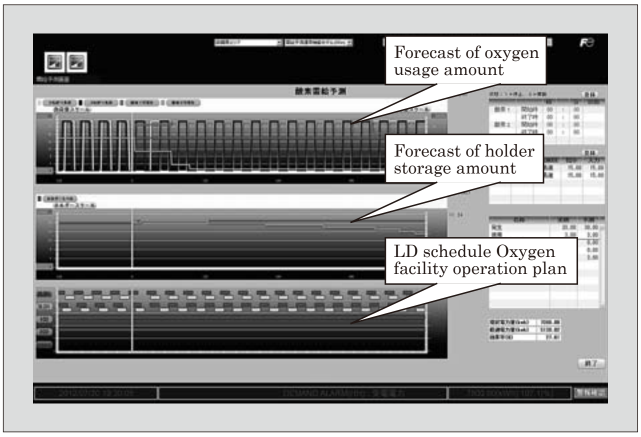

Fig.5 Screen example of optimal operation for oxygen facility

air, stored in the oxygen holder and then is sent to inside the steelworks as necessary. Optimal operation achieves energy saving by minimizing consumption power from the forecasted necessary oxygen amount. It is possible to predict up to eight hours ahead of the time at intervals of five minutes. Figure 5 shows screen example of optimal operation for oxygen facility

From a trial calculation of effect, 2.8% reduction (year) in energy consumption of oxygen facility is expected.

5.3 Optimal operation of power generation facility

In order to operate each unit of facility in steelworks, electric power is indispensable. Electric power is purchased from a power company; however, there are steelworks, where electric power is supplied from power generation facility using by-product gas in steelworks. With optimal operation, difference in efficiency of multiple units of power facilities is perceived, fuel for boiler and steam for turbine are distributed to ob-

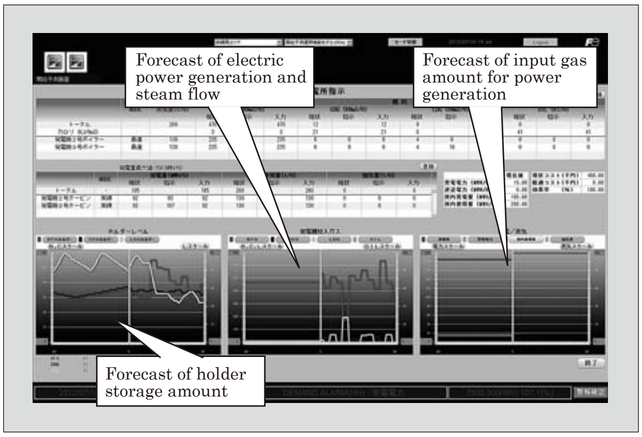

Fig.6 Screen example of optimal operation for power generation facility

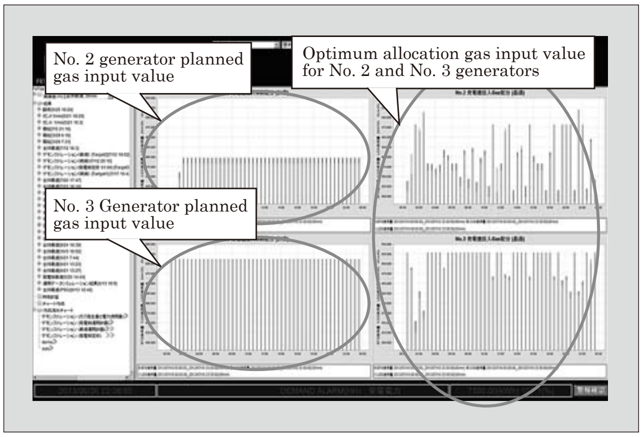

Fig.7 Example of simulation screen

tain the maximum electric power generation from by-product gas, achieving energy saving by minimizing the purchase of electric power. It is possible to predict up to three hours ahead of the time at intervals of five minutes. Figure 6 shows a screen example of optimal operation for power generation facility.

From a trial calculation of effect, a 2.0% (year) increase in electric power generation is expected, which leads to a reduction in the purchase of electric power generation.

5.4 Overall optimal operation (daily, monthly plan)

With optimal operation, energy saving is realized by minimizing daily running cost. Based on a generation and usage forecast of each type of energy, while meeting the energy demand required in the steelworks, the optimum allocation for three types of by-product gas, electricity, and steam for one day is drawn up in 30-minute intervals. In the same manner, by drawing up optimum allocation plan for one month, minimization of the monthly running cost is achieved. Optimization of operational balance of each unit of energy facility is also performed in order to minimize the emission amount of greenhouse gases.

In addition, a simulation environment for a case study of energy facility operation is implemented and it is possible to compare operation results when the current operation is continued with operation results based on forecast after optimization. The screen example in Fig. 7 shows the simulation result of optimum allocation from forecast of generation and usage of each type of energy in steelworks and gas input plan for power generation. From a trial calculation of effect, a 3.5% reduction (year) in electric power purchase cost is expected.

6. Postscript

This paper described the "Steel EMS Package" to optimize energy management in steelworks. EMS makes it possible to achieve energy saving through optimization utilizing the long experience in operation of the Energy Center, state-of-the-art control technology and software technology. Fuji Electric will meet customers' expectation by forecasting the energy consumption amount, performing efficient energy operation without waste, and reducing energy cost and ultimately production cost.

Reference

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(2) Kennedy, J. and Eberhart, R. Particle Swarm Optimization, Proceedings of IEEE International Conference on Neural Networks, 1995, vol. IV, p.1942-1948.

EMS for Large-Scale Commercial Facility

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ABSTRACT

In large-scale commercial facilities that consume vast amounts of energy, power conservation, energy savings, and the efficient utilization of energy are challenges requiring urgent attention, and the introduction of an EMS is being promoted as a solution.

Fuji Electric has developed a large-scale commercial facility EMS to generate optimal supply and demand management plans based upon demand forecasts and power generation forecasts, and to realize the optimal application of energy. With the introduction of this system, operation can be guided precisely toward power conserving and energy saving behaviors, energy management can be implemented by area, by application, and by basic unit or the like, and a reduction in energy consumption and CO_2 emissions can be expected.

1. Introduction

Due to the electricity shortage after the Great East Japan Earthquake, social needs for power saving and energy saving are increasing. For large-scale commercial facilities such as department stores, shopping centers, hypermarkets and complex facilities, thorough implementation of energy saving and efficient use of energy are urgent tasks and introduction of energy management system (EMS) is promoted.

Fuji Electric improved the existing EMS further and developed an EMS that is specialized for use in large-scale commercial facilities. Optimal use of energy is achieved by drawing up optimal supply and demand plans from supply and demand forecasts and electric power generation forecasts.

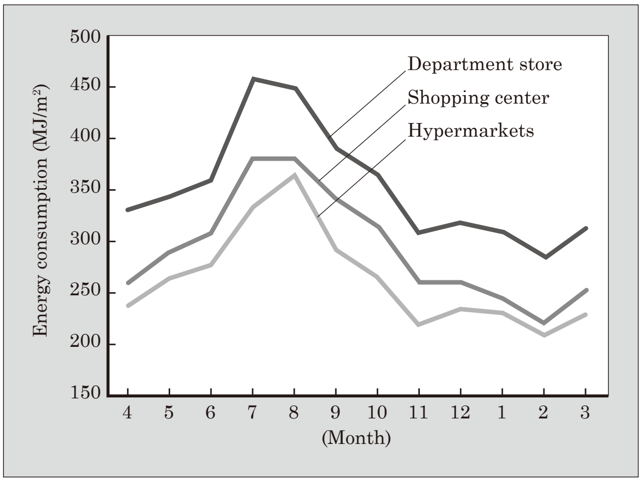

Fig.1 Energy consumption in large-scale commercial facilities by month

2. Environment Surrounding Large-Scale Commercial Facilities and Energy Management

2.1 Energy consumption trend

A large-scale commercial facility is comprised of multiple tenants in different type of industries in general, that is, large-scale store (core of the facility), specialty stores, restaurants and common-use space. Figure 1 shows energy consumption per month of the entire facility[(1)] and Fig. 2 shows a breakdown of energy consumption per business category.

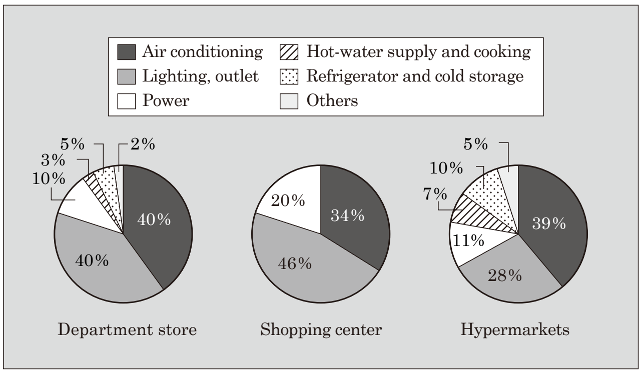

Fig.2 Breakdown of energy consumption

Although the energy consumption trend by month is similar among business categories, the breakdown differs. However, air conditioning, lighting, and, power energy consumption account for a high ratio in a facility of any business category; therefore, reduction of energy consumption is a promising solution that can be encouraged by deliberate energy management and

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energy saving actions.

2.2 Energy management situation

Energy management in large-scale commercial facilities is performed by monitoring and controlling individual equipment such as power source, heat source, air conditioning, lighting and elevator, by using building automation system (BAS). However, the existing central monitoring system lacks functions to perform energy management efficiently, and there were many cases where an operation manager carried out the following measures manually.

(a) Curtailing some lighting appliances in the building
(b) Controlling air conditioning in the building
(c) Stopping elevators etc.
(d) Controlling heat sources

By introducing an EMS for large-scale commercial facilities, it is possible to automate these operations, gather and analyze operational information of the equipment, and achieve optimal operation with consideration to energy efficiency.

2.3 Challenges in energy management

(1) Subdivision of energy management and full participation in energy saving actions

Since in most cases, facility management division performs energy management tasks along with their ordinary jobs, energy management is not united with the energy demand side. Energy management and energy saving actions where the supply and demand sides are unified is required. For example, the demand side operates energy while being aware of the supply side, and the supply side provides an optimal supply while being aware of load fluctuations[(2)].

In shopping center, there are many tenants, who are the demand side, and these tenants account for a large proportion of the total energy consumption. It is necessary to perform detailed management that links to feasible measures by analyzing the energy using situation by energy category and type of business, and clarifying the challenge for improving efficiency of energy use. In order to do this, it is required to have a mechanism to share energy information between tenants, who are on the demand side, and the facility division, which is on the supply side, and to allow everyone to participate in energy saving activities.

(2) Optimal operation of electricity, heat (fuel) and new energy

Due to the energy situation, power rates and fuel rates tend to show a medium-to long-term increase. Therefore, it is required to positively operate electricity and heat (fuel) in the facility through the best mix. Optimal operation of equipment is becoming more and more important in order to minimize CO_2 emissions and running costs, by considering the unit price of electricity and heat (fuel) rate.

(3) Achieving peak cut and peak shift of electric power load

Since the Great East Japan Earthquake, the maximum supply capacity of power companies has decreased due to the suspension of nuclear power plants, and as a result, a situation occurred in which the power supply becomes tight. In order to suppress power demand peaks in addition to the amount of power demand, restriction on use of electricity was enforced by the "Electricity Business Act" and large-volume utility customers are required to correspond to peak cuts and peak shifts of electricity demand.

Using renewable energy (solar power generation, wind generation etc.) and introducing electricity storage system and/or thermal storage system are effective ways to respond to such situation. However, energy managers are required to judge which equipment needs to be operated in which time period, and the operation of these equipment becomes very complicated.

It is necessary to forecast the energy load of the facility considering temperature, humidity, day of the week, and the number of visitors in advance; and at the same time, to predict the amount of electric power generated by solar and wind power, which are influenced by the weather. After that, it is required to schedule electricity storage and discharge, and heat storage and discharge, as well as operation of load facilities.

(4) Supporting energy saving actions

It is necessary to enable energy management and energy saving actions to be implemented without burdening the person in charge.

It is ideal to provide support functions in terms of software for the energy manager and person in charge of tenants such as sending demand adjustment guidance and energy saving action messages accurately, by utilizing past results and operation know-how.

(5) Visualization of energy

In general, since the equipment management division performs energy analysis and management tasks while carrying out operation and management tasks of equipment, it is required to perform the task efficiently. In particular, environmental enhancement for visualization of energy, which enables analysis and management of the energy usage situation from various angles, is important.

3. Fuji Electric EMS for Large-Scale Commercial Facilities

In order to resolve such issues on energy management as mentioned in Section 2.3, Fuji Electric applied the "Integrated EMS platform" technology and developed EMS for large-scale commercial facilities[(3)].

There are the following four main functions in the integrated EMS platform.

(a) Data access function of devices, which gathers measurement information of various types such as electric power, gas, water and heat.

(b) Function to comprehensively manage time-series forecasts and result information related to energy.
(c) Modeling function of an energy system that is customizable according to the scale of the target facility.
(d) Operation management function of the EMS business application that achieves energy saving optimal control

By having an integrated EMS platform with excellent flexibility and extensibility, application to a wide range of business areas from implementing to a single large-scale commercial facility to linkage with other systems in Smart Community is achieved.

3.1 Function of EMS for large-scale commercial facilities

Energy management tasks are carried out primarily with the EMS implemented in large-scale commercial facilities. Figure 3 shows the overall structure of EMS for large-scale commercial facilities and Fig. 4 shows its functional configuration.

EMS for a large-scale commercial facility judges each type of condition that occurs inside and outside of the facility, controls devices at the optimal timing, and gives instructions to managers and employees of the tenants. EMS for large-scale commercial facilities provides the following characteristic functions.

(1) Demand forecast

Demand forecast (see Fig. 4-A) makes it possible to calculate micro forecast values per area by using load results accumulated from each area having different consumption properties. By summing up the forecast values of each area, macro demand forecasts of an entire facility are calculated with high accuracy. In addition, in order to improve the forecast accuracy further, a correction function specialized in large-scale commercial facilities is available.

Figure 5 shows a screen of the entire facility. A facility is divided into several areas and forecast demand of the target area is shown. In this screen, it is possible to grasp energy demand and supply plan, the results, and the electric power usage situation of the tenants with a bird's-eye view and easily display detailed information of the area and tenants with a drill-down operation.

(2) Optimal operation plan

An optimal operation plan (see Fig. 4-B) makes it possible to draw up a supply and demand plan and control schedule to carry out highly efficient operations (to reduce cost and CO_2). This is achieved by conducting a simulation of energy supply and demand based on the modeling information and forecast information of the energy system that is composed of various unit of equipment such as power generation, electricity storage, power transmission, load and heat source. Figure 6 shows input and output information of the optimal operation plan (see Fig. 4-B). According to the drawn up supply and demand plan and control schedule, and by implementing control and setting of each device at the optimal timing, highly efficient operation of energy is enabled, and optimal operation of electricity, heat (fuel), and new energy is achieved.

In addition, an engineering tool for modeling of energy system that depicts types of equipment and re-

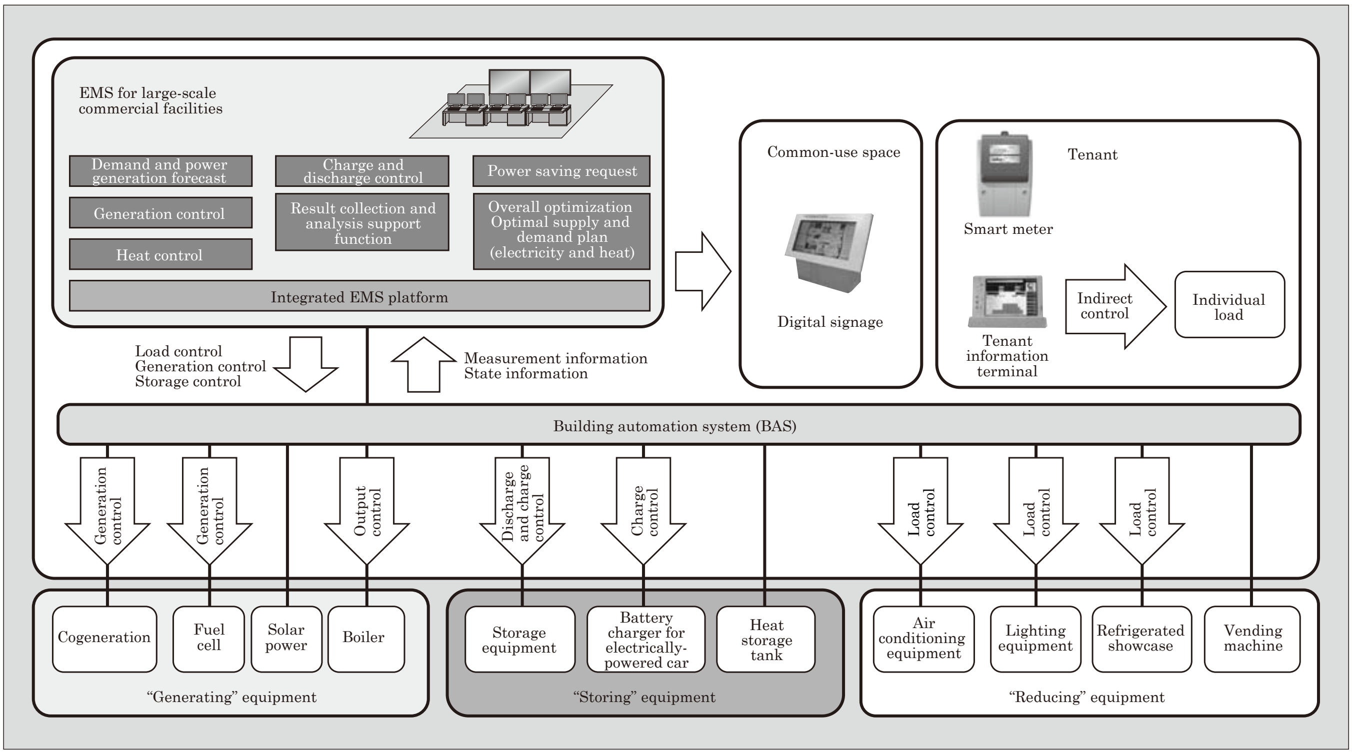

Fig.3 Overall structure of EMS for large-scale commercial facilities

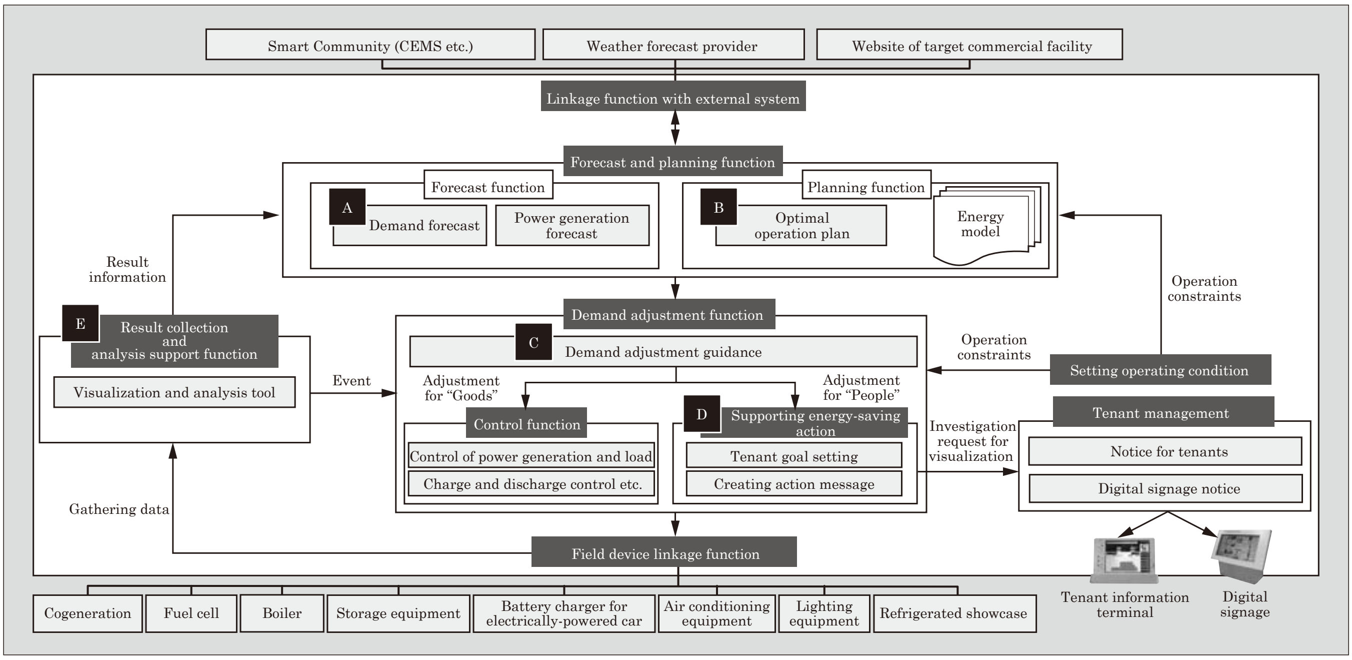

Fig.4 Overall functional structure of EMS for large-scale commercial facilities

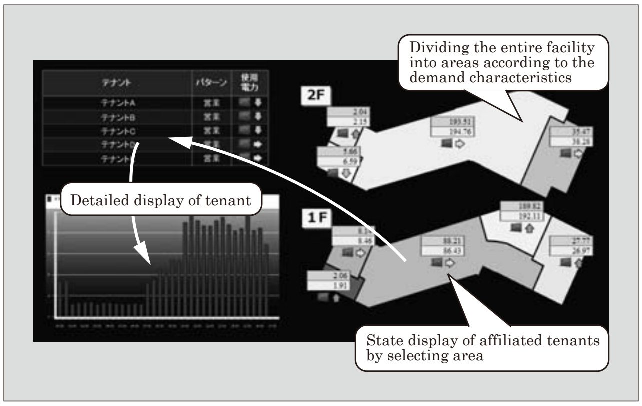

Fig.5 Screen for entire facility

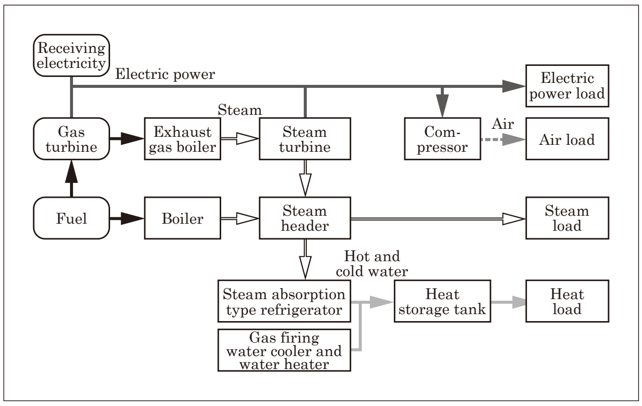

Fig.7 Model of energy system

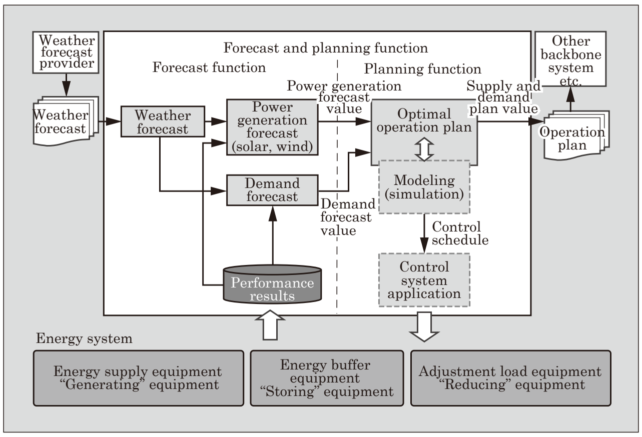

Fig.6 Input and output information for optimal operation plan

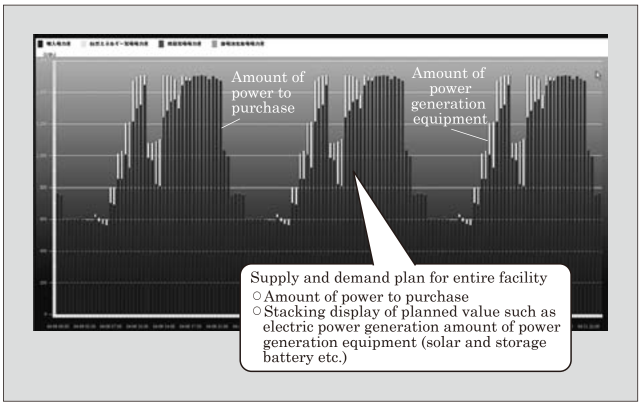

Fig.8 Supply plan for three days based on optimal operation plan

lationships (input and output of energy), which become basic data of optimal operation plan, is implemented. From this, it is possible to use the system to draw up capital investment plan by creating a model for equipment replacement off-line and by simulating the effect.

Figure 7 shows a model of an energy system and Fig. 8 shows a supply plan for three days using optimal operation planning.

(3) Demand adjustment guidance

Demand adjustment guidance (see Fig. 4-C) makes it possible to create recommended operation guidance for the operation manager by detecting changes in the operation state of devices and supply and demand state of energy.

It notifies the operation manager of "When," "What has occurred," "Information that needs to be grasped" and "Recommendable action and effect," and provides "awareness" immediately.

Shown below is an example of demand adjustment guidance that is notified before the time period when the power rate unit price goes up.

- ○ When: 30 minutes later
- ○ What has occurred: Reached time period of power rate unit price increasing
- ○ Information that needs to be grasped: Supply and demand plan, results, and rate information
- ○ Recommendable action and effect: Change lighting setting of common-use area from 100% to 75% (reduction effect: 200 kW)

By selecting "Information that needs to be grasped," the screen is switched to a screen displaying related functions. This is a means to improve operability.

(4) Supporting energy saving actions

Supporting energy saving action (see Fig. 4-D) is aimed at promoting energy saving actions by displaying energy consumption trends and the supply and demand state. In large-scale commercial facilities, tenants account for a large proportion of the total energy consumption. Therefore, in order to realize optimal energy control (energy saving, peak cut, peak shift etc.), it is important to "change the way of thinking" of employees (people) of the tenant and enables them to carry out concrete energy-saving actions at times such as when supply and demand becomes tight. Details of how to support energy saving actions are described below.

(a) Installation of tenant information terminal

A tablet-type information terminal is installed at each tenant and a function to enable tenant employees to grasp energy consumption trends anytime. Figure 9 shows a screen example of the tenant information terminal. By linking with Smart Meter, results of each use (lighting, air conditioning, power) is gathered per tenant and visualized with display items and display scale according to the scale and characteristic of the tenant, to improve visibility of the tenant information terminal.

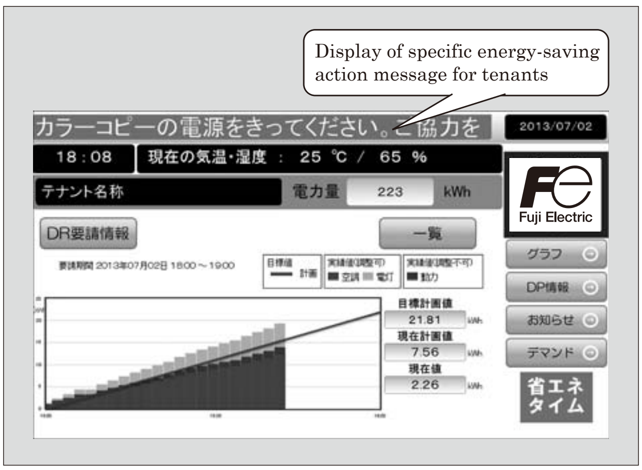

Fig.9 Screen example of tenant information terminal

(b) Display of energy saving action request message

There are various types of energy saving actions that each tenant can implement depending on the characteristics of business type, scale and operation time-zone of each tenant. EMS for large-scale commercial facilities manages and calculates specific request messages with which tenant employees can actually take action, and energy saving target values on a tenant basis, and then notifies those on tenant information terminals together with an alarm when supply and demand balance becomes tight.

The screen configuration makes it possible to confirm and actually experience the effect of the action on the spot by updating the display of results in intervals of one minute at times such as during demand and supply tight time periods. The idea is to let tenant employees feel a "sense of satisfaction" and "sense of achievement" in the facility-wide energy saving action, instead of a "sense of being forced to do something."

(c) Quantitative evaluation on the degree of cooperation by tenants

EMS for large-scale commercial facilities makes it possible to manage the effect of energy saving actions quantitatively, and analyze the degree of cooperation of each tenant. In addition, it is possible to develop incentive systems according to the degree of cooperation to energy saving in the future.

(d) Linkage with digital signage

Linkage with digital signage contributes to improve "corporate brand value" by presenting the energy saving state of the entire facility and efforts to visitors (customers).

In addition, facilities participating in Smart Community aims at improving energy efficiency in entire region by notifying the users of special sales information in the time period when power rate within the region becomes higher due to a tight supply and demand, and attracting a large number of people from entire region.

(5) Visualization of energy

Visualization of energy (see Fig. 4-E) means the effort to make referencing and compiling energy information easier, enabling to achieve efficient and effective analysis of evaluation by the energy manager. The following two ideas were implemented.

(a) Speed-up of the time to reach information desirous to know

Figure 10 shows a hierarchical collection screen

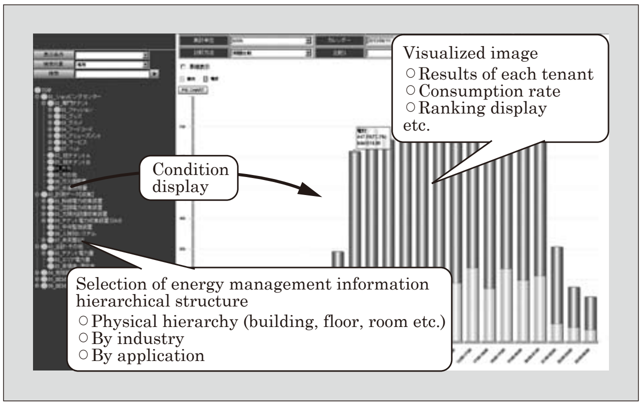

Fig.10 Hierarchical collection screen for visualization

for visualization. Information structure to search energy information was set as an interface which allows the user to search from a hierarchical tree with business type of the tenant (sale of goods, food and beverage, services, etc.) as an axis.

Managers can reference and sum up energy information (per industry, usage amount per application, consumption rate, ranking etc.), which was subdivided under a hierarchical tree, with an easy operation from various angles.

(b) Shorter time to process information desirous to know

With referenced and summed up energy information, it is possible to create an arbitrary report form by downloading the information to the personal computer of the manager, in the file format that can be used in spreadsheet software.

3.2 Future technological deployment

To optimize energy effect and investment cost for entire facility, it is necessary to introduce a mechanism that allows evaluation in a cross-sectional way including maintenance cost. For example, when a piping abnormality was detected, the optimal timing to repair is determined while considering energy loss cost, which has a trade-off relationship with maintenance management cost, and risk.

In the future, Fuji Electric will aim to build an EMS that enables further optimization of energy use in the building of a large-scale commercial facility by blending sensor technology, equipment maintenance management solution and the EMS solution that we have, and by adding an analysis environment in which task information can be evaluated in a cross-sectional way.

4 Postscript

In this paper, visualization of energy at large-scale commercial facilities and the function and features of EMS that perform optimal operation have been described.

By utilizing the results achieved up to now and by implementing further functional enhancement, Fuji Electric will realize optimal energy operation, contribute to electric power supply and demand adjustment and realize Smart Society in which efficient and rational energy usage is promoted.

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Energy Management Support Service with Cloud-Based EMS

AZUMAYA Naoki *

ABSTRACT

In the energy environment surrounding customers of electrical power in Japan, major changes are underway in regards to the supply-demand balance and the cost of energy usage, and energy cost-reducing measures such as strengthening energy management and introducing energy-saving equipment are urgently needed.

With a proven track record for successfully installing EMSs at major customers of electrical power, Fuji Electric has aggregated energy-saving analysis know-how accumulated in energy management operational support, and has begun supplying an energy management support service based on a shared-use EMS that utilizes cloud technology. Because a company will not have to install, maintain or manage the system, the introduction of EMSs to small and medium sized power customers is expected to accelerate.

1. Introduction

Recently, in the energy environment surrounding domestic utility customers, power companies are raising electricity prices one after another against the background of rapidly increasing fuel costs because resuming nuclear power plant operations is uncertain. In addition, while the recovery of supply systems up to the previous level cannot be expected for the time being, thorough energy saving is required in order to keep a balance between supply and demand.

However, when looking at large-volume utility customers from the point of view of the power demand side, successive efforts for energy saving actions have been continued but the situation is that the increase in electricity rate offsets such improvement efforts.

On the other hand, as for small and medium-size utility customers, although requests for comprehensive energy saving are stronger, due to small-scale electric power consumption, return on investment becomes an obstacle and capital investment for strengthening energy management and energy cost reduction in ways such as introducing energy saving equipment has not progressed.

In order to correspond to these challenges and needs, Fuji Electric put together various implementation results of an energy management system (EMS) for large-volume utility customers and know-how in energy saving analysis, which have been accumulated by energy management operation support, promoted development of basic technology of an EMS utilizing cloud technology, and started to provide the technology as energy management support service since 2012.

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2. Ideal State of Energy Management and Utilization of EMS

2.1 Ideal state of energy management

The first step in energy management is to "visualize how much energy is consumed." However, except for some large-scale power electric utility customers, the situation is that only the "current" usage situation is grasped for the purpose of implementing electricity saving measures at the consumption peak in summer and winter.

In order to flexibly respond to the energy use environment, which will become more serious in the future, more proactive energy management is required. Therefore, the following points were focused.

(a) Promote continuous cost saving measures against energy cost that shows a rising trend
(b) Identify risk of unstable energy supply and prepare for the measures in advance

In addition, in order to perform such energy management, it is necessary to improve the operation basis that enables the following analysis.

(1) Analysis from the viewpoint of cost reduction measures and energy saving
(a) Specifying peak electric power time period by understanding application and consumption trend per area and extracting wasteful consumption and loss
(b) Monitoring the slack in energy saving activities compared to the same period (previous day, previous week, previous season, previous year)
(c) Review of implementation order of the work by cause and effect analysis of energy consumption and production activity
(d) Analysis of operation efficiency of operation pattern by monitoring efficiency of important equipment

(e) Prevention of loss due to deterioration and incomplete inspection and cleaning

(2) Analysis from the viewpoint of risk at power failure and power saving

(a) Classification by importance of facility, area and equipment

(b) Risk analysis of human and economic damage caused by a power outage in areas and equipment with high importance

(c) Review and monitor of measures based on risk analysis of damage

2.2 Utilization of EMS

As one of the methods to achieve an ideal energy management state, utilization of an EMS is effectual. EMS grasps and manages information related to energy by grasping the daily energy use situation (supply and consumption), identifying challenges and supporting the calculation of assumed effect when the measure is implemented.

EMS is composed of the following equipment (see Fig. 1).

(1) Measurement equipment

It measures energy data in real time.

(2) Data gathering and control device

It gathers measured data, and then performs demand monitoring and control while transferring data to upper-level systems.

(3) Database server

It accumulates measured data.

(4) Analysis support server

It figures out the trend of use situation and detects abnormality.

By incorporating an EMS into daily energy management tasks and operation, it becomes possible to grasp items that have not been visualized, including consumption loss and conveyance loss of energy, deterioration of energy efficiency of equipment, excessive supply of energy supply equipment, and oversight and slack in energy saving activities quantitatively and in real time. This enables to act more promptly with certainty.

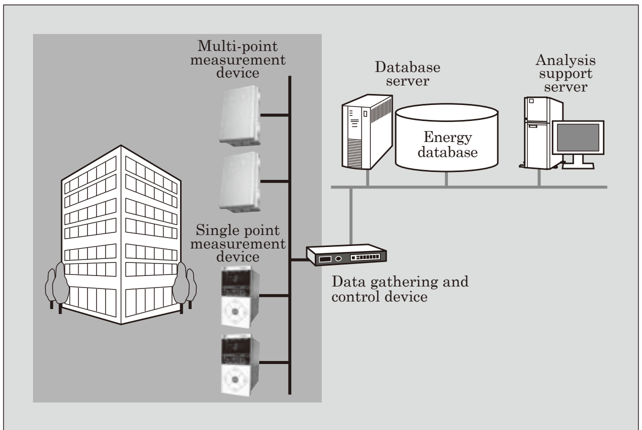


Fig.1 Structure of EMS

In addition, it becomes possible to measure the effect after the measure is implemented; and by providing feedback to review the subsequent measures, it is possible to create more accurate action plans and set a quantitative energy saving target at equipment replacement.

2.3 Needs and challenges for implementing EMS

As mentioned in Section 2.2, although implementing an EMS enables energy saving, there are requests from customers in actual implementation, operation and maintenance as described below.

(a) To perform comprehensive energy operation involving multiple locations such as production bases and sales bases.

(b) To share know-how in energy saving and deploy it to each base horizontally.

(c) To respond to power failures and power saving risks promptly, grasp the situation and evaluate the results.

(d) To minimize investment on system implementation because a recovery plan becomes an issue in investment to bases with low energy demand.

(e) To reduce systems subject to in-house operation management as much as possible.

(f) To enable system maintenance and management without a dedicated system manager.

3. Utilization of Cloud Technology in EMS

3.1 Cloud-based EMS

Figure 2 shows an overall picture of the energy management support service achieved with EMS utilizing cloud technology. The characteristics of this service are as follows.

(a) Since this is a share-use type of EMS service at the nationwide level, it is possible to reduce the

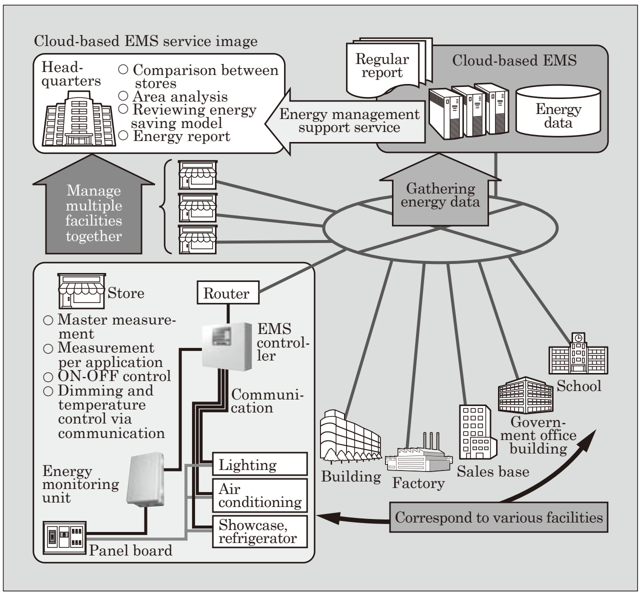


Fig.2 Overall picture of cloud-based EMS service

initial cost of implementation and running cost of an energy management system.
(b) Securing human resources related to system operation management becomes unnecessary.
(c) Providers who own multiple facilities can manage them all together or hierarchically per region or per management section, in addition to grasping the energy use situation of each facility.
(d) It is possible to send power saving information all at once when a risk occurs such as tight power supply and demand.
(e) Points to be improved can be easily identified by acquiring the situation in real time and conducting comparison and difference analysis with the normal state.

3.2 Service and functions provided by cloud-based EMS

An overview of the service and functions of Fuji Electric's cloud-based EMS are given below.

(1) Data analysis support function

It utilizes gathered and accumulated information on energy use results and support diversified analysis such as trend per time period and application, comparison between facilities, comparison of consumption rate based on floor space and actual production. Figure 3 shows a screen example of the function.

(2) Report issuing function

It provides daily, weekly and monthly reports on energy consumption situation in Excel*1 format.

(3) Energy saving analysis service

It implements simple diagnosis of energy use results and provides advice for energy saving.

(4) Demand monitoring function

According to the specified threshold, it provides demand alarm notification and abnormality alarm notification. Figure 4 shows a screen example of the function.

(5) Demand control function

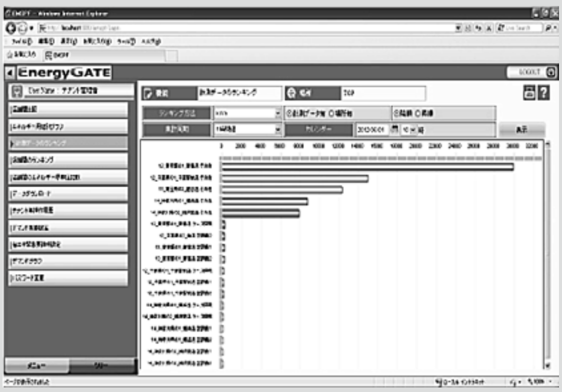
According to the specified threshold and control rules, it automatically controls equipment such as air conditioning and lighting.

(6) Zone demand monitoring function

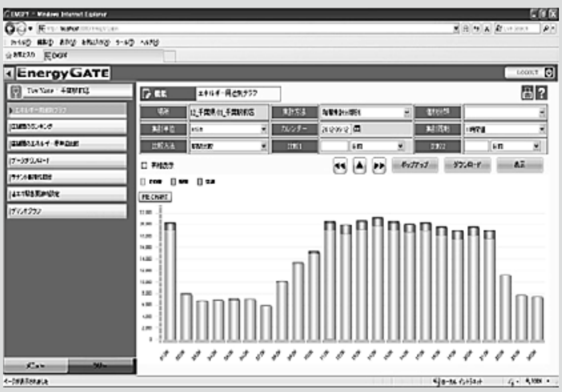
Based on the demand forecast per time period zone, which was calculated from past energy consumption trends, it monitors the energy consumption situation of the relevant time period and prompts power saving activity by issuing an alarm according to the threshold. Figure 5 shows a screen example of the function.

(7) Digital signage function

In order to support a participatory EMS, it delivers information using a large monitor. Figure 6 shows a screen example of the function.



(a) Ranking graph between bases



(b) Graph by energy application

Fig.3 Screen example of data analysis support function

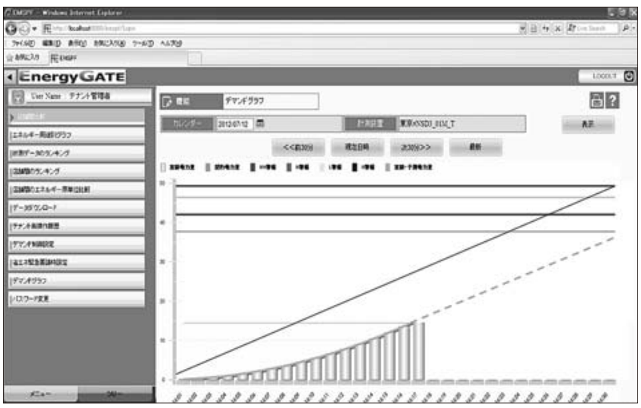


Fig.4 Screen example of demand monitoring function

Fig.5 Screen example of zone demand function

*1: Excel: Trademark or registered trademark of US Microsoft Corp.

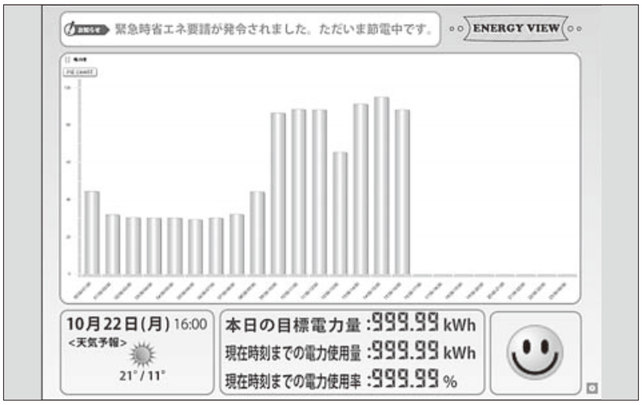


Fig.6 Screen example of digital signage function

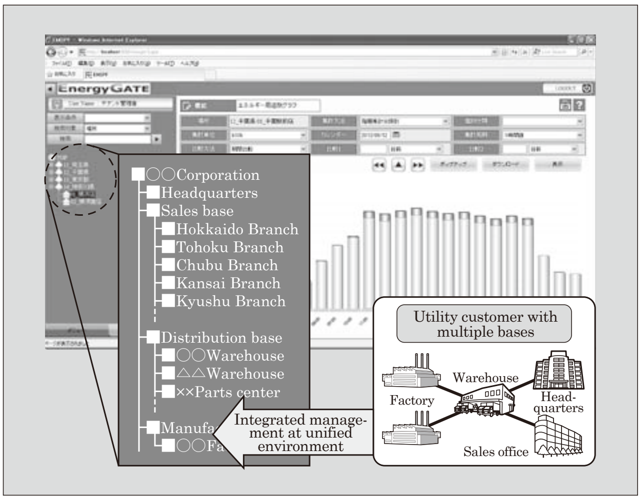


Fig.7 Integrated management of multiple bases

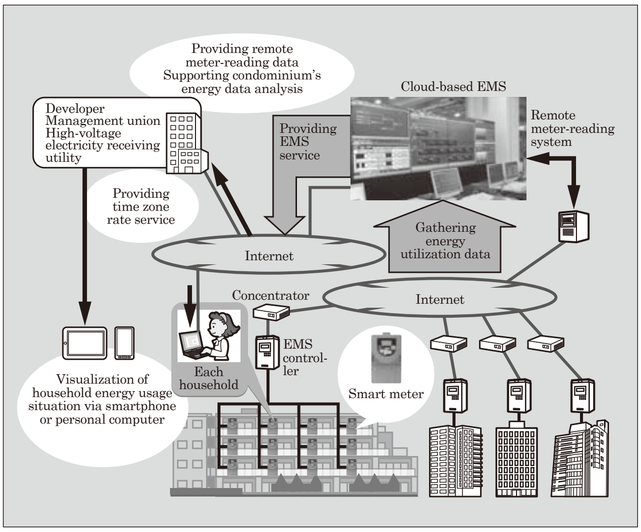


Fig.8 Energy management support service for condominiums

4. Prospect of Cloud-Based EMS

4.1 Expansion of servicing range

Needs for a cloud service, which does not require implementation, maintenance, or management of a system within the company, are expected to increase more and more in the future.

Fuji Electric utilizes the characteristics of a cloud-based system such as reduction of system implementation cost and maintenance operation management cost and integrated management of multiple bases, and aims to provide its energy management support service in multiple sectors as shown below.

(1) Factories, buildings and commercial facilities

By enhancing services such as operation monitoring of equipment at a manufacturing site, security management support and actual production management, cloud-based EMS expand customer's business support range and provide an advanced analysis service to make obvious challenges for further energy saving such as analysis of cause and effect relationship with energy use results.

For large-volume utility customers, EMS achieves support for energy control of the entire company by integrating sales base, warehouse, manufacturing site and headquarters, and provide integrated management environment (see Fig. 7).

(2) General household

Cloud-based EMSs provide a service for visualization of energy use situation for smart condominium, which is expected to show rapid diffusion in the future (see Fig. 8).

In addition, they provide a power rate service per time zone by linking with high-voltage batch electricity receiving service provider. It promotes further energy saving activity and suppression of local peak power demand by utilizing know-how obtained from Dynamic Pricing demonstration in "Kitakyushu Smart Community Creation Project."

(3) Coordination with self-governing body

Along with introduction of a cloud-based EMS to a facility of a self-governing body, the EMS sends information to promote energy saving action by launching a portal site for businesses and regional residents, disclosing energy saving action led by the self-governing body and releasing its effect in real time.

In addition, through cooperation with the self-governing body, it aims at activation of energy saving actions by organizing events such as energy saving contest by providers and local residents who registered as a member through the portal site (see Fig. 9).

4.2 Exporting of system and operation know-how to overseas infrastructure

Energy supply and demand environment in South East Asia, with its fast economic growth, is under the situation where energy supply infrastructure cannot catch up with demand and influence to corporate activities are being revealed. In addition, there are many cases where the power rate is set rather expensive compared to local commodity prices, and energy cost in corporate activities is relatively high. However, investment and measures against energy saving at the

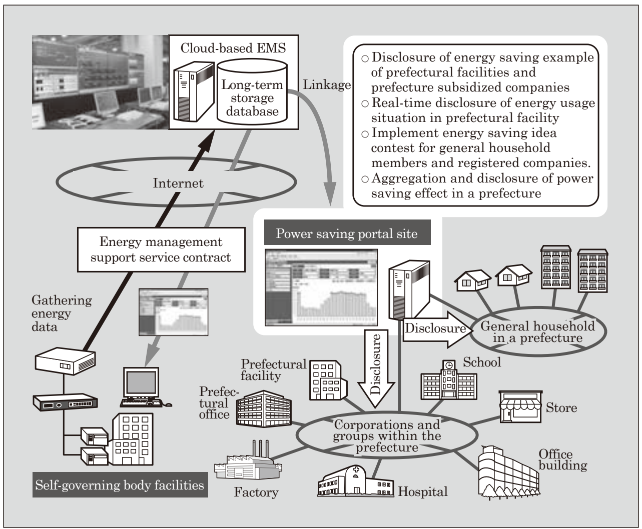


Fig.9 Linkage with self-governing body portal site

same level as in the developed nations are difficult. Furthermore, there are also issues on operation such as lack of personnel with know-how of energy saving and the unestablished daily energy saving activities.

Against such situation, Fuji Electric can provide a service by cloud-based EMS, which integrates energy management operation support and analysis support at a low price. Furthermore, by utilizing know-how of energy saving and advanced energy management that were cultivated in Japan, we will carry out expansion of our energy management support service.

5. Postscript

Domestic electric power supply and demand circumstance is expected to go through significant change in the future with deregulation of the electric utility industry, separation of electric power producers and suppliers and liberalization of retail sale; and diversification of services in the field of energy management is also expected.

In addition, there is a strong trend in shifting from implementing the system as the company's own equipment to utilizing a cloud-based service in small and medium-volume utility customer and outsourcing minded large-volume customer under the severe investment environment.

Fuji Electric will expand its service to match customers' new needs while pushing forward in diffusion of the energy management support service by cloud-based EMS, whose operation has already been started, and will flexibly follow change in energy environment surrounding utility customers.

The "ECOMAX Controller" Realizes an EMS for Use in Stores

KIDO Takeshi * KANZAKI Katsuya ‡

ABSTRACT

According to energy consumption trends by sector in Japan, energy consumption in the consumer product sector, which includes retail business, is increasing at a high rate. Moreover, 85% of the energy consumed by retail business activities is in the form of electric power, and power savings is increasingly being requested. Fuji Electric has developed the "ECOMAX Controller" that collectively manages and controls refrigeration, freezer, air conditioning and lighting equipment inside a store to realize comprehensive energy savings. A configuration that is compatible with various interfaces is used in order to enable collective control of the equipment, to reduce installation costs, and to increase the efficiency of the management and operation of the equipment. Additionally, infrastructure management functions for electricity, water and gas are incorporated so that a store-use EMS may be configured easily with a single controller.

1. Introduction

Looking at energy consumption state in Japan by sector such as industry, transportation and consumer, increase in the energy consumption rate of the operation division in the consumer sector (the tertiary industries excluding household division etc.) stands out at 41%. Among them, electric power in the wholesale and retail division, which occupies 23% of the total, accounts for about 85% of the energy consumption, and demand for power saving is increasing (see Fig. 1).

The retail industry is a typical domestic demand industry where domestic trend of the time is strongly reflected. In particular, recently, there has been great interest in making efforts for an energy management system (EMS) in response to an obligation for energy management by the enforcement of the revised Act on the Rational Use of Energy (Energy Saving Act), and energy supply issue after the Great East Japan Earthquake. However, it is very difficult for a small-scale retail business to invest large capital in introducing energy measurement devices and improving energy saving performance.

Fuji Electric has been providing to the market an energy saving linkage control system "ECOMAX V" to perform energy saving operations for showcases and refrigerators with small capital investment. This time, Fuji Electric expanded this system further and developed the "ECOMAX Controller" enabling comprehensive management of overall store equipment.

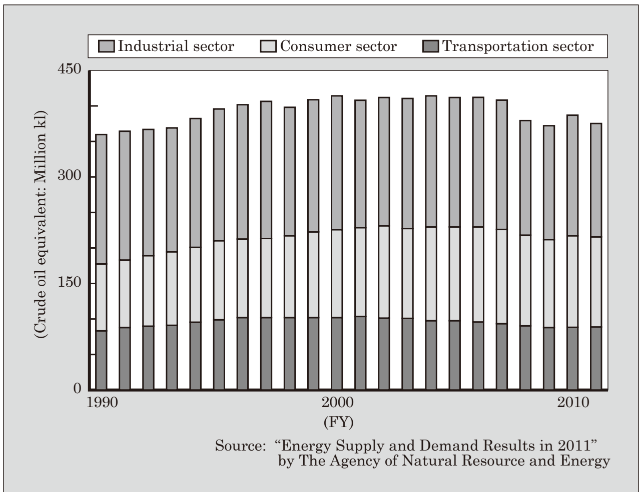


Fig.1 Transition of energy consumption by field

2. Overview of "ECOMAX Controller"

Figure 2 shows system configuration of store equip-

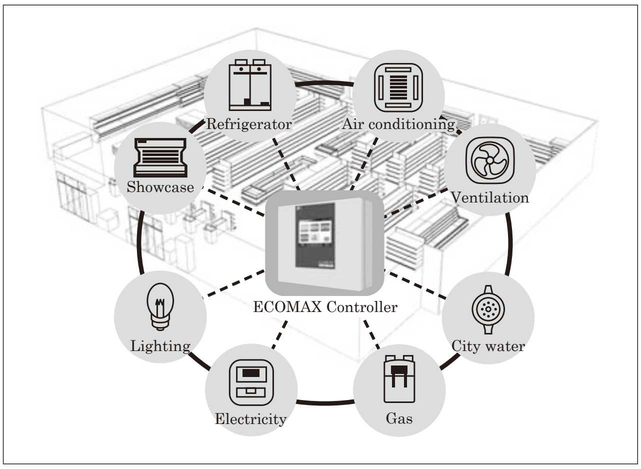


Fig.2 System configuration of store equipment management using "ECOMAX Controller"

* Corporate R&D Headquarters, Fuji Electric Co., Ltd.
‡ Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.

ment management using the ECOMAX Controller. By focusing on and achieving the following points at the time of development, it became possible to realize an EMS for use in stores easily with one controller.

(a) By collective control of store equipment, system introduction cost suppressed, achieving more efficient management operation of devices.
(b) An optimal system is provided corresponding to the store equipment scale and device configuration.
(c) By linking control of cooling equipment such as showcases and refrigerators with air conditioning and lighting equipment, comprehensive energy saving is achieved at the store.
(d) Monitoring function for infrastructure such as electricity, water and gas is installed.
(e) A structure easily applicable to equipment other than retail stores is employed.

3. Configuration and Characteristics of ECOMAX Controller

3.1 Software configuration

(1) Platform

Figure 3 shows the software configuration of the ECOMAX Controller. Combined management of store equipment was achieved by building a platform.

This platform consists of the following three layers.

(a) Kernel layer

It performs direct control of hardware resources such as device drivers and resource allocation management for software.

(b) Standard library service layer

It provides versatile network communication services such as Web server, FTP server and e-mail.

(c) Application framework layer

It provides an interface that an application program directly uses such as input and output control, communication control, screen display and operation, and log.

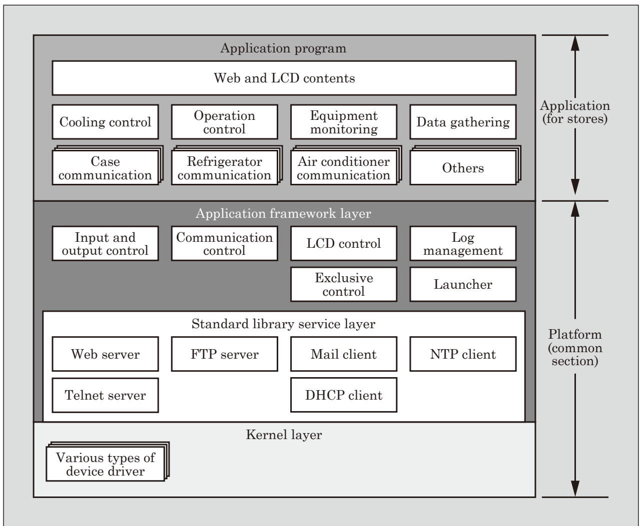


Fig.3 Software configuration of "ECOMAX Controller"

(2) Application for stores

An application program is built as an independent process for individual function and made it possible to operate each process efficiently.

An application program that controls store equipment was built by using a service provided by the platform and it was built in units of function such as refrigerator control and air conditioning control. This enables to append or update required functions easily.

(3) Avoidance of control interference

When multiple controls are performed for one unit of equipment, mutual control interference becomes an issue.

For example, such a case is considered that the following two requests occurred at the same time: a power suppression request resulting from the demand control forecast that the target electricity will exceed, and a request for increasing the output resulting from the air conditioning optimal operation control detecting deterioration of amenity in the store are provided to one air conditioner.

Originally, in order to avoid such control interference, a restriction has been employed so as not to perform multiple controls for the same equipment. However, with the ECOMAX Controller, such restriction was eliminated by installing a mechanism to judge the priority output for control requests from each application program.

In the above-mentioned example, if "Demand control prioritizes air conditioning optimal operation" has been set, the platform executes control output according to the request of demand control to suppress power control even if air conditioning optimal operation control requests an increase in operation output.

This software configuration allows for utilizing various energy saving control functions effectively, and a high energy effect can be expected.

3.2 Characteristics

(1) Various interface support

With the general store equipment, there are many cases where the connection method differs depending on the type of the device and the quantity of equipment to be implemented differs depending on the store. In order to correspond to these cases, installation and extension of dedicated interface devices were required.

The ECOMAX Controller is equipped with multiple interfaces such as digital input and output, general-purpose serial communication (RS-485), network communication (Ethernet[*1]), and provides a mechanism that makes it possible to change the interface flexibly according to the specification of equipment.

For connection with an air conditioner, it sup-

*1: Ethernet: Trademark or registered trademark of Fuji Xerox Co., Ltd.

ports LonWorks*2, which is widely disseminated as a network connection technology for equipment management, and the air conditioning system HTTP interface, which specification was drawn up by The Japan Refrigeration and Air Conditioning Industry Association for small and medium-size building management.

Based on these, it is possible to connect to various units of equipment without implementing or appending a dedicated interface device.

(2) Improvement of operability

Figure 4 shows the user interface of the ECOMAX Controller. By installing a touch panel type liquid crystal display (LCD), it is possible to grasp the state of store equipment and perform operation easily.

The touch panel type LCD is devised to perform intuitive operations without the need for the instructions manual etc. Therefore, it is possible for employees without any specialized knowledge to perform equipment management easily.

In addition, when an abnormality is detected from store equipment, there is a function to immediately switch the screen to the operation information monitoring display of the relevant equipment and notify by an alarm buzzer and e-mail. This improves the efficiency of management operation for the equipment. A built-in Web server function enables more detailed information management from a personal computer via an Ethernet.

Furthermore, by supporting tablets, which have become very popular recently, various operation styles are available such as enlarging the operation screen or performing information management while carrying the device.

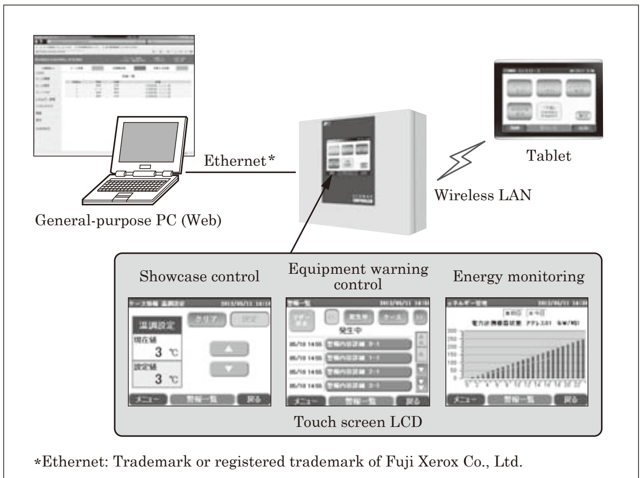


Fig.4 User interface of “ECOMAX Controller”

*2: LonWorks: Trademark or registered trademark of Echelon Corporation (US).

4. Function at Retail Stores

4.1 Satisfying energy saving function

The ECOMAX Controller is equipped with the following four energy functions in addition to the energy saving operation functions for refrigerators and showcases that were achieved with the existing “ECOMAX V.”

(1) Air conditioner optimal operation function

This function is used to adjust the operation mode and temperature & air flow of an air conditioner so that the total power consumption of air conditioner and refrigerator becomes the minimum value, based on the air temperature and humidity of outside and inside of the store, and the ventilation operation state of the store. In this way, it becomes possible to reduce power consumption when there are many fluctuations in the temperature and humidity of the outside air such as at change of seasons.

When changing the setting of air conditioner, evaluation by Predicted Mean Vote (PMV) was introduced considering the influence on showcase cooling and heating load, as well as amenity in the store. PMV is an indicator of warm-cold sensing by six elements: temperature, humidity, air current, radiation, amount of wearing cloths and amount of one’s activity.

(2) Intake and exhaust control function

This is a function to optimally control the amount of ventilation according to the air circumstances in the store such as the CO_2 concentration. By controlling the airflow of the fan, it is possible to suppress the heat-entering amount due to outside air that becomes a load on the air conditioner, and to save energy.

(3) Demand control function

This is a function to control the power consumption in the entire store so that the amount does not exceed the target value. The ECOMAX Controller enables detailed power control according to the state of customer’s equipment operation because of collective control of store equipment.

(4) Scheduled operation function

Reducing the unnecessary operation time of the equipment is an efficient measure for energy saving. Therefore, it is necessary to have a function to set an operation schedule of the equipment easily and optimally in accordance with the schedule of the store activity.

The ECOMAX Controller can register multiple schedules as sales patterns, such as store opening and closing time for each selling area and by day of the week, and can change them as necessary. In addition, master setting is performed so that a sales pattern will work simultaneously with an operation schedule of the equipment. Therefore, by changing sales patterns, the setting of an equipment operation schedule can be changed at once and detailed schedule operation becomes possible in accordance with the operation type of the store.

4.2 Energy management function

The ECOMAX Controller can provide a service to monitor the energy use situation of an entire store chain because it can link with the center monitoring system, “ECOMAX Net,” which Fuji Electric has already deployed.

In addition, for the store to carry out energy saving activities independently and effectively, energy use situation can be acquired with a touch panel type LCD.

Specifically, display of the energy use situation per day or per hour, and comparison with a past energy use amount can be performed by simple operation.

Such data as the energy use situation accumulated by the ECOMAX Controller and operation state condition of equipment can be acquired using network communication via the standard library service of the platform. In this way, a customer can build its own energy management system easily without carrying out dedicated customization development.

4.3 BEMS aggregator project

Building and energy management system (BEMS) aggregator project is a subsidized project run by the Ministry of Economy, Trade and Industry for high-voltage small-size utility customers such as small and medium-size buildings and commercial facilities, and is aimed at reducing contract demand by 10%. A BEMS aggregator means an information managing operator using energy who promotes power saving of utility customers, by helping them to implement a BEMS and installing a centralized management system using cloud technology by himself.

Fuji Electric is registered as a BEMS aggregator and promotes implementation of BEMS. To implement BEMS to commercial facilities such as small and medium-size supermarkets, an energy monitoring function, demand control function, and energy-saving operation control function of the ECOMAX Controller are utilized. The following functions become available by linking a BEMS aggregator server that has an energy management service function as mentioned in Section 4.2, and the ECOMAX Controller.

(a) Device schedule operation control function that performs automatic on-off control for registered devices
(b) Demand forecast function to perform demand forecast based on the past data and weather forecast of the current day, for setting target power consumption

4.4 Kitakyushu Smart Community Project

“Next Generation Energy and Social System Demonstration” is positioned as a new growth strategy of the government, and it involves efforts to establish a Japanese style Smart Grid and expand it overseas. One of such efforts is the “Kitakyushu Smart Community Project.”

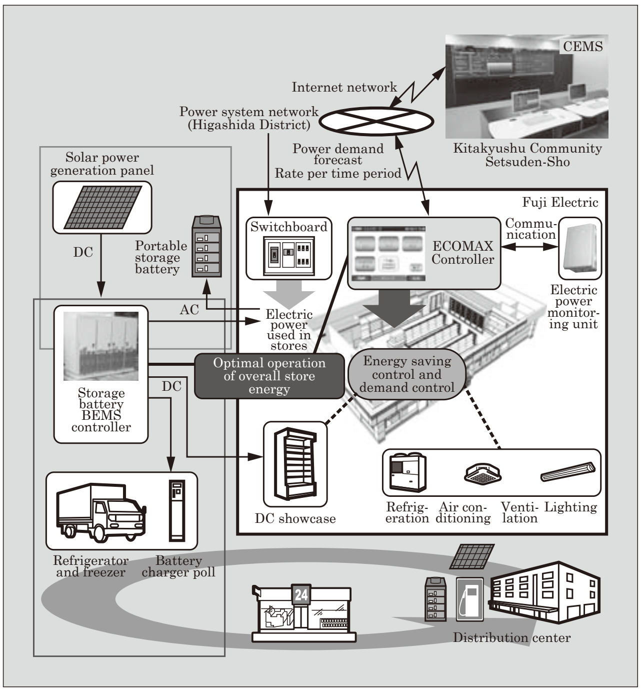


Fig.5 Configuration of Kitakyushu smart store demonstration verification project

As one of the participant companies, Fuji Electric developed an EMS for use in stores that is linked to a regional energy management system (CEMS: cluster energy management system), and carried out demonstration verification to contribute toward peak cutting, peak shifting and reduction of electric power consumption for power demand supply stabilization within the region in Higashida District of Yahata-higashi Ward in the city of Kitakyushu. Figure 5 shows the configuration of Kitakyushu smart store demonstration verification within the project.

The EMS in the store draws up device operation plan and charge & discharge plan of a storage battery system to always minimize the power consumption, based on a power supply forecast and solar power generation forecast in the store. In addition, according to the demand and supply adjustment request and dynamic pricing request sent from the CEMS, it draws up a power supply and demand plan again, and deploys it to the equipment operation plan in the store, and controls equipment in the store.

In demonstration verification, optimal operation control of air conditioning, ventilation and lighting equipment, storage battery charge and discharge control, as well as cooling equipment operation control such as showcase are performed. The operation began in the summer of 2013, and the ECOMAX Controller is working as the core system of the equipment control in the store.

5. Postscript

The “ECOMAX Controller” achieves comprehensive management of overall store equipment such as air conditioning and lighting, not only cooling equipment. In this way, it became possible for retail stores to reduce equipment maintenance management cost and reduce energy consumption at low cost.

In addition, the ECOMAX Controller makes it possible to provide services by flexibly corresponding to equipment size and equipment configuration of individual utility customers because the structure allows easy application to equipment other than those in a retail store.

In the future, to promote expansion of application to various types of utility customers, Fuji Electric will make an effort to establish an optimal system that conforms to individual needs.

A Framework for Optimal Planning Systems on the EMS Platform

KAWAMURA Yu * HORIGUCHI Hiroshi * ONO Takeshi ‡

ABSTRACT

To promote further energy savings, the demand for electrical, thermal and other types of energy and the amount of energy supplied by self-generation facilities must be integrally managed and planned. Fuji Electric has developed a framework for optimal planning systems that runs on the integrated EMS platform. This framework has a uniform energy network model that automatically generates a plant model according to the arrangement and connection of equipment on a display screen, and an optimal planning function that develops operational plans. As a result, the configuration and properties of the equipment can be changed and maintenance can be performed without the need for a professional engineer, and operational planning becomes easier.

1. Introduction

As global energy demand and CO_2 emissions are increasing, efforts to implement renewable energy and to conserve energy (energy saving) are promoted to realize a sustainable society. An increasing number of utility customers, such as plants and buildings, are not only replacing their facilities with conventional energy saving equipment but also implementing private power generation equipment, such as photovoltaic power generation equipment and cogeneration equipment. Achieving further energy saving requires the development of a scheme for centrally controlling and handling the amount of energy (electricity and heat) in demand and the amount of energy supplied by utility facility (electric power generation equipment, heat sources and other equipment that supply energy to plants, offices, etc.). Thus, a function for planning and controlling the operation of a utility facility based on energy supply amount prediction and energy demand prediction (optimal operation planning function) must play a more important role than before in addition to the function of the conventional energy management system (EMS) which is intended mainly to visualize energy.

Fuji Electric Co., Ltd. has so far developed optimal operation planning functions focusing on energy supply and demand in a wide range of sectors, such as electric power, steel, water treatment, industry and retail distribution[(1)(2)]. To make it possible to provide operation planning systems in a timely manner in response to future needs, which are expected to be more diverse, Fuji Electric developed an optimal operation planning function construction framework. It runs on an integrated EMS platform, and has been developed based on knowledge and data concerning the optimal operation of energy on the utility customer side, which were obtained through past development projects. This framework is characterized by a high level of usability achieved by plant model creation and simulation functions, and the capability of formulating plans with excellent serviceability through the flexible selection of the planning functions.

This paper describes an overview of the integrated EMS platform, and describes the features of the optimal operation planning function construction framework and its application examples.

2. Integrated EMS Platform

Figure 1 shows the configuration of the integrated EMS platform and its peripheral functions[(3)]. The integrated EMS platform is the middleware forming the core of the construction of an EMS. It is provided with the functions of an ordinary EMS, such as result data management and driver management responsible for the management of communication with sensors, controllers and other field devices, as well as the following three functions:

(1) High-speed program linkage service, “Fuji Service Bus”

The server configuration of EMS comes in various forms, from single server configuration to distributed server configuration consisting of several dozen servers, according to the scale of system to be controlled, the number of required functions, the monitoring and control cycle and the redundancy of the server. Fuji Service Bus functions to link processing among programs installed in distributed servers or among programs and Web screens, regardless of these server

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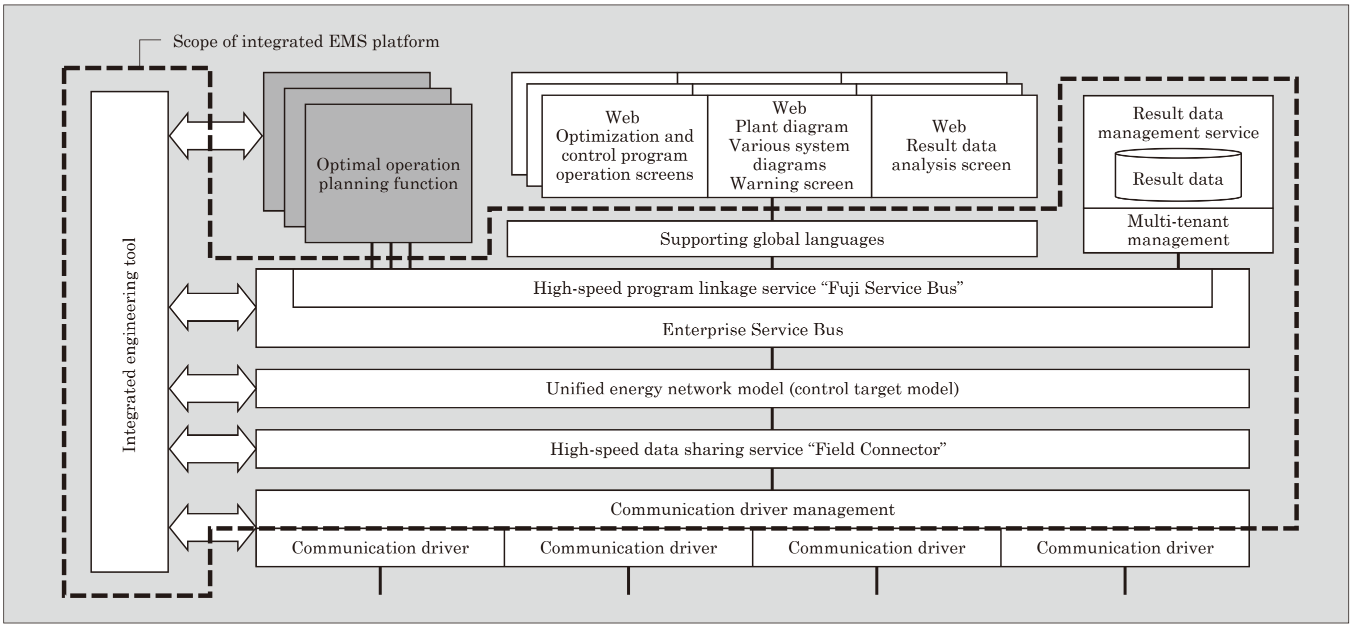

Fig.1 Configuration of integrated EMS platform and its peripheral functions

configurations. This function enables users to expand or delete program functions on the integrated EMS platform.

(2) Unified energy network model

The unified energy network model defines how energy, such as electricity, gas and steam, is converted and transferred in/among the control target devices. It is intended to plan the operation of in-plant utility facilities that produce or consume electricity, gas, steam, or another form of thermal energy.

(3) High-speed data sharing service, “Field Connector”

The Field Connector is a function that enables programs on the integrated EMS platform to refer to online data and give control instructions, irrespective of the server configurations. This function manages online data, result data and prediction data with the aid of TAG management (system designed to manage data with TAG names, such as “TAG001” and TAG values).

3. Optimal Operation Planning Function Construction Framework

The optimal operation planning function construction framework is an aggregate of programs for developing optimal operation planning functions that run on the integrated EMS platform. Below are the main features of the framework.

(a) The framework provides a group of functions required to construct planning systems, such as the unified energy network model and a planning algorithm (optimal operation planning function).

(b) Plant models are created by the unified energy network model from the viewpoint of the energy flow, whatever the type of plant and energy to be controlled. The framework provides tools for analyzing and converting these plant models.

(c) The optimal operation planning function provides an optimization algorithm with the minimization of energy cost, including power consumption and CO_2 emissions, as the objective function to plan the operation of a utility facility. For this optimization algorithm, a suitable system for the characteristics of the plant concerned, such as the input and output characteristics and constraints of equipment, can be selected from among multiple systems at the stage of programming.

3.1 Configuration of the optimal operation planning function construction framework

The configuration of the optimal operation planning function construction framework and its peripheral functions is shown in Fig. 2. The optimal operation planning function construction framework consists of the components described below.

(1) Optimal operation plan drawing up function

The optimal operation plan drawing up function formulates an optimal operation plan and is made up of the following elements:

(a) Structured data [extensible markup language (XML) file]

Structured data is an output file of the unified energy network model for plant modeling.

(b) Model analysis part

The model analysis part analyzes the XML file and converts it into the model format (definition for optimal calculation model) requested by the optimization calculation part.

(c) Data gathering part

The data gathering part collects result data and prediction data required for the planning of opera-

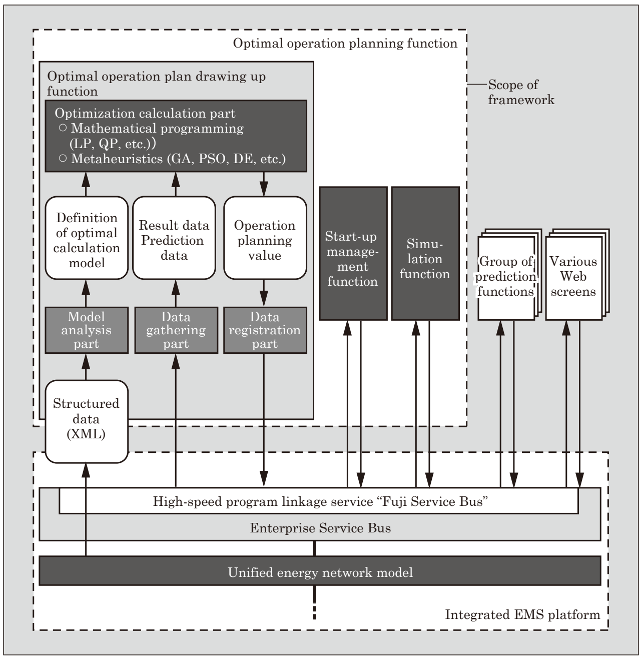

Fig.2 Configuration of optimal operation planning function construction framework and its peripheral functions

tion from the database under the integrated EMS platform.

(d) Optimization calculation part

The optimization calculation part carries out optimal calculations and draws up operation plan based on the definition of optimal calculation model and the gathered data.

(e) Data registration part

The data registration part stores the calculated operation planning values in the database under the integrated EMS platform.

(2) Start-up management function

The start-up management function manages coordinated start-up of the prediction and other functions as well as the start-up timing of the optimal operation planning function.

(3) Simulation function

The simulation function calculates the operation plan in multiple operation cases and displays it on the screen in order to validate the operation planning values before actual operation.

Other functions that are not included in the optimal operation planning function construction framework but are important in operation planning are provided as a group of prediction functions for predicting electric power demand, or the amount of electric power generated by photovoltaic power generation, etc.; and various Web screens related to the optimal operation planning function and prediction functions.

3.2 Unified energy network model

An operation plan aiming to minimize energy costs, including electric power consumption or CO_2 emissions is formulated using the optimization algorithm. This step requires describing the transfer relationship of energy, for which a plan will be drawn up in the form of an equation. In the past, an engineer well versed in optimization performed modeling by selecting a model representation system suitable for the algorithm and directly describing the equation. This approach, however, required corrections to the mathematical model each time the number of units of equipment inside the plant increased or decreased or any of the characteristics changed due to aging, etc.

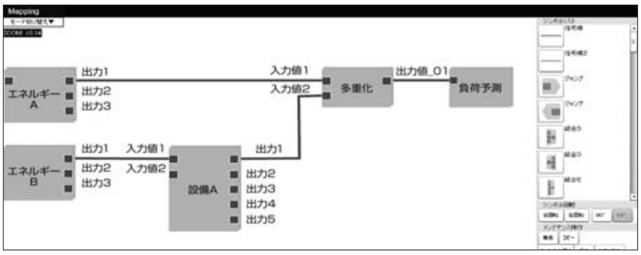

Fig.3 Example of definition screen of unified energy network model

As a solution to this problem, Fuji Electric developed a unified energy network model, which enables ordinary users to define plants and automatically create plant models through simple operations.

The unified energy network model shows the energy flow of a plant in graphic form. Tree-structured points (nodes) in the graph represent the devices, and branches indicate the relationships of connection among them.

Figure 3 shows an example of the definition screen of the unified energy network model. The user selects nodes from the symbol list displayed at the right-hand end of the screen, places them in the model definition window in the center of the screen and opens the property input window to input values such as the coefficient of conversion efficiency and upper and lower limit characteristics. The relationships of connection among the devices are defined by connecting the input/output of the placed nodes with signal lines. The model defined in this way will be output as XML data, which is then converted by the model analysis part into the file format requested by the optimization calculation part.

3.3 Optimization calculation part

The optimization calculation part is the core function of the planning algorithm. Based on the plant information entered in the unified energy network model, result data and prediction data, this part outputs an operation plan relating to utilities inside the plant that minimize energy costs or CO_2 emissions.

Optimization of an operation plan for a utility facility is an optimization problem to simultaneously determine the start-up and stop (discrete quantity) and output (continuous quantity) of the devices that minimize the operation cost or CO_2 emissions, while taking into account the supply and demand balance of each type of energy and the mechanical and operational constraints. Such optimization problem of operation plans were once resolved by linearizing the characteristics and constraints of devices and then formulating as a mixed integer programming problem. To obtain an operational solution that is more effective in saving energy and that can be used in actual operation, however, the strict characteristics of appliances and field operation rules and other constraints must be considered. If these factors are not considered, the calculated value of energy consumption will deviate from the actual value, and operation planning values not complying with the operation rules will be output, which will result in failure to achieve intended energy saving, or other problems will occur. It is, therefore, necessary to formulate an operation plan as a mixed integer nonlinear programming problem considering the nonlinear characteristics of the devices and the operation rules. In general, an optimal solution to such an issue is said to be difficult to obtain efficiently.

Fuji Electric developed an original algorithm to resolve this problem. This algorithm combines leading-edge metaheuristics optimization techniques, such as the particle swarm optimization (PSO) method[4] and differential evolution (DE)[5, 6], as the core of optimal solution search methods, with know-how on the operation planning of utility facilities. This algorithm makes it possible to obtain highly accurate solutions to mixed integer nonlinear programming problems, which were difficult to solve in practical calculation time, within 30 minutes (assuming 30-minute balancing).

In addition to the abovementioned algorithm, Fuji Electric has a mathematical programming algorithm available, which solves the problem in a shorter time when the input and output characteristics or constraints of utility facilities can be modeled by linear functions or quadratic functions.

With regard to CPUs mounted in computers, the design policy has been shifting from the one aimed at increasing processing performance of the CPU by clock frequency to the one aimed at increasing computation performance of the CPU by using multiple cores, and, in consequence, multi-core CPUs are becoming popular. In response to this trend, Fuji Electric is committed to research and development of the parallelization of optimization algorithms to obtain high-quality solutions even to large-scale problems within the desired time, allowing high-speed calculations with multi-core CPUs.

3.4 Start-up management function

The optimal operation planning function receives a start-up request at fixed cycles of 30 minutes or an hour and plans the operation of a utility facility based on the demand value predicted by the prediction function or the operation planning value planned by another operation planning program.

The start-up management function requests the prediction function and the abovementioned optimal operation planning function to start up according to the predefined start-up cycle (30 minutes, an hour, etc.) and the start-up sequence (electric power generation prediction, demand prediction, operation planning function, etc.). This function manages and executes a series of tasks, from prediction and calculation to optimal operation planning, at fixed cycles.

3.5 Simulation function

Whenever an operation planning system is implemented or there is a change in the facility after implementation, the energy saving performance and serviceability of the drawn up operation plan must be verified using data assuming various operating states. In this verification, we execute the operation planning function by batch processing, and confirm the planned result with the simulation function.

The simulation function consists of a function to convert data input by the optimal operation planning function into desired data and calls it up in a batch, and the function to verify the result on the screen.

The simulation function uses the data input screen shown in Fig. 4 as the means to input data of various patterns. Input data will be obtained from the pre-planned group of prediction data at preset given time. If the given data is improper for the contents verified, the user can adjust it by changing the value displayed in the data input field to any value.

There are two means available to verify operation planning results. One is verification of data values on the screen, and the other is verification on a graph. Data values can be verified on the data input screen; and in the case of verification on a graph, the data to be graphed or the type of graph to be used depend on the type of the plant and the event to be evaluated and studied. Thus, the simulation function is designed to be capable of outputting various graphs by predefining types of data and graphs through an operation called graph definition, which links operation planning data for evaluation and study to these predefined types of data and graphs. Graph definition is executed on the graph definition screen shown in Fig. 5, where general

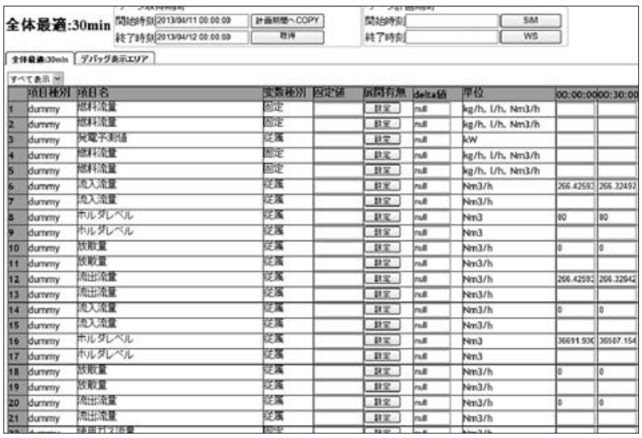

Fig.4 Data input screen of simulation function

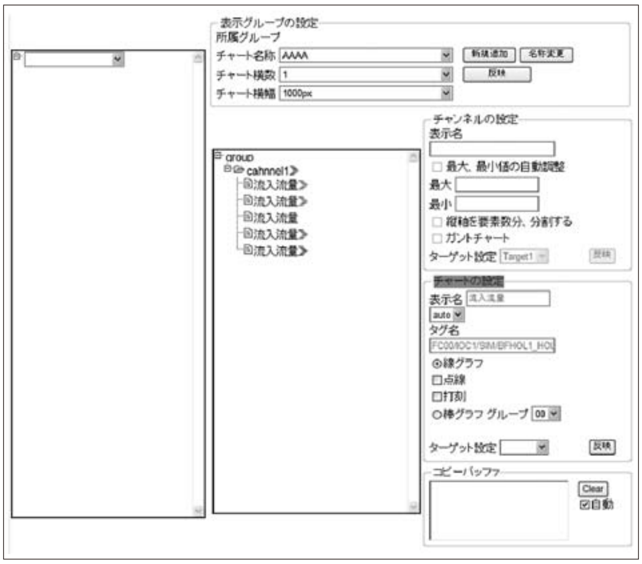

Fig.5 Graph definition screen of simulation function

setting items relating to the creation of graphs can be selected.

4. Application to EMS for Steelworks

This section describes the EMS package for steelworks "Steel EMS Package," which was developed using the optimal operation planning function construction framework, as an application example (see "'Steel EMS Package' Optimizing Energy Management at Steelworks" on page 165).

The "Steel EMS Package" consists of a group of optimal operation planning functions, a start-up management function, a simulation function and a prediction function, as the system configuration is shown in Fig. 6. The group of optimal operation planning functions includes holder facilities optimal operation, oxygen facility optimal operation, power generation facility optimal operation and overall optimal operation. The prediction function is made up of demand prediction, which predicts the demanded quantity of gas and electric power consumption within the steelworks. Optimization by each function of the group of optimal operation planning functions is linked to demand prediction to formulate an operation plan based on the predicted generated and consumption of energy planned by the relating prediction function.

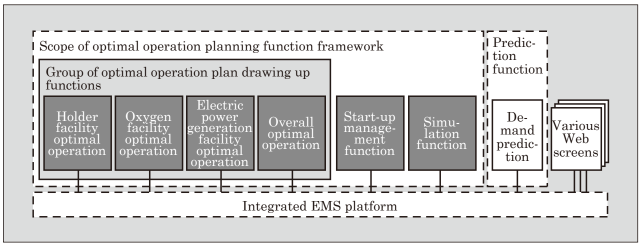

Fig.6 System configuration of "Steel EMS Package"

Holder facilities optimal operation, oxygen facility optimal operation and power generation facility optimal operation are required to perform high-speed calculations every five minutes. Thus, oxygen facility optimal operation and electric power generation facility optimal operation are achieved by applying an algorithm capable of performing high-speed calculations. Holder facilities optimal operation ensures high-speed calculations by using parallelization metaheuristics for the algorithm. Overall optimal operation starts up at fixed cycles of once a day. However, since operation planning expands in scale, this function also achieved high-speed calculations by parallelization processing of the multi-core CPU.

In addition, even the Steel EMS Package requires verification whenever a trial calculation of the effect is performed or any equipment parameter is changed, and therefore validity of the operation plan can be checked in advance by applying the simulation function described above.

5. Postscript

In this paper, the optimal operation planning function construction framework running on the integrated EMS platform was described.

We will continue working to add the latest optimization calculation algorithms, and develop integrated energy network models, simulation functions and other engineering tools; while enhancing their usability and help to realize a sustainable society through the sophistication of operation planning functions.

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Supply and Demand Control System for Power Systems with Distributed Power Supplies

KATSUNO Tohru * IIZAKA Tatsuya * HAYASHI Naoki *

ABSTRACT

The output of renewable energy sources such as solar and wind power fluctuate frequently. Therefore, it is concerned that maintaining the supply-demand balance in a rural area or an isolated island is difficult. To solve this problem, Fuji Electric has developed a hierarchical supply and demand control system with different control cycles for supply and demand planning, economic load dispatching control and load frequency control. The above functions of the developed system have been verified by digital simulations with promising results.

1. Introduction

Distributed power supplies, which utilize such renewable energy as photovoltaic power generation and wind power generation, are rapidly attracting interest on a global scale; and many countries are promoting efforts to expand the implementation of renewable energy. In Japan, it is pointed out that expanding the implementation of renewable energy is an urgent necessity to achieve the basic principles of the energy conservation policies, or 3Es (energy security, environmental protection from global warming, and efficient energy supply).

The government's "Basic Energy Plan" revised in June 2010 also set a high goal of increasing the percentage of distributed power supplies using renewable energy to 10% of primary energy supply by 2020. To accomplish this goal, there is a plan to implement 28.00 million kW by photovoltaic power generation and 4.90 million kW by wind power generation in 2020. However, there is a concern that distributed power supplies using renewable energy will cause the frequency of vulnerable electric power systems to fluctuate on isolated islands, resulting in adversely affecting loads because output from distributed power supplies varies every moment with the natural conditions, such as insolation and wind velocity.

As a technological solution to this problem, micro grids come under the spotlight. Especially on isolated islands where there is a concern that fluctuation in frequency may increase by implementing renewable energy, a supply and demand control system using an energy management system (EMS) is expected to come into widespread use at an early stage.

This paper describes an overview of the hierarchical supply and demand control system that Fuji Electric Co., Ltd. developed, with particular emphasis on the supply and demand control function compatible with distributed power supplies, and the results of simulation-based verification of its performance.

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2. Overview of the Hierarchical Supply and Demand Control System

Figure 1 shows an overview of the hierarchical supply and demand control system. This system adjusts generator and storage battery output by controlling output from distributed power supplies continuously, such as photovoltaic power generation and wind power generation, as well as various frequencies corresponding to load fluctuation cycle, to maintain a balance between intermittently changing loads (demand) and power generation (supply). To deal with daily slow fluctuation, activation and deactivation of generators and storage batteries and the dispatching of output from them are planned based on supply and demand

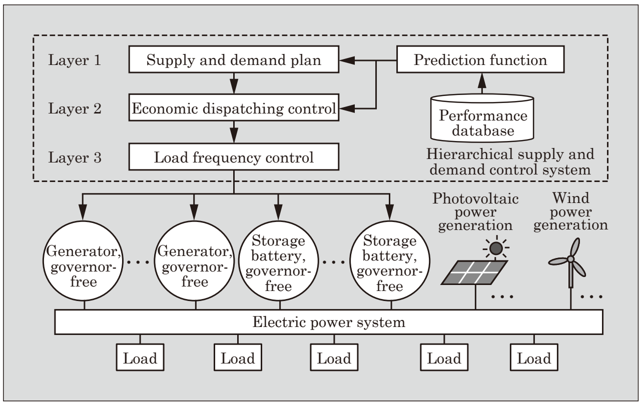

Fig.1 Overview of hierarchical supply and demand control system

plan, with economy taking into account [see Fig. 1 (Layer 1)]. Next, to handle fluctuation for about 60 minutes interval, the dispatching of output is finely adjusted by activating and deactivating the generators and storage batteries whose supply and demand plan was determined by economic dispatching control (EDC) [see Fig. 1 (Layer 2)]. To respond to fluctuation for about 20 minutes interval, output is controlled by load frequency control (LFC) so that the frequencies will fall within the specified range [see Fig. 1 (layer 3)]. Finally, to cope with fast fluctuation for about 1 minute interval, output is controlled by the governor-free operation function provided with the generators and storage batteries.

2.1 Supply and demand plan

The supply and demand plan is formulated as a mixed integer programming problem, which determines the activated and deactivated states of generators and storage batteries and the dispatching of output from them. In this mixed integer programming problem, increase in the number of generators and storage batteries increases their number of combinations enormously. It is, therefore, practically infeasible to evaluate objective functions relative to all combinations of activation and deactivation. For this reason, processing time is reduced by implementing the following processing to the determination of activation and deactivation patterns of generators and storage batteries:

(a) Relieve constraints to reduce calculation time, and determine the activated and deactivated states of the generators approximately and tentatively by means of quadratic programming.

(b) Apply the preset logic to the activated and deactivated states of the generators tentatively derived in (a) to finally determine the activated and deactivated states of the generators.

(c) Determine the dispatching of output from the generators and storage batteries relative to the activation and deactivation of the generators determined through the processing up to (b) by quadratic programming.

The objective function of this approach is shown below in Equation (1). The target is the minimum economic cost of generator operation and activation costs. The generator operation cost was approximated by the quadratic function of the output.

$$\mathrm{Obj}_{\mathrm{UC}}=\sum_{t=1}^{T}\sum_{k=1}^{N}\left(a_k P_k^2(t)+b_k P_k(t)+c_k u_k(t)\right)+\sum_{k=1}^{N}\Delta u_k K_k \quad \cdots(1)$$

$\mathrm{Obj}_{\mathrm{UC}}$: Objective function of supply and demand plan

$P_k(t)$: Output from generator k at time t

$u_k(t)$: Variable of activation and deactivation of generator k at time t (0: deactivation, 1: operation)

a_k, b_k, c_k: Coefficients of fuel cost characteristics of generator k

Δu_k: Presence or absence of activation of generator k

K_k: Activation cost of generator k

N: Number of generators

T: Calculation time period from present to time T

The considered constraints include supply-demand balance, the upper and lower limits of output from generators, the upper and lower limits of the rate of change of output from generators, the minimum continuous deactivation time of generators, the minimum continuous operation time of generators, reserved capacity, the upper and lower limits of charged and discharged electric power of storage batteries, and the maximum charged and discharged electric power of storage batteries. The charge and discharge loss of storage batteries is also taken into account.

2.2 Economic dispatching control (EDC)

The dispatching of output from the generators is calculated using economic dispatching control (EDC) based on the activation and deactivation plan worked out in the supply and demand plan. EDC minimizes costs for a future specific period with consideration given to constraints concerning the upper and lower limits and rate of change of output from the generators. As an approach to realizing it, the quasi-optimization solution applying the equi-incremental fuel cost method is used. The formulation of EDC is shown below.

$$\mathrm{Obj}_{\mathrm{EDC}}=\sum_{t=1}^{T}\sum_{k=1}^{N}\left(a_k P_k^2(t)+b_k P_k(t)+c_k\right) \quad \cdots\cdots (2)$$

Constraints are shown below.

$$\sum_{t=1}^{T} P_k(t)=P_{load}(t) \quad \cdots\cdots (3)$$

$$P_{k\_lower}(t)\le P_k(t)\le P_{k\_upper}(t) \quad \cdots\cdots (4)$$

$$-\delta_k\le P_k(t+1)-P_k(t)\le\delta_k \quad \cdots\cdots (5)$$

$\mathrm{Obj}_{\mathrm{EDC}}$: Objective function of economic dispatching control

P_{load} (t): Predicted total demand at time t

P_{k_lower} $(t+\mathrm{i})$, P_{k_upper} $(t+\mathrm{i})$: Upper and lower limits of output from generator k (the upper and lower limits can be set at each time)

δ_k: Rate of change of maximum output from generator k (absolute value)

N: Number of generators

T: Calculation time period from present to time T

Of the constraints, Equations (3), (4) and (5) represent the supply-demand balance constraint, the constraint of the upper and lower limits of output from the generator, and the constraint of the upper and lower limits of the rate of change of output from the generator, respectively.

2.3 Load frequency control (LFC)[1]

A block diagram of load frequency control is shown

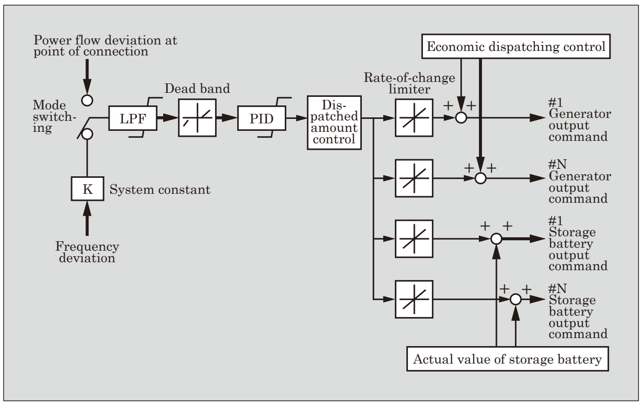

Fig.2 Block diagram of load frequency control

in Fig. 2. In load frequency control, the input value is different between when the system under control is linked to another system and when it is an independent system. To be specific, the power flow deviation of the point of connection is used as the input value when the system under control is linked to another system, or the deviation of the frequency is used as the input value when it is an independent system; and generator and storage battery output is controlled to minimize the respective deviation. Load frequency control can switch the input value between the case of a linked system and the case of an independent system.

The method of load frequency control is such that the power generation unit with the slowest response shall be set to first undertake control, and those that could not be controlled with it alone are operated by other unit in the order of response. This control method, however, may place a burden on the storage battery with the fastest response and use up remaining electric power of the storage battery when many distributed power supplies are linked to the system under control. To prevent this, a control function was added to allow a slow responding power generation unit with some margin to use its remaining power to so as bring the state of charge (SOC) of the storage battery closer to the target value. By using this function, the possibility that the remaining electric power of storage batteries to be used up can be reduced even if many distributed power supplies are linked to the system under control.

3. Performance Verification by Simulation

The effectiveness of the hierarchical supply and demand control system must be confirmed by verifying the performance of the supply and demand operation plan, the performance of load frequency control and the performance of economic dispatching control(1). We simulated the developed hierarchical supply and demand control system to verify the supply and demand operation plan and load frequency control. For the performance verification results of economic dispatching control, see Reference (1).

3.1 Performance evaluation of supply and demand plan

To confirm the effectiveness of the proposed approach, a simulation of 48 points a day (planned time interval: 30 minutes) was performed on a model system consisting of generators and storage batteries. We used loads which were reprocessed appropriately for the number of generators based on the value calculated by subtracting the load value of photovoltaic power generation and wind power generation from the load value actually set in the "Kyoto Eco-Energy Project(2)." A PC equipped with a Pentium4*1 with 3 GHz CPU and 1 GB of memory was used.

(1) Comparison with the exact solution

Figure 3 shows a plan obtained from the developed supply and demand planning function and a supply and demand plan obtained from mixed integer quadratic programming (exact solution), using five generators. For the exact solution, LINGO*2, optimization package software, was used. Table 1 shows a comparison of economic cost (fuel and activation costs of generators) and processing time between the proposed approach and the exact solution. The economic cost is indicated as a relative value with the exact solution as

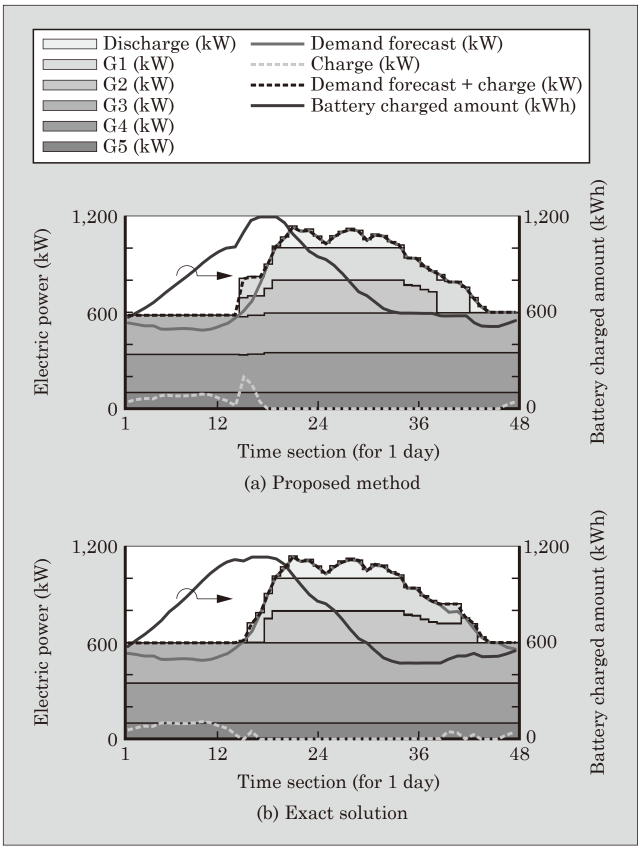

Fig.3 Comparison of supply and demand plans

*1: Pentium4: Trademark or registered trademark of Intel Corporation.

*2: LINGO: Trademark or registered trademark of LINDO SYSTEMS INC.

Table 1 Comparison of economic cost and processing time

Solution	Economic cost	Processing time
Proposed approach	100.31%	13 seconds (0.13%)
Exact solution	100.00%	9,907 seconds (100.00%)

Table 2 Comparison of processing time according to used quantity of generators in the proposed approach

Quantity of generators	5	10	15
Processing time	13 seconds	51 seconds	114 seconds

100%. The economic cost of the proposed approach is only about 0.3% higher than that of the exact solution, although the processing time of the proposed approach is about 1/1000 the exact solution. When comparing the results of the plans, two generators at rest (G1, G2) are activated in the load rise time period to charge the storage batteries with excess electric power in the proposed approach. On the other hand, only one generator (G1) is newly activated in the exact solution. Despite this difference, the results of the plan by the proposed approach meet the constraints, proving that the proposed approach is adequate for practical applications in terms of economic cost and processing time.

(2) Number of generators and processing time

Table 2 shows processing times with different numbers of generators. The processing time is 114 seconds when 15 generators are used, and is considered satisfactory assuming that the supply and demand plan is formulated with a micro grid at intervals of 30 minutes.

3.2 Performance evaluation of load frequency control

To verify the effectiveness of the proposed approach, a system made up of generators, a storage battery, a photovoltaic power generation unit and a load was built on a real-time simulator.

(1) System model

The system model represented a 500 kW system linked to a higher-order system (infinite power supply), and constant control of the power flow was performed at the point of connection. The system model used for the simulation is shown in Fig. 4. The system model consists of two generators, a storage battery, a photovoltaic power generation unit and a load. The supply and demand control system uses the value of the power flow measured at the point of connection as input to control the active power of the generators and the storage battery so that the power flow at the point connection reaches the target value. In this verification, the target value of the power flow at the point of connection was set at 0 kW. Output from the photovoltaic power generation unit and electric power demand used for the verification are shown in Fig. 5. The implementation rate of photovoltaic power generation was assumed to be 30% of the capacity of the system, output from the storage battery to be 30% of output from photovoltaic power generation, and the capacity to be dischargeable for 30 minutes at rated output. In this verification, the model was set to control the SOC of the storage battery to 60%.

(2) Verification results

Using the abovementioned system model, the performance of load frequency control with a function to control the SOC of the storage battery was evaluated on the real-time simulator. The control target of the power flow at the point of connection was set at 3% or less in average error of 5-minute movement. This is slightly stricter than the 30-minutes balancing target where the error is specified as 3% or less between the amount of electric power generated and the amount of load electric power for 30 minutes. Figures 6, 7 and 8 show the verification results. The simulation revealed that the average error of 5-minute movement was up to about 0.1% at the maximum (see Fig. 6) and fulfilled the evaluation target of 3% or less set for control of the

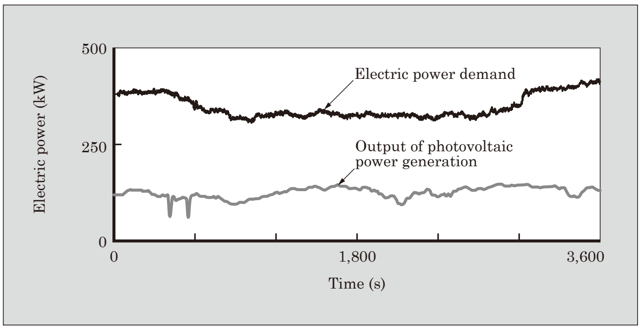

Fig.5 Output from photovoltaic power generation and electric power demand

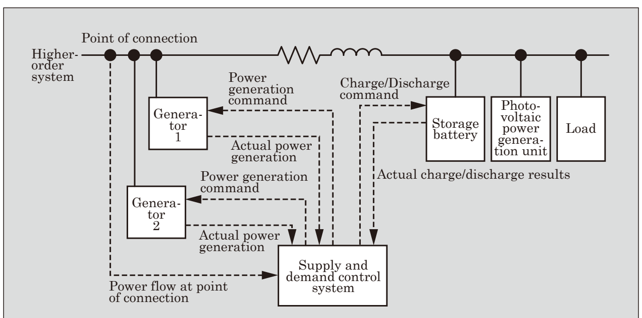

Fig.4 System model

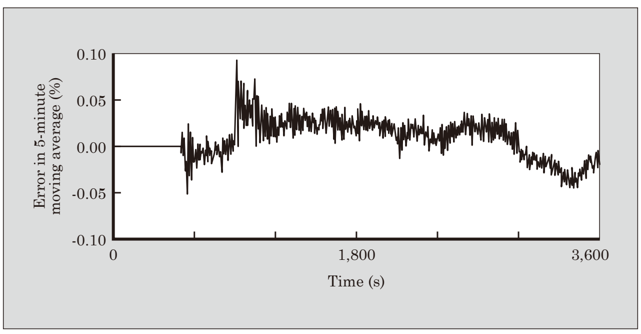

Fig.6 Error in 5-minute moving average

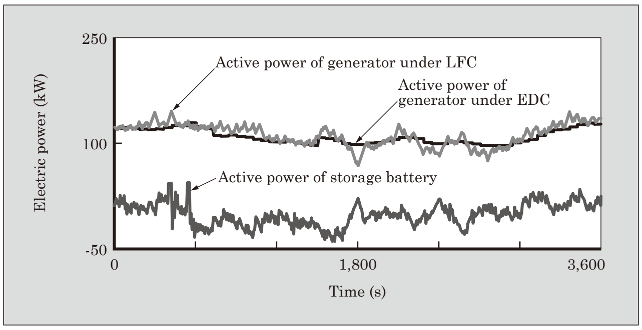

Fig.7 Output from generators and storage battery

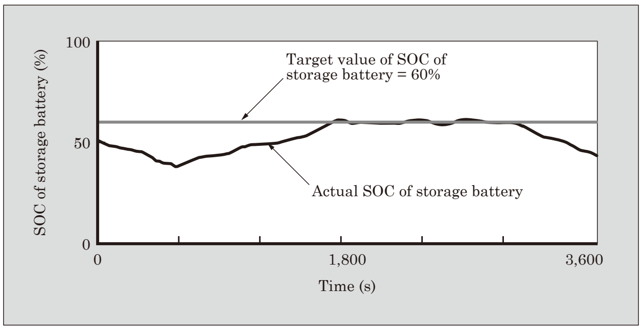

Fig.8 SOC of storage battery

power flow at the point of connection. Next, we will discuss the verification results of the function to control the SOC of the storage battery.

Figure 8 shows that the SOC of the storage battery is controlled to the target value of 60% for the period from 1,800 to 3,000 seconds. The SOC, however, is far from the target value of 60% before 600 seconds and after 3,000 seconds. This is because photovoltaic power generation and the load showed large fluctuation in these time periods and the storage battery carried out its intended function of fluctuation absorption. For the period from 600 to 1,800 seconds, on the other hand, fluctuation in photovoltaic power generation and the load are small, and the generators alone can often deal with these fluctuation. We confirmed that the developed function was effective in bringing the SOC of the storage battery close to 60% while maintaining supply-demand balance on the whole by setting output from the generators higher in this time period and issuing a charge command to the storage battery.

4. Postscript

This paper outlined a hierarchical supply and demand control system for distributed power supply systems, which consists of supply and demand planning, economic dispatching control and load frequency control; and described the verification results of the performance of the system through simulation. We will strive to make this system applicable to actual grid systems.

Reference

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Photovoltaic Power Generation Forecasting Technology for Supporting Energy Management Systems

ISHIBASHI Naoto * **IIZAKA Tatsuya** * **KATSUNO Tohru** *

ABSTRACT

With the aim of realizing a low-carbon society, photovoltaic power generation is being promoted worldwide. The amount of photovoltaic power generation will fluctuate dramatically according to the weather conditions, and may adversely affect the power system if introduced in large quantities. Therefore, it is necessary to forecast the amount of power generation and to control the supply and demand. In order to achieve supply and demand control that is stable, Fuji Electric has developed technology for forecasting the amount of power generation. By predicting the amount of insolation from numerical weather forecast data, and converting that prediction into an amount of power generation based on the properties of photovoltaic modules, the amount of power generation can be forecasted for up to several days in the future in any region of the world.

1. Introduction

Recently, the implementation of a large amount of photovoltaic power generation to electric power systems is planned in response to ongoing efforts toward the realization of a low-carbon society and the experience of electric power shortages after the Great East Japan Earthquake. However, there is fear that photovoltaic power generation affects electric power systems adversely because its output electric power greatly fluctuates depending on meteorological conditions. It is, therefore, important to predict the output electric power of photovoltaic power generation and apply an energy management system (EMS) to the planning and control of generators and storage batteries in order to achieve stable supply and demand control of electric power systems.

This paper describes an output electric power prediction approach developed by Fuji Electric Co., Ltd. and the simulation results of its effectiveness.

2. Overview of Output Electric Power Prediction Technology

Two methods are used to predict the output electric power of photovoltaic power generation: direct prediction, which directly predicts output electric power, and indirect prediction, which predicts the amount of insolation and converts it into output electric power. Direct prediction requires modelling the relationship between output electric power and various factors for each photovoltaic power generation module.

Indirect prediction, on the other hand, has recently become the mainstream of output electric power prediction as a versatile approach. This approach needs to model the relationship between meteorological information and the amount of insolation, and can be classified into the following three methods according to the meteorological information to use:

(1) Method using weather forecasts

This method predicts output electric power based on the weather conditions such as fair and cloudy. It has the drawback of not being able to provide high prediction accuracy because forecasting can be performed only discretely in weather forecasts.

(2) Method using numerical weather forecast data

The Japan Meteorological Agency calculates detailed numerical weather forecast data by dividing the horizontal surface of the Earth into grids at intervals of several kilometers in several dozen layers above the ground. This method uses such numerical weather forecast data to predict output electric power. It is characterized by the advantage that diverse meteorological elements are available for the prediction of output electric power and high prediction accuracy can be thus expected. On the other hand, many meteorological elements must be processed in properly, and advanced statistical processing technology is required.

(3) Method using meteorological numerical simulation

This method calculates the intervals between calculation grids more minutely with numerical weather forecast data as initial values. Although this method has the advantage of being able to predict detailed output electric power, in the unit of several minutes for example, it incurs an enormous cost. It is reported that it takes 2 to 20 hours to calculate output electric power, depending on the calculation conditions, which is far beyond the EMS's calculation updating cycle of 30 minutes.

Since the EMS must control the supply and demand balance, high accuracy and quick calculations

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are indispensable for predicting the output electric power of photovoltaic power generation. Fuji Electric, possessing advanced statistical process technology, developed a photovoltaic power generation prediction function using numerical weather forecast data described in (2) above.

The functional configuration of the output electric power prediction system is shown in Fig. 1. It receives numerical weather forecast data released by the Japan Meteorological Agency and extracts weather forecasts for the target forecast area. These weather forecasts do not include the amount of insolation. Thus, the output electric power prediction system predicts the amount of insolation from weather forecast values and finally converts it into output electric power using the characteristics of the photovoltaic power generation module installed at the target forecast area.

The features of this system are shown below.

(a) The system is applicable in any area of the world.

(b) The system is capable of predicting output electric power up to 192 hours ahead.

(c) The system is capable of predicting output electric power with high accuracy because it uses multiple meteorological elements.

(d) It calculates within one minute, which is faster than the EMS's calculation update cycle of 30 minutes, and therefore the burden on the system is small.

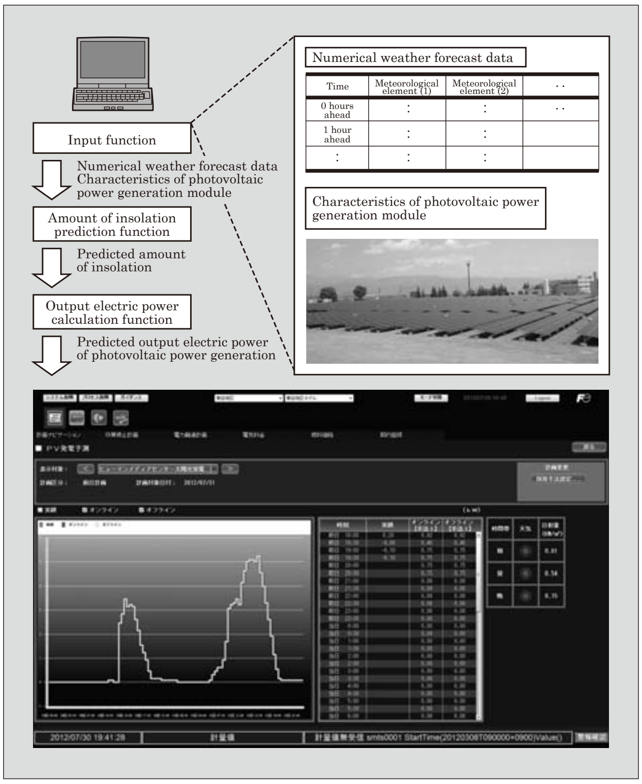


Fig.1 Functional configuration of output electric power prediction system

3. Output Electric Power Prediction Approach

3.1 Numerical weather forecast

Numerical weather forecasts require a huge volume of observation data and calculation capability because the air is covered with a three-dimensional grid of several-kilometer intervals and changes in meteorological elements on grid points, such as the air (temperature, wind velocity, wind direction, atmospheric pressure) and water vapor (relative humidity, amount of precipitation, amount of cloud), are numerically resolved over time. For this reason, numerical weather forecasts are carried out only by the meteorological agencies of major countries. The Japan Meteorological Agency calculates three types of weather forecasts — GSM (global area), GSM (area of Japan), and MSM (area of Japan). As shown in Table 1, the range of forecast, the grid interval, the distribution interval, and the forecast period are different among these types of forecasts. Numerical weather forecasts predict various meteorological elements but do not include the amount of insolation, which is required to predict output electric power.

The output electric power prediction approach developed by Fuji Electric is compatible with all three types of numerical weather forecast data.

3.2 Amount of insolation prediction method

The amount of insolation on the ground is the amount of insolation from the sun attenuated by the air. To predict the amount of insolation with this physical characteristic taken into account, the three steps described in (1) to (3) below were used, as shown in Fig. 2.

(1) Calculation of amount of extraterrestrial insolation

The amount of extraterrestrial isolation means the amount of solar radiation energy before it enters the atmosphere and it can be calculated from the location of the area and the orientation of the sun, as expressed by the equation shown below.

Table 1 Details of numerical weather forecasts

Type of forecast	Range of forecast	Grating interval	Distribution interval	Maximum forecast period
GSM (global area)	Whole world	East to west: 0.5° North to south: 0.5° 17 vertical layers	6 hours	192 hours
GSM (area of Japan)	North latitude: 20 to 50° East longitude: 120 to 150°	East to west: 0.25° North to south: 0.2° 17 vertical layers	6 hours	192 hours
MSM (area of Japan)	North latitude: 22.4 to 47.6° East longitude: 120 to 150°	East to west: 0.05° North to south: 0.0625° 16 vertical layers	3 hours	33 hours

enon in which a proper model cannot be constructed if a strong correlation occurs between the items of input data. When there are many items of input data, as shown in Table 2, the problem of multicollinearity sometimes occurs, resulting in a failure to create a proper model with the multiple regression method. To prevent this problem, we constructed a model using a statistical approach called partial least squares (PLS). PLS has the advantage of being able to handle multicollinearity between explanatory variables and calculate a stable regression coefficient. As PLS deals with multicollinearity, explanatory variables are aggregated into an intermediate variable called a latent variable, and the output variable is expressed by the equation shown below.

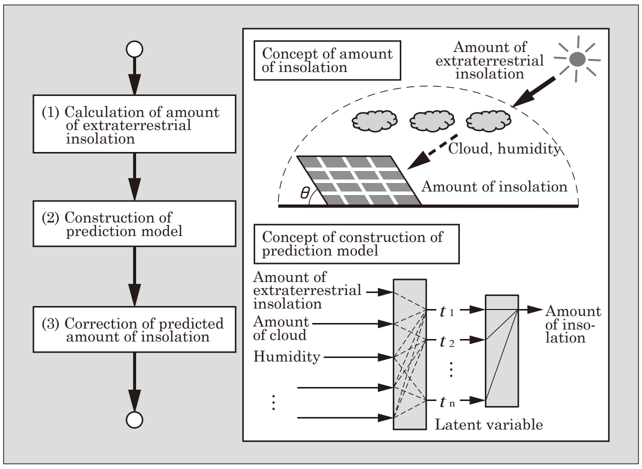


Fig.2 Flowchart for predicting amount of insolation

$$H_0 = I_0 \sin(h) \quad (1)$$

$$\sin(h) = \sin(\delta)\sin(\phi) + \cos(\delta)\cos(\phi)\cos(\omega) \quad (2)$$

(When $\sin(h) < 0$, then $\sin(h) = 0$.)

H_0 : Amount of extraterrestrial insolation
I_0 : Solar constant
h : Solar altitude
δ : Celestial declination
ϕ : Latitude
ω : Hour angle

(2) Construction of a model for predicting the amount of insolation on the ground

The amount of extraterrestrial insolation in the air is affected by many meteorological elements, such as moisture in the air and the amount of cloud. Thus, it is desirable that these many elements be used to predict the amount of insolation on the ground with high accuracy.

Table 2 shows the input and output data used for prediction. The multiple regression method has been the most widely used prediction model, but its prediction accuracy may deteriorate due to the problem of multicollinearity. Multicollinearity is the phenom-

Table 2 Input and output information for model for predicting amount of insolation

Input/Output	Major Item	Detailed item
Input	Amount of cloud	Total amount of cloud Amount of cloud (upper layer) Amount of cloud (middle layer) Amount of cloud (lower layer)
	Humidity	1,000 hPa surface humidity 925 hPa surface humidity 850 hPa surface humidity 700 hPa surface humidity 600 hPa surface humidity 500 hPa surface humidity 400 hPa surface humidity 300 hPa surface humidity
	Amount of insolation	Amount of extraterrestrial insolation
Output	Amount of insolation	Amount of insolation

$$t = (W^{\mathrm{T}} P_{\mathrm{C}})^{-1} W^{\mathrm{T}} x \quad (3)$$

$$y = Q_{\mathrm{C}}\, t = Q_{\mathrm{C}} (W^{\mathrm{T}} P_{\mathrm{C}})^{-1} W^{\mathrm{T}} x \quad (4)$$

x : Input variable
t : Latent variable
y : Estimated output variable
W : Weighting matrix
P_{C} : Coefficient matrix relating to input variable
Q_{C} : Coefficient matrix relating to output variable

(3) Correction of predicted amount of insolation

The predicted amount of insolation on the ground calculated in (2) may deviate from a physical value, although slightly, because of the effect of variation in the data used for the construction of the model. If the predicted amount of insolation deviates from the physically allowable range, correct it to the maximum or minimum amount of insolation. In addition, since the amount of insolation in rainy weather is minimal, whenever rainy weather is expected from the predicted amount of precipitation, correct the predicted amount of insolation to the minimum value.

3.3 Output electric power prediction method

Output electric power can be calculated from the amount of insolation and the efficiency of the solar panels using the following equation:

$$P_{\mathrm{out}} = y P_{\mathrm{rate}} E_{\mathrm{trans}} E_{\mathrm{temp}} \quad (5)$$

P_{out} : Output electric power
y : Amount of insolation
P_{rate} : Rated output
E_{trans} : Transformation efficiency
E_{temp} : Coefficient of transformation efficiency of module at each temperature (module temperature efficiency)

The module temperature efficiency of the solar panels, however, shows a different degree of change depending on the type of solar panel, as shown in Fig. 3. Therefore, the model was made compatible with various types of solar panels by providing a table of module temperature efficiency.

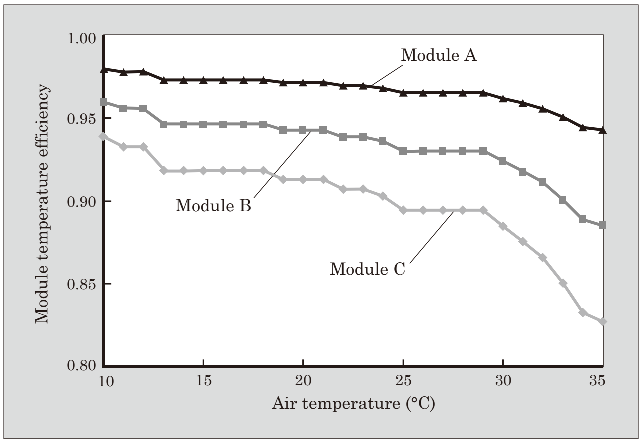


Fig.3 Relationship between air temperature and module temperature efficiency

4. Simulation Example

We conducted a simulation based on the developed output electric power prediction approach. Figure 4 shows a comparison between predicted amounts of insolation and actual values, and Fig. 5 makes a comparison between predicted output electric power generated by photovoltaic power generation and actual values. We used GSM (area of Japan) released at 3 a.m. before sunrise for numerical weather forecast data, and predicted the amount of insolation and output electric power for 24 hours from 4 a.m. to 3 a.m. on the following day. We evaluated them for a full month in April and July, respectively.

The predicted results analyzed were satisfactory on the whole. There was a gap between some predicted values and the corresponding actual values, but we found that it resulted from errors in the distributed numerical weather forecasts themselves. In addition, the prediction accuracy of photovoltaic power generation is shown in Table 3. The prediction accuracy required of photovoltaic power generation is equal to or less than the rated capacity of one generator in terms of preventing adverse effects on the startup and stop of generators. Assuming that the number of generators controlled by the EMS is 10 (number of generators used on a large-size isolated island) and photovoltaic power generation is 30% of the system capacity (implementation target in Japan in 2030), the required prediction accuracy of photovoltaic power generation is 0.33 p.u. (rated capacity of one generator) when the rated output electric power by photovoltaic power generation is 1.0 p.u. Judging from Table 3, this approach is capable of predicting output electric power with an accuracy of 0.2 p.u. at all times, proving its effectiveness in predicting output electric power.

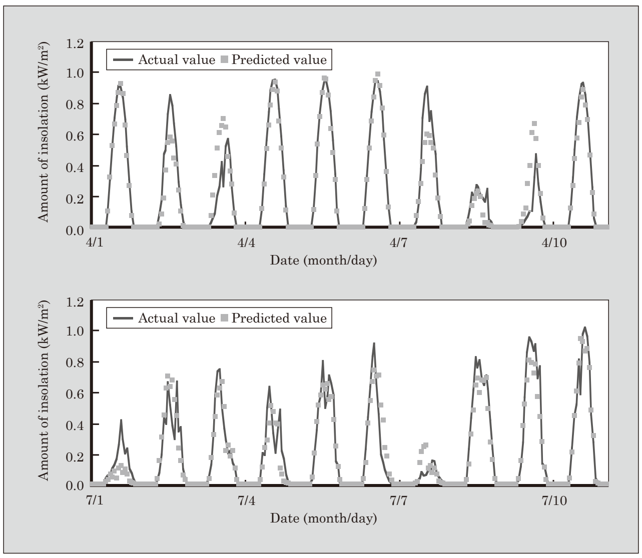


Fig.4 Prediction results of amounts of insolation

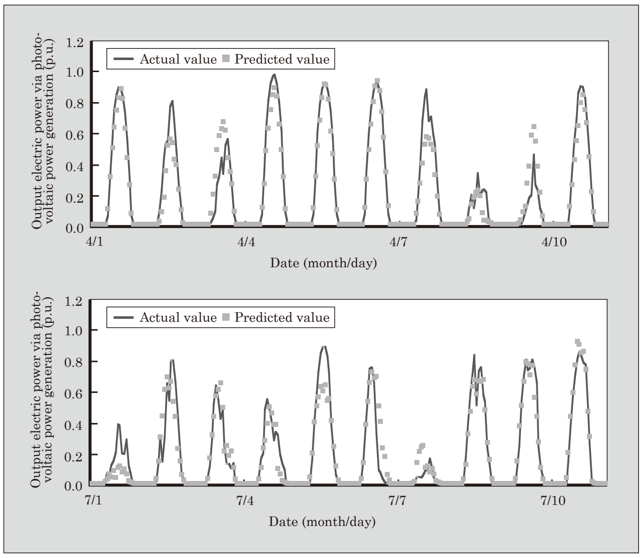


Fig.5 Prediction results of output electric power via photovoltaic power generation

Table 3 Prediction accuracy of photovoltaic power generation

Calculation method	6:00	7:00	8:00	9:00	10:00	11:00	12:00
RMSE (p.u.)	0.01	0.04	0.07	0.12	0.15	0.18	0.20
MAE (p.u.)	0.01	0.03	0.06	0.09	0.12	0.15	0.15

Calculation method	13:00	14:00	15:00	16:00	17:00	18:00	Average
RMSE (p.u.)	0.18	0.16	0.16	0.12	0.08	0.04	0.12
MAE (p.u.)	0.14	0.12	0.12	0.09	0.06	0.03	0.09

RMSE: Root mean square error
MAE: Mean absolute error
p.u.: Per unit method

5. Postscript

In this paper, we described photovoltaic power generation prediction technology that is indispensable for planning the starting and stopping of generators under the control of the EMS. This technology is characterized by a high level of prediction accuracy because it predicts output electric power using many pieces of weather forecast data distributed by numerical weather forecasts, such as the amount of cloud and humidity. It is also applicable in any area of the world as numerical weather forecasts cover the whole world.

This technology, together with technology for predicting output electric power by wind power generation, is undergoing a demonstration test as technology for predicting renewable energy in the "Kitakyushu Smart Community Creation Project." We will strive to improve its prediction accuracy and expand the times covered by its prediction.

“F-MPC PV,” String Monitoring Unit for Photovoltaic Power Generation Systems

MACHIDA Satoshi *

The “Feed-in Tariff Scheme for renewable energy” based on the “Act on Special Measures Concerning Procurement of Renewable Energy Sourced Electricity by Electric Utilities” enforced in July 2012 has bought a rapid increase in places that are introducing photovoltaic power generation facilities.

With photovoltaic (PV) cells, however, the potential induced degradation (PID) phenomenon that causes output degradation and PV panel failure due to reasons including inadequate soldering have reportedly occurred in over 10% of all installations within ten years, and this cannot be overlooked in power generation projects.

Fuji Electric launched “F-MPC PV,” a string monitoring unit for PV power generation systems that measures current and voltage in order to promptly identify a failure of any string, which is a serial/parallel connection of PV panels (see Fig. 1).

1. PV String Monitoring

Figure 2 shows the configuration of a PV power generation system.

In PV power generation, multiple PV panels are connected and the obtained current and voltage are grouped. This group as a unit is called a “string.” The power generated by respective strings is integrated in junction box and connection box, and then transmitted to a power conditioner (PCS). For example, assuming a power generation system of 1 MW at the rated voltage of 500 V DC, with a string being 10 A DC (generally 10 A DC or less), 200 strings are calculated to be required. In general, output of a string with any PV panel failure decreases by 10 to 20% as compared with sound PV panels. A 20% reduction in the output of a string leads to a generation loss of 1 kW, which accounts for about 0.1% with reference to 1 MW for the entire generation system. Because power generated by sunlight varies from hour to hour, changes of this level are difficult to identify with collective power measurement in or after the connection box. However, it is unacceptable for any power generation project to leave 1 kW generation loss unattended for a long time. In addition, it is not easy to regularly inspect 1,000 or more PV panels installed in a vast area of the site and verify their soundness. With this background, there has been growing demand for monitoring the generated power for each string in a junction box.

Fig.1 “F-MPC PV”

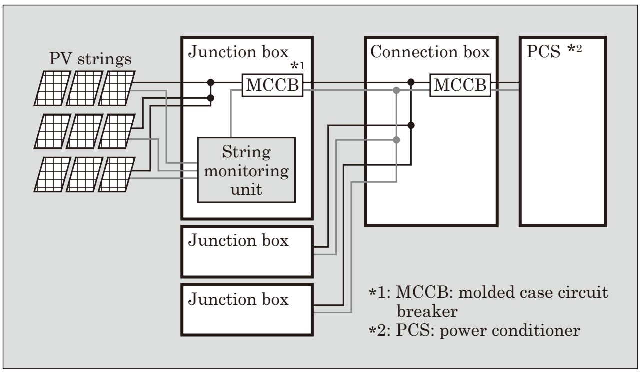


Fig.2 Configuration of PV power generation system

2. Outline of “F-MPC PV”

2.1 Features

F-MPC PV measures the current and voltage for each string and transmits the current and calculated power value to the host monitoring system.

The host monitoring system uses as the reference the average of output current and power by more than one string connected to a junction box and identifies any reduction in the output current or power value for each string as an error, which causes an alarm to be output. This can prompt the facility manager to conduct maintenance. The portion with failure can be promptly detected and located, which helps reduce the generation loss and facility inspection person-hours.

In order to facilitate monitoring by the host, F-MPC PV is equipped with a function of outputting

* Technology & Manufacturing Group, Fuji Electric FA Components & Systems Co., Ltd.

the results of calculations such as a total of all circuits, in addition to the current and power values for each circuit.

2.2 Specifications

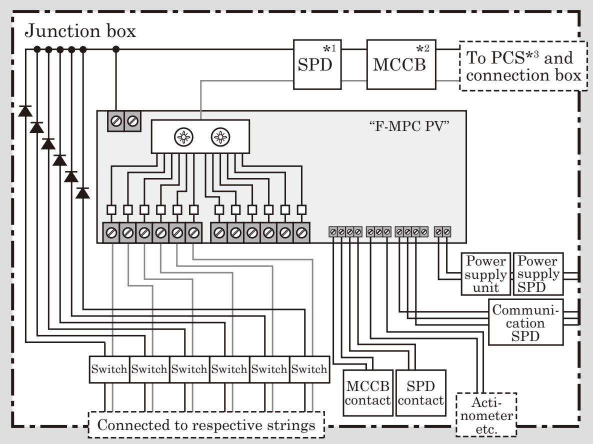
Table 1 shows the specifications of F-MPC PV. Figure 3 shows an example of wiring in a junction box.

(1) Output voltage of 1,000 V DC supported by standard
(2) Rating per string (10 A) × 12 strings measured
(3) Monitoring and measurement function
  (a) Digital input (Di) × 2 circuits: monitoring of molded case circuit breaker (MCCB) open/closed status, surge protective device (SPD) operating status, etc.
  (b) Analog input (Ai) × 2 circuits: connection of 0 to 10 V and 4 to 20 mA inputs with 1 circuit each (non-insulation) and various environmental sensors
  (c) Temperature measurement in junction box × 1
(4) Anti-condensation measures by moisture-resistant coating
(5) RS-485 communication function

Supports MODBUS*1 RTU and "F-MPC-Net" (Fuji Electric specifications) protocols (selectable with switch setting).

Table 1 "F-MPC PV" specifications

Item		Specifications
Measurement specifications	Current	1.0 to 10.0 A DC × 12 circuits, FS ±1%
	Voltage	100 to 1,000 V DC × 1 (common), FS ±1%
	Digital input	24 V DC rated 5 mA × 2 circuits
	Analog input	0 to 10 V and 4 to 20 mA 1 circuit each (non-insulation) Percent value output, FS ±1%
	Temperature	−25 to +75 °C, within ±5 °C
Dimensions		W284×H128×D71 (mm)
Mounting		DIN rail mounting



*1: SPD: surge protective device
*2: MCCB: molded case circuit breaker
*3: PCS: power conditioner

Fig. 3 Example of wiring in junction box

3. Background Technologies

3.1 Environment resistance technology

A junction box, which houses F-MPC PV, is installed outside adjacent to PV panels. While the temperature in the box may reach 70 °C in the summer with strong sun, the box may be exposed to a temperature below zero in the winter. Another fear in a vast field is lightning hazard. In such a severe environment, it operates stably for 10 years or longer and needs to be replaced one time in 20 years, which is a common assurance period of PV panels and purchase price guarantee period of generated power. To realize that, a design approach with high environmental resistance has been applied based on the technology for commercialization of measurement and monitoring equipment used for cubicles in power receiving and distributing systems and electric vehicle chargers. Electronic components for in-vehicle use that feature wide allowable temperature ranges have been adopted and electrolyte capacitors that significantly affect product lifespan have been eliminated.

As a measure against lightning hazard, the withstand voltage and lightning resistance performance levels of a unit itself have been improved in the main circuit that measures the output current and voltage. In addition, use of the time-proven SPD for low-voltage power supply and communication circuits and SPD for main circuit that supports 1,000 V DC in combination can strengthen the lightning resistance performance of the entire system.

3.2 Measurement technology in view of host monitoring system

On the host monitoring system, in addition to ordinary measurement for grasping the conditions, ability to identify errors in a string has been provided by adding the calculation functions as described below.

(a) Current power value (each string×12, total of all strings)
(b) Maximum, minimum and average values in period (each string×12, total of all strings, maximum and minimum strings)

The maximum, minimum and average values in a period are very effective data for grasping rapid changes in the respective measurement points in a monitoring system, and Fuji Electric has long provided its power management equipment with this feature. The data collected by the host monitoring system at intervals of a few tens of seconds to a few minutes show the current values as of the timing of communication.

In order to grasp the conditions other than as of the timing of communication, F-MPC PV uses the current values measured every 100 ms as the basis to out-

*1: MODBUS: Trademark or registered trademark of Schneider Automation, Inc. of France.

put the maximum, minimum and average values in a certain period (selectable between 1, 5, 10, 15 and 30 minutes). This makes it possible to grasp the maximum and minimum values in the same way as a data logger with high-speed sampling.

The host monitoring system can easily identify any "string with a generation loss" based on these measured data.

Launch time

August 2013

Line-Up Expansion of Compact Inverter "FRENIC-Mini (C2S) Series"

MIZUNO Osamu *

The compact inverter "FRENIC-Mini (C2S) Series" has been expanded with the market launch of the three-phase 400 V and single-phase 200 V models. Figure 1 shows the line-up of models of the Fuji Electric inverter "FRENIC Series."

Standard inverters are used in wide-ranging fields including conveyors, fans and various processing machines, and addition of new functions and improvement of performance have been in demand. In particular, there have been increasing needs for functions including an ability to drive synchronous motors, which are attracting attention with their ease of use and energy saving effect.

The FRENIC-Mini (C2S) Series is a successor to the "FRENIC-Mini (C1S) Series," which was launched in 2002. The three-phase 200 V models have been released and the three-phase 400 V and single-phase 200 V models have now been added to the line-up. This expansion is intended to meet the needs mentioned above and pursue improved ease of use and replacement for customers.

1. Features

The characteristics of the FRENIC-Mini (C2S) Series are as described below. Figure 2 shows the external appearance of the products.

(1) Support for power supplies of three-phase 200 V, three-phase 400 V and single-phase 200 V
(2) Same dimensions as those of the FRENIC-Mini (C1S) Series-allowing easy replacement of the existing series
(3) RS-485 communication interface provided as a standard
(4) Ability to drive synchronous motors
(5) Design service life improved to 10 years

Setting conditions: average ambient temperature 40 °C, load factor 80% and availability factor 50%

(6) Enhanced maintenance functions for improved ease of use (see Table 1)
(7) Remote keypad with USB (optional)

Easy configuration of various settings and monitoring of the inverter have been made available from the inverter support loader software on the PC connected via a remote keypad with USB (see Fig. 3).

(8) Enhanced performance

(a) Adoption of dynamic torque vector control

Fuji Electric's proprietary dynamic torque vector control, which is well-established with high-end models, has been adopted to achieve a stable torque (200% at 3 Hz) even at a low speed (see Fig. 4). This allows the product to be used for a variety of applications including machine tools and conveyance machinery, which require high starting torques.

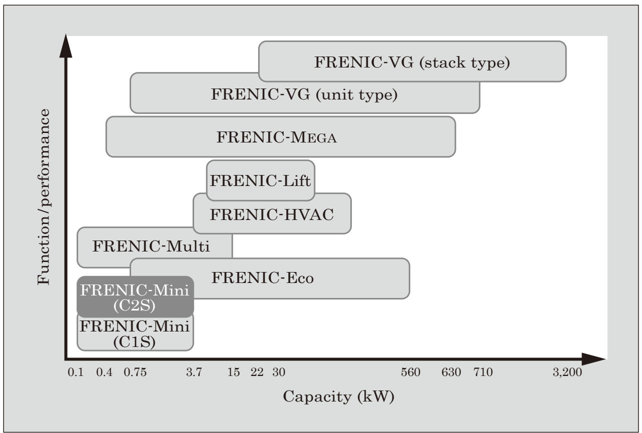


Fig.1 Fuji Electric inverter "FRENIC Series" line-up of models

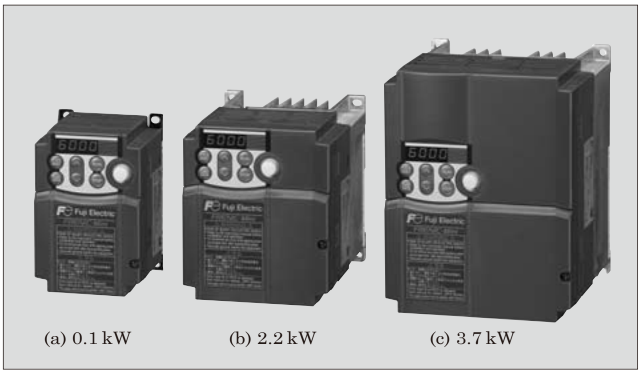


Fig.2 "FRENIC-Mini (C2S) Series"

Table 1 Improved maintainability

Function	Description
Mock alarm	Outputs dummy on-off alarm signals
Cumulative startup count	Counts the cumulative number of starts and stops
Cumulative motor run time	Monitors the motor operation time
Input watt-hour	Measures the on-off integral power
Trip history	Stores and displays up to four recent trips

* Power Electronics Business Group, Fuji Electric Co., Ltd.

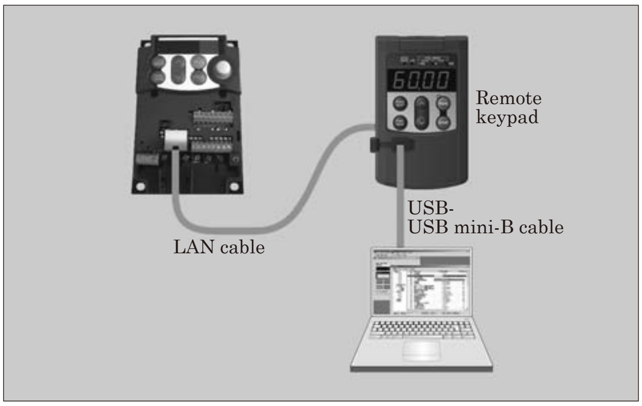


Fig.3 Remote keypad with USB (optional)

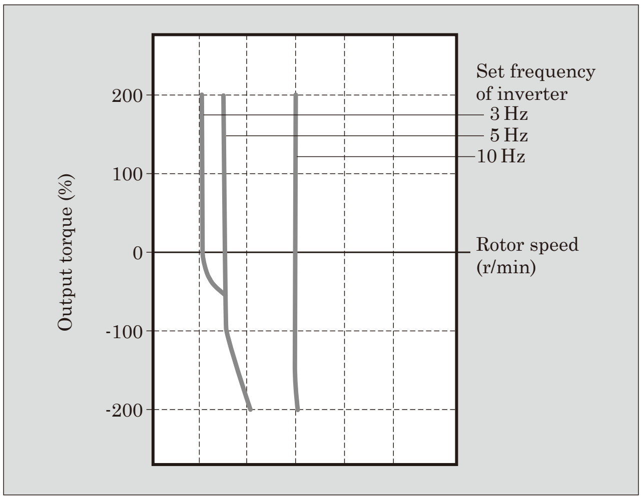


Fig.4 Speed - torque characteristic

(b) CPU among the fastest in class

The CPU provided is among the fastest of those of inverters in the same class, doubling the computation and processing capacity of the conventional inverters and has improved the control performance.

(9) Wide-ranging variety

As with the FRENIC-Mini (C1S) Series, models with built-in electromagnetic compatibility (EMC) filter and for single-phase 100 V are being developed to expand the line-up. This, together with a wide variety of input power supply systems, increases applications in various areas and environments (see Fig. 5).

	Capacity (kW)	0.1	0.2	0.4	0.75	1.5	2.2	3.7
Standard	Three-phase 200 V/0.1 to 3.7 kW	■	■	■	■	■	■	■
	Three-phase 400 V/0.4 to 3.7 kW			■	■	■	■	■
	Single-phase 200 V/0.1 to 2.2 kW	■	■	■	■	■	■	
	Single-phase 100 V/0.1 to 0.75 kW (under development)	■	■	■	■			
EMC filter built-in type (under development)	Three-phase 200 V/0.1 to 3.7 kW	■	■	■	■	■	■	■
	Three-phase 400 V/0.4 to 3.7 kW			■	■	■	■	■
	Single-phase 200 V/0.1 to 2.2 kW	■	■	■	■	■	■	

* Product lines vary by region.

Fig.5 Product line-up

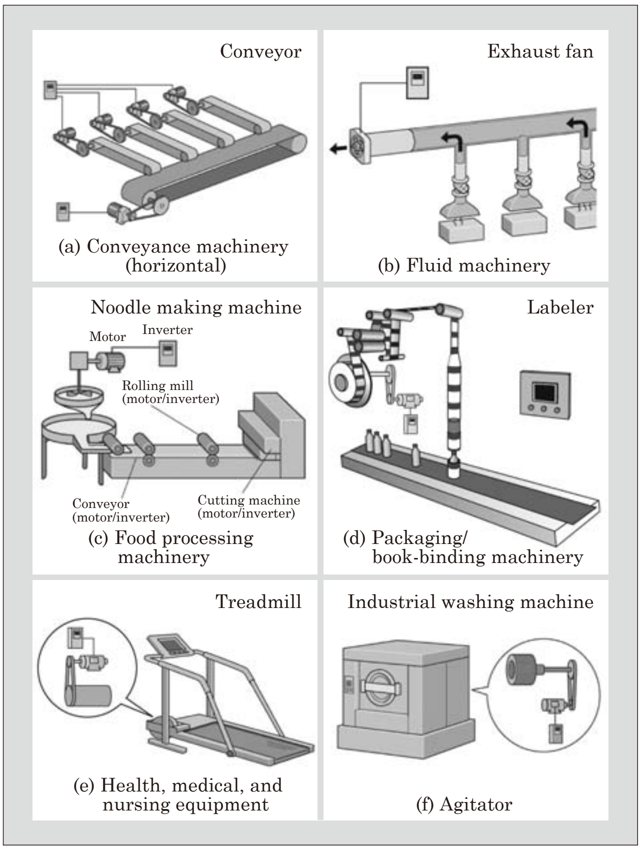


Fig.6 Application examples

2. Application Examples

Figure 6 shows major application examples. In addition to small machines for industrial and business use, the inverters can be used for various applications including food processing machines; health, medical, and nursing equipment; and agitators. This allows them to meet the needs for performance improvement, system compatibility, and energy saving of machines and equipment.

3. Background Technologies

3.1 Built-in RS-485 communication interface

The RS-485 communication interface (RJ-45 connector), which was optional with the existing FRENIC-Mini (C1S) Series, is built-in as standard, and this allows a remote keypad (optional) to be connected with a LAN cable (see Fig. 7).

3.2 Driving of synchronous motors

The ability to drive synchronous motors is provided as standard. Sensorless V/f control is adopted as the control system and presetting the armature resistance and inductance allows the motors to be driven in the optimum state. In addition, the overcurrent protection level can be set to prevent synchronous motors from demagnetizing due to overcurrent.

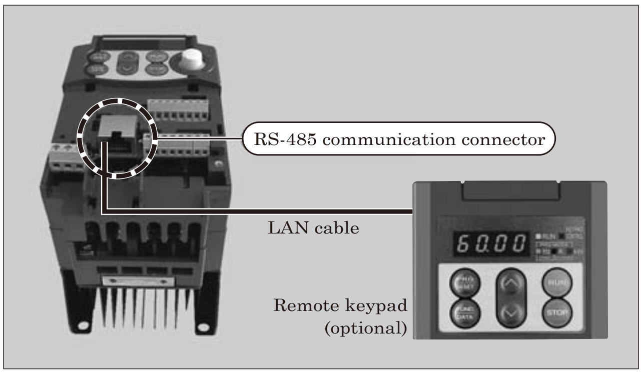


Fig.7 RS-485 communication interface and remote keypad

3.3 Enhancement of functions

For application to various uses, some functions that were provided only for high-end models have been added.

An alarm history function allows the four most recent alarms to be stored, and the time required for restoring equipment can be reduced by referring to detailed information (23 items in total) about the conditions of an alarm that occurred. Table 2 shows an excerpt of the detailed information.

In addition, the inverters can output a brake signal, allowing them to control the timing of braking and releasing, which was done by an external PLC and the like up to now. This makes it easy to use the product for vertical conveyance applications.

On top of this, functions including limited direction of rotation, Mock alarm generation and low water volume stop in PID control are provided to allow the product to be used for applications that were previously served only by high-end models.

Table 2 Available detailed information about conditions of alarm that occurred (excerpt)

Output frequency	DC link bus voltage
Output current	Maximum temperature of heat sink
Output voltage	Terminal input/output signal status
Torque calculation value	Number of consecutive occurrences
Set frequency	Overlapping alarm
Direction of operation	Overlapping alarm (accelerating, decelerating, DC braking, etc.)
Cumulative run time	
Cumulative startup count	

4. Areas of Rollout

The compact inverter “FRENIC-Mini (C2S) Series” conforms to CE marking and UL Standards. This series will be rolled out to various countries around the world including Japan, China and countries in Asia, North America and Europe.

Launch time

For China: Already available
For Asia: Already available
For Europe: Already available
For North America: January 2014

Product Inquiries

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Residential Fire, Gas and Carbon Monoxide Alarms "KN-95"

KAMIOKA Tsuyoshi * WATANABE Tadashi *

We have launched "KN-95," a residential fire (smoke type), gas and CO alarm realizing a low profile and reduced power consumption. A gas alarm is a product that alerts the user with a warning sound and lamp indication in the event of a gas leak. Recently, gas alarms have been undergoing functional enhancement to offer multiple detection functions, so that they can detect carbon monoxide (CO) in combustion exhaust gas and fire as well as gas leaks. In addition, there have been demands to give them a lower profile for ease of installation and a good appearance, and for reduced power consumption from the perspective of conserving energy.

KN-95 has not only integrated a new function of a fire alarm that works by detecting smoke but also achieved a 20% lower profile and 50% lower power consumption from the conventional products. It helps ensure the safety of gas consumers and contributes to gas utilities' efforts for realizing a safe and secure society as well.

1. Features

Figure 1 shows the external appearance and Table 1 shows the specifications of KN-95.

(1) Low-profile design (industry's lowest profile)

With a thickness of 41 mm, a profile that is approximately 20% lower than the conventional products has been achieved. The white-based color scheme provides a clear design that matches a variety of kitchens.

Fig.1 "KN-95"

Table 1 "KN-95" specifications

Item		Fire	Gas leakage	Imperfect combustion
Detection target		Smoke	City gas (12 A/13 A)	CO
Detection system		Photoelectric smoke sensor	Semiconductor gas sensor	
Alarm concentration	Advisory	5 to 15%/m	Approx. 1/100 of lower explosive limit	25 to 300 ppm
	Alarm		1/4 or lower of lower explosive limit	550 ppm or lower
External output		Fire linkage I/O for mutual sounding	Voltage output (monitoring) 6 V Gas leakage alarm 12 V CO detection alarm 18 V Failure diagnosis 0 V	

(2) Reduced power consumption (industry's lowest power consumption)

Power consumption during monitoring is 0.5 W (1.2 W during alarming), which is a reduction of approximately 50% from the conventional products.

(3) Improved discrimination of lamp indication

A wide red lamp indication is adopted for the fire alarm providing easy differentiation from other types of alarm.

(4) Easy initial inspection

The automatic initial inspection function, which allows inspection without the need for blowing gas at the time of installation, is provided to facilitate initial inspections.

2. Application Examples

City gas (consisting mainly of methane gas), which is a detection target, has a lower specific gravity than air and for this reason CO and smoke generated by a fire collect near the ceiling. Accordingly, KN-95 is installed at a high location in the kitchen of general gas consumers (see Fig. 2).

For gas and CO alarms, KN-95 is equipped with a voltage external output function, which allows linked operation with the central monitoring and control system and a microcomputer gas meter. For fire alarms, linked operation with a fire alarm equipped with an external output function is possible, and this allows fire linkage alarms to be activated by KN-95 in response to

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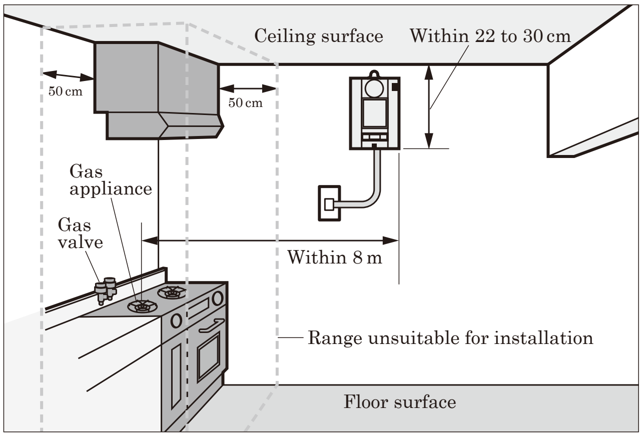


Fig.2 Example of installation of "KN-95"

outputs from other fire alarms installed in places like a bedroom or living room.

KN-95 sounds an audible alarm in two stages according to the level of emergency. In the initial stage of detection of a fire, it sounds "woo, woo, beep, beep, the fire alarm has gone off, check and see." If the fire detected status continues, it sounds another message, "woo, woo, beep, beep, fire, fire."

3. Background Technologies

3.1 Smoke detection technology

Figure 3 shows the external appearance of the smoke sensor. The smoke sensor is of a photoelectric type and has light-emitting and light-receiving elements in a dark box with all external light cut off. An increase in the amount of light scattered by smoke particles along with an increase in the concentration of smoke is detected by the light-receiving element and a detection signal exceeding the threshold is judged as a fire.

The fine mesh along the circumference of the dark box and sensitivity-adjustment function can successfully reduce the incidence of false alarms. The fine mesh lets any smoke that needs to be detected to pass through but prevents entry of insects and dust, which cause false alarms. The sensitivity-adjustment function constantly adjusts the sensor sensitivity, thereby reducing the incidence of false alarms due to soiling and aging.

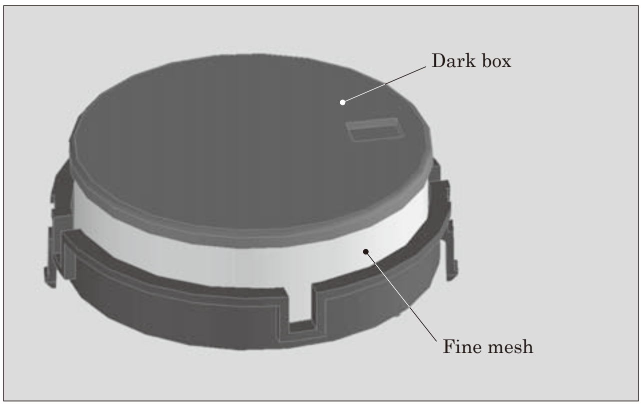


Fig.3 Smoke sensor

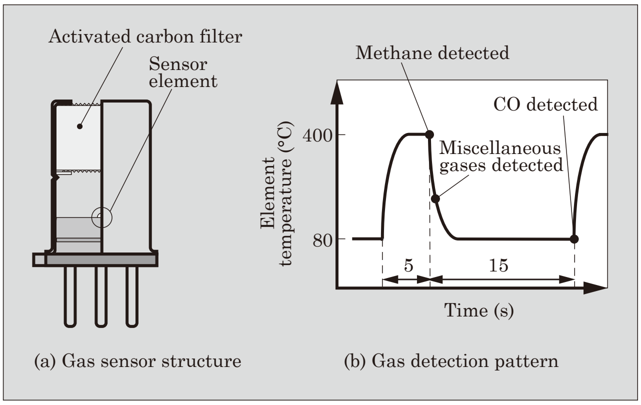


Fig.4 Gas sensor structure and gas detection pattern

3.2 Gas detection technology

KN-95 is equipped with a gas sensor capable of detecting both city gas (methane gas) and CO gas. As shown in Fig. 4, the temperature of the gas sensor element is controlled alternately between high (400 °C) and low (80 °C) temperature for the gases to be detected. It detects city gas with the element at the high temperature and CO at the low temperature. At an intermediate temperature, miscellaneous gases that may cause false alarms are detected, and this reduces the incidence of false alarms due to miscellaneous gases. The sensor cap is equipped with an activated carbon filter for absorbing and removing substances including alcohol generated during cooking to suppress false alarms. By taking these measures, false alarms are reduced to achieve high reliability.

3.3 Fire detection technology (grasping of smoke and CO generation behavior)

Real fire tests have been conducted using KN-95 with futon (bedclothes) smoldering (flameless combustion) fires, stove fires, deep frying oil fires and such like. Figure 5 shows an example of smoke and CO concentrations during a futon smoldering fire. It indicates that, in a smoldering fire, which occurs in the initial stage of a fire, the CO concentration rises before that of smoke. Meanwhile, the smoke concentration rises before that of CO in stove and deep frying oil fires. An alarm capable of detecting both smoke and CO like KN-95 can reliably sound an alarm in the initial stage of a fire.

3.4 Approach to high reliability

Alarms are security apparatus that must reliably function in the unlikely event of an emergency and are required to have high reliability.

KN-95 ensures high reliability not only of the sensor itself but also as a product with traceability and failure self-diagnosis function of the alarm.

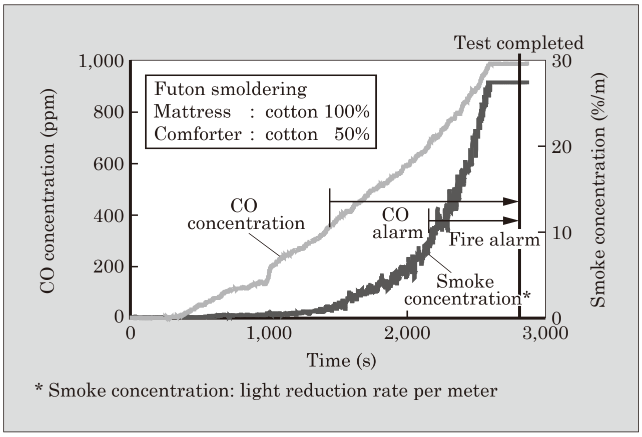


Fig.5 Example of smoke and CO concentrations during futon smoldering fire

(1) Traceability

Information on the manufacturing history such as the component lot, worker and facility in use is managed for each unit to raise the quality of the entire manufacturing process. If any abnormality is found, the cause and extent of the impact of the abnormality can be promptly and accurately identified.

(2) Failure self-diagnosis function

Self-diagnosis is conducted regularly for automatic testing to confirm normal operation of the alarm. Major components including the power circuit in addition to the smoke and gas sensors are diagnosed and the user is notified of any failure found with a failure alarm.

Vacuum Circuit Breaker Fixed-Type “MULTI.VCB”

OKAZAKI Takayuki *

Among high-voltage utility customers who receive power from the 6 kV system in Japan, vacuum circuit breakers (VCBs) are widely used as the main circuit breakers. In particular, most the cubicle-type, high-voltage, power receiving units specified in JIS C 4620 have panel-fixed VCBs and are often installed on the roofs of buildings and outside of stores as well as indoors. This means they need to have a high performance in a severe environment containing such as dust and/or high humidity.

To deal with these issues, we have developed and launched a new fixed-type high-voltage vacuum circuit breaker “MULTI.VCB.” Our aim was to improve its environmental resistance and reduce its life cycle cost including maintenance, introduction and replacement costs. Figure 1 shows the external appearance and Table 1 shows the specifications.

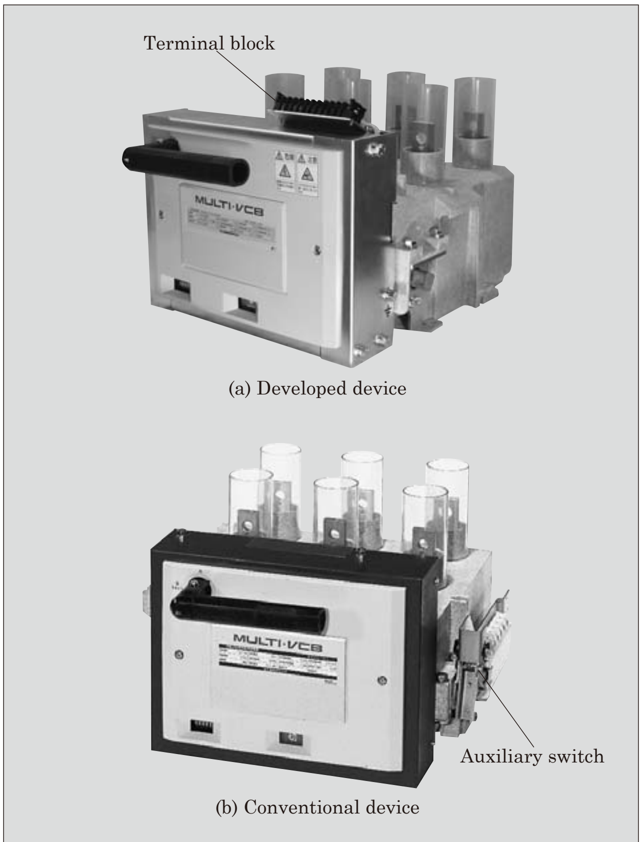


Fig.1 Fixed-type “MULTI.VCB”

* Technology & Manufacturing Group, Fuji Electric FA Components & Systems Co., Ltd.

Table 1 Fixed-type “MULTI.VCB” specifications

Model	HA08A-H	HA12A-H
Installation	Board type, Cubicle type, Portable type	
Closing operation	Manual-spring	
Rated voltage	3.6/7.2 kV	
Rated breaking current	8 kA	12.5 kA
Rated current	400 A	600 A
Power-frequency withstand voltage	22 kV 1 min	
Lightning impulse withstand voltage	60 kV	
Frequency	50/60 Hz	
Making current (crest value)	20 kA	31.5 kA
Short-time current 2 s	8 kA	12.5 kA
Operating duty	A: O*1-1 min-CO*2-3 min-CO B: CO-15 s-CO	
Opening time	0.035 s	
Breaking time	3 cycles	
Operation durability	1,000 times	
Auxiliary switch	2a+2b (3a+3b max.)	
Tripping system	Shunt trip or Current trip	
Mass	Board type, Cubicle type: 26 kg Portable type: 27 kg	
Conforming Standard	JIS C 4603 JEC 2300	

*1 O: Opening operation
*2 CO: Closing operation followed immediately by opening operation.

1. Features

1.1 Reduced life cycle cost

(1) Extension of lubrication cycle (halving of lubrication frequency)

To maintain the lubricity of the grease used in the actuating mechanism, regular lubrication is required. With the developed device, the lubrication cycle, which was conventionally three years, has been extended to six years by using high-performance fluorinated grease with resistance to aging degradation, successfully reducing the lubrication frequency by half.

(2) Reduced lubrication time

To reduce the burden of lubricating the actuating mechanism, which takes time during inspections, this product has been given a structure to allow lubrication from the front. In addition, the number of lubrication points has been reduced from 13 to 6 points.

1.2 Improved environmental resistance of insulation

(1) Insulation frame

The phase-to-phase insulation structure of the insulation frame that houses the vacuum interrupter composing the main contact has been revised in order to improve the tracking resistance.

(2) Main circuit protective cover

The material of the main circuit protective cover, provided for covering the openings of the insulation frame, has been changed from the conventional polycarbonate to polyester resin, which is the same as the material used in the insulation frame. This has improved the tracking resistance and mechanical strength. The number of openings has also been reduced to help prevent dust and droplets entering the vacuum interrupter part from outside.

1.3 Improved ease of use

(1) Streamlining of panel cutout shape

In order to simplify panel cutting for installing the VCB on a cubicle-type, high-voltage power receiving unit, the amount of panel cutting required other than for securing the device to the main unit has been reduced to one square hole, which has successfully halved the number of cuts and made it easy to lubricate this product from the front.

(2) Terminal block supplied as standard

For wiring, the conventional device required direct wiring with auxiliary switch terminals, which are laid out differently depending on the installation, and leads from the main unit (current tripping system). With the developed device, wiring has been consolidated and a common terminal block independent of the installation is provided at the top of the actuator frame, which has improved wiring workability (see Fig. 1 (a)).

1.4 Mounting compatibility

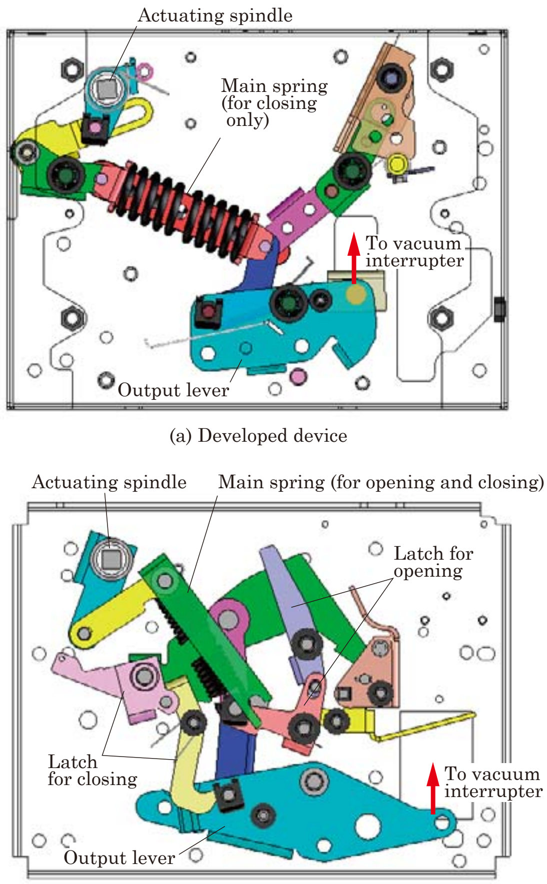
The mounting dimensions of the main unit and the layout of the main circuit are compatible with the conventional device. This allows the developed device to be mounted on a panel with the conventional device mounted, without the need for additional panel cutting.

1.5 Miniaturization

The auxiliary switch, which was provided outside the main unit, has been housed in the actuator to realize miniaturization. Volumes among the smallest in the industry have been achieved with the board and cubicle types.

2. Background Technologies

In order to reduce the work time required for inspection after introducing the equipment, a mechanism structure where the number of lubrication points themselves has been reduced must be provided. To achieve miniaturization while maintaining compatibility with the conventional device, a space must be ensured for housing the auxiliary switch, which was provided outside the main unit, in the actuating mechanism.



(a) Developed device

(b) Conventional device

Fig.2 Actuation link mechanism

To that end, we have fundamentally revised the design concept of the conventional actuating link mechanism to reduce the number of components and streamline the actuating mechanism (see Fig. 2).

While the main spring of the conventional device has an actuation function for both opening and closing, the spring of the developed device only functions for closing. To realize the switching characteristic as a VCB, the conventional device used latches to hold the link mechanism until immediately before closing or opening. Meanwhile, the developed device is provided with a structure that uses spring return action for closing or opening, and this has eliminated the need for latches for closing and opening.

To specifically study the actuating mechanism, we have made use of 3D mechanism analysis linked with 3D CAD (see Fig. 3). With the new and old structures, we have simulated the closing, opening and trip operations with a simulated manual handle to verify and

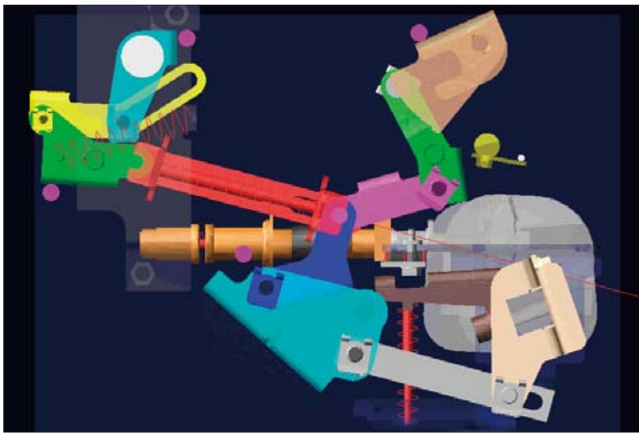


Fig.3 3D mechanism analysis model

modify the actuation load characteristics and switching speed, thereby optimizing the structure.

To examine the actuation load characteristics, we have used a simplified model of the actual device for sensory evaluation on operational feel to identify the optimum actuation characteristics, and provided tuning based on a simulation, which has successfully led to a product with an excellent operational feel.

Launch time

May 2013

"MICREX-SX SPH3000MG" with Built-in High-Speed and Large-Capacity Network

NYUI Naoki * **YUO Yukiteru** ‡

At manufacturing plants for steel, paper and the like, high-speed control and large-capacity data acquisition capability are required in order to improve product quality and achieve efficient operation.

To meet these requirements, Fuji Electric has developed the "SX-Net," a high-speed, large-capacity control network, the "MICREX-SX SPH3000MG" controller (see Fig. 1) that is equipped with the SX-Net and supports high-speed large-capacity networks, and the "SX-Net board" (see Fig. 2), which is a PCI Express*1 personal computer interface board that supports SX-Net.

This paper describes features and an example application of the SX-Net and MICREX-SX SPH3000MG.

1. Features

SX-Net specifications are listed in Table 1. SX-Net is a control level network that connects controllers and PCs and has the following features.

Table 1 SX-Net specifications

Item		Specification
Number of connections		126
Scan cycle		0.5 to 30 ms (on a 0.5 ms basis)
Transfer mode		Common memory, Message transmission
Common memory function	Data area	128 K words (64 words × 2,048 blocks)
	Area definition	64-word fixed block selection method

(a) Proprietary protocol based on Gigabit Ethernet*2
(b) Common memory-type high-speed data transfer (8K words/ms)
(c) PC connection via PCI Express board
(d) Data acquisition throughput that is ten times faster than before (1 K words/ms)

The MICREX-SX SPH3000MG, an extension of the existing "MICREX-SX series," is a controller for high-speed large-capacity networks and has the following features.

(a) Built-in SX-Net
(b) Built-in "E-SX bus" for high-speed high-accuracy motion control {input refresh performance is 512 words/ms (in the case of 32 stations)}
(c) Synchronous execution function for SX-Net, E-SX bus and user application programs

Fig.1 "MICREX-SX SPH3000MG"

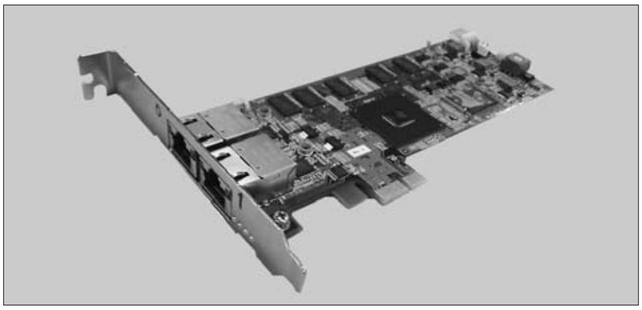


Fig.2 "SX-Net board"

2. "SX-Net" and "MICREX-SX SPH3000MG" Application Example

Figure 3 shows an example application to a steel processing line. This example is configured from a drive system that drives several hundred motors, a large number of solenoid valves, and detectors and monitoring equipment. To convey steel strips at the appropriate speed and tension, high-accuracy equal speed control, tension control, load balance control and the like are required. The control cycle of the control system is several tens of milliseconds, and the number of inputs and outputs exceed 40,000. Requirements of such as system are as follows.

* Industrial Infrastructure Business Group, Fuji Electric Co., Ltd.
‡ Corporate R&D Headquarters, Fuji Electric Co., Ltd.

*1: PCI Express is a trademark or registered trademark of PCI-SIG.
*2: Ethernet is a trademark or registered trademark of Fuji Xerox Co., Ltd.

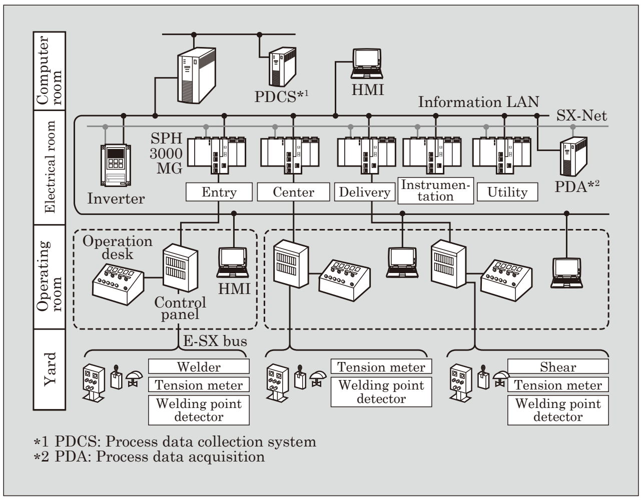


Fig.3 Example application to steel processing line

(a) Scalability that can support the system size
(b) High-speed communication among distributed devices
(c) High-speed large-capacity acquisition of control data

The MICREX-SX SPH3000MG is able to utilize the assets of the MICREX-SX series that have been developed to date, and can utilize various existing I/O modules and communication modules to construct flexible systems.

Moreover, systems that require distributed controllers can be configured easily through leveraging the large-capacity data transfer capability and high-speed transfer performance of the SX-Net. Control data on the SX-Net can be referenced directly by a personal computer via the SX-Net board, and can be used in the analysis and control of the overall system.

3. Technical Background

3.1 "SX-Net" high-speed large-capacity network

SX-Net uses Gigabit Ethernet and employs Fuji Electric's common memory-type proprietary protocol. The physical layer supports Ethernet connectivity, and protocols are provided in software to enhance the portability and ease of maintenance.

The following technology has been incorporated into the SX-Net.

(1) Time-deterministic control network based on time division

SX-Net is a time-deterministic network that performs sequential communication processing according to a preset cycle. A local station participating in the SX-Net can broadcast local station data to the addresses of all other SX-Net participant stations at the transmission timing assigned to that local station. As a result, applications at each station can reference the data of all other stations, and controller applications can be designed without awareness of the network. The data update cycle of the SX-Net can be selected within the range of 0.5 to 30 ms in accordance with the number of stations and the common memory data capacity, and high-speed data exchanges with a data transfer rate of 8 K words/ms can be achieved.

The size of common memory data transmitted and received by broadcasting divided in blocks of 64 words is maximum 128 K words (2,048 blocks) available.

(2) Timer synchronization function

To realize the functionality of paragraph (1) above, the master station transmits to each station on the SX-Net a synchronization frame to correct the transmission timing.

Based on this synchronization frame information from the master and the reception timing thereof, each station on the SX-Net corrects for any deviation from the cycle of the master station.

3.2 "E-SX bus" for motion control

The E-SX bus built-into the MICREX-SX SPH3000MG is able to handle large quantities of input and output data due to ultra high-speed and high-accuracy synchronous transmissions. The main features are listed below. The E-SX bus is controlled with a Fuji Electric proprietary LSI.

(a) Supports large-scale configurations of up to 238 connected stations with a total length of 1 km and a station spacing of 100 m, and a maximum I/O size of 4,096 words
(b) High-speed refresh of 67 words/0.25 ms, 512 words/1 ms (in the case of 32 stations)
(c) The output timing of 32 stations is highly synchronized in accuracy of 1μs.

3.3 High-accuracy synchronization function for communication and control

The MICREX-SX SPH3000MG is a controller for high-speed large-capacity networks, and the above-mentioned SX-Net and E-SX bus are mounted on the front of it, while the SX bus, which is the existing backbone bus, is mounted on its back. Making the most of its integrated modular structure, the MICREX-SX SPH3000MG realizes a synchronization function for the SX-Net, the E-SX bus and the computation cycle (see Fig. 4).

The data update cycle of the SX-Net can be set to integer multiples of the control cycle of the E-SX bus. A MICREX-SX SPH3000MG connected to the SX-Net corrects the control timer of the E-SX bus according to a synchronization frame sent from the master station. As a result, the SX-Net, E-SX bus and application computation cycles can all be synchronized, and the output timings of multiple devices controlled by different controllers can be synchronized with an accuracy of ±80 μs.

With these synchronization functions, large-scale high-accuracy applications that require the synchronous processing of control timings and control data throughout an entire system can be realized easily

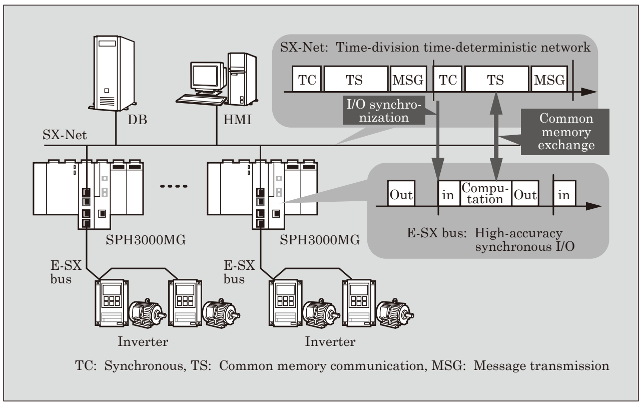


Fig.4 Synchronizing function for "SX-Net," "E-SX bus" and computation cycle

with distributed controllers.

Launch time

October 2013

Product Inquiries

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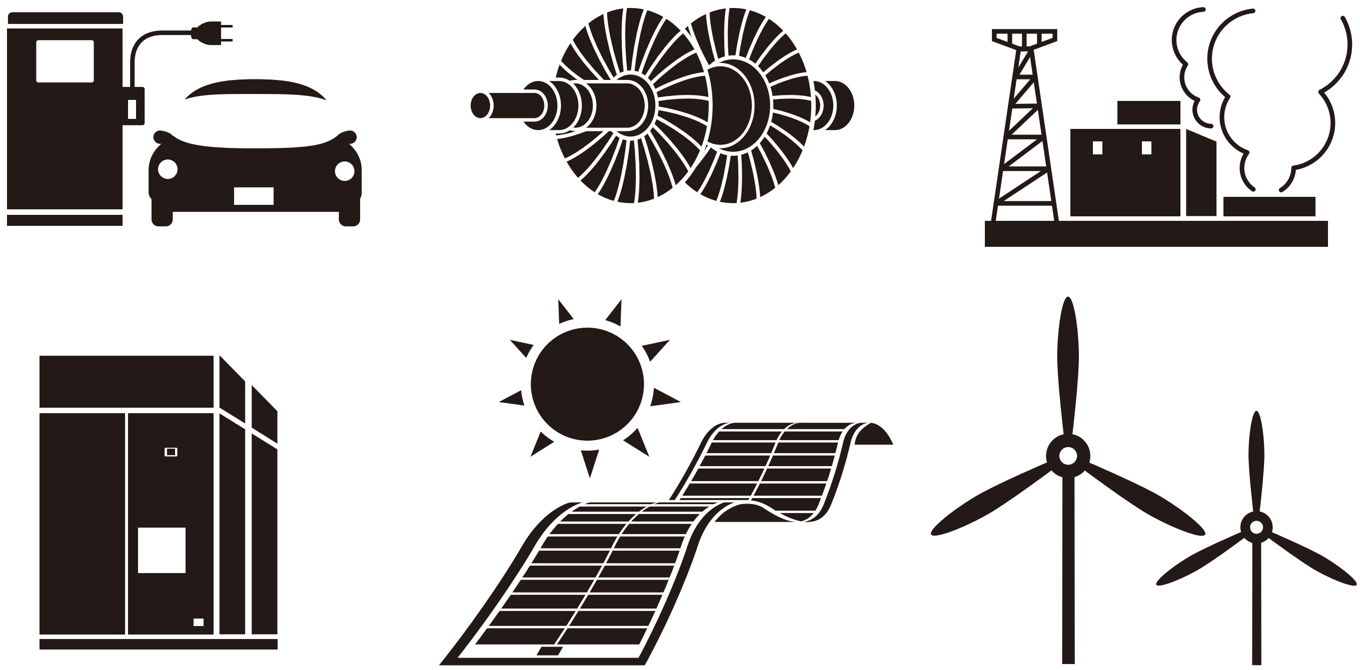
Innovating Energy Technology



Fuji Electric will meet the demands
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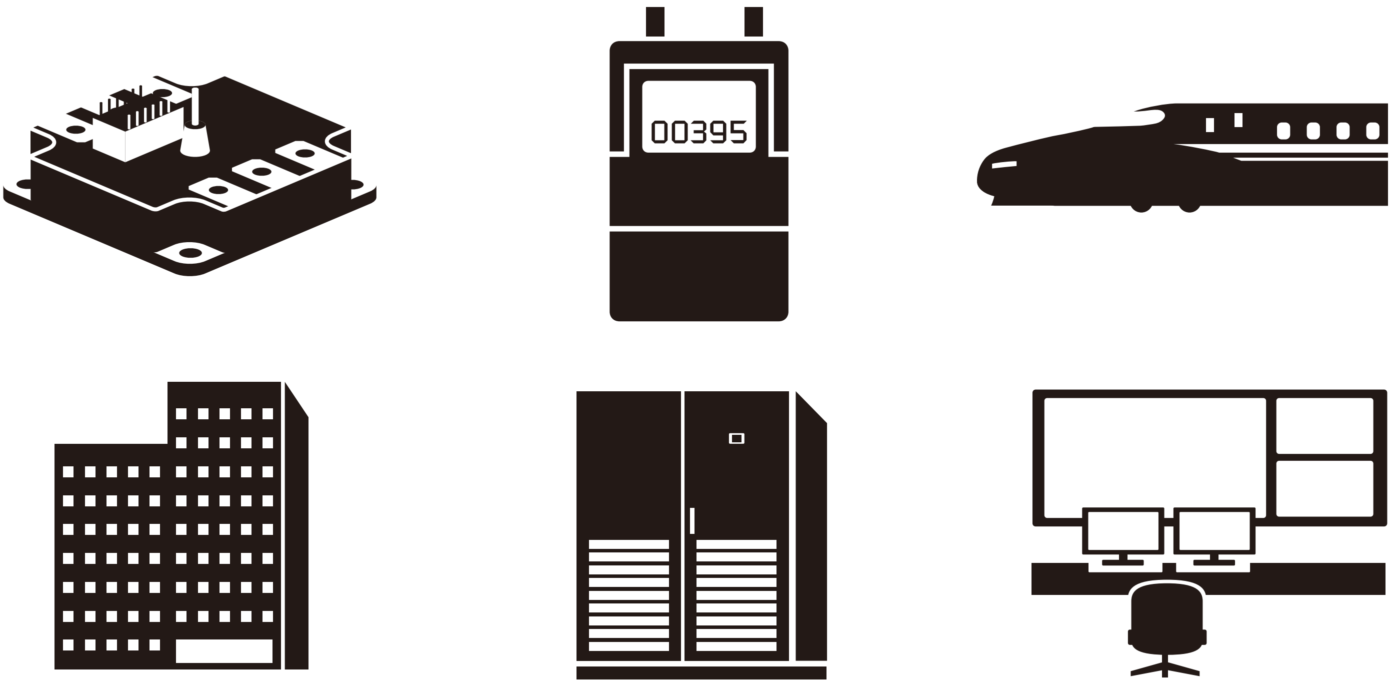

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