ISSN 0429-8284
Whole Number 235

e-Front runners

FUJI ELECTRIC REVIEW

4
2011 VOL.57

Smart Community

Fuji Electric

FUJI ELECTRIC
REVIEW

4

2011 VOL.57

Smart Community

CONTENTS

Cover photo:

To expand the adoption of renewable energy, smart grids, which are used to create intelligent power networks, are being deployed in smart communities that aim to reduce their environmental impact through the efficient use of electrical and thermal energy.

Fuji Electric supplies energy-creating technologies, such as photovoltaic generation and wind power generation and fuel cells, energy saving technologies, power stabilization technologies, energy management systems and a variety of other technologies including products for electric vehicles.

The cover photo shows a representation of the necessity for energy-creating technologies, such as photovoltaic generation and fuel cells, and energy management systems for using energy efficiently, in smart communities.

FUJI ELECTRIC REVIEW vol.57 no.4 2011

date of issue: November 20, 2011

editor-in-chief and publisher Naoya Eguchi
Corporate R & D Headquarters
Fuji Electric Co., Ltd.
Gate City Ohsaki, East Tower,
11-2, Osaki 1-chome, Shinagawa-ku,
Tokyo 141-0032, Japan
http://www.fujielectric.co.jp

editorial office Fuji Electric Journal Editorial Office
c/o Fuji Office & Life Service Co., Ltd.
9-4, Asahigaoka 1-chome, Hino-shi, Tokyo 191-0065, Japan

Preface

Towards to a smart community: the role of smart grids


Deqiang Gan


Rongxiang Zhao

Deqiang Gan † **Rongxiang Zhao** ‡

In a smart community, customers will be able to interact, in various ways, with power suppliers in such a way that the social welfare of customers and suppliers are maximized. The idea of smart grid, originated in the USA early 2000, further developed in Europe, now widely accepted across the world including China, can help accomplish this goal. The emergence of smart grids is often motivated by the need of reducing emissions, maintaining energy security, preventing large-scale blackout, and providing reliability-differentiated powers.

The fundamental principles of modern electric power grid were invented about half a century ago. Under the classic notion of regulatory economics, power industry had been considered as a natural monopoly, where power suppliers are obliged to supply, at regulated prices, electrical power to demands which are generally inelastic. This “golden rule” was altered with the introduction of electric power market some 20 years ago in many countries. However, this market is not a truly ideal market, not without the introduction of demand participation. A smart grid does just that.

Enabled by the state-of-the-art communication/control technology, a smart grid allows power suppliers to collect the real-time information of electric power customers such that differentiated electric powers are delivered. A smart grid better facilitates the penetration of green power, which is often difficult to accommodate in existing grid. A smart grid may also allow customers to sell a variety of electric power services, such as but not limited to, downward reserves (turn on a washer midnight you may end up with earning credit!), frequency regulation, etc., to the grid. In a nutshell, a smart grid serves as the next-generation infrastructure which permits customers to enjoy in an ideal market.

The notion of smart grid is rapidly gaining publicity in China. In May 2009, State Grid Corporation of China (SGCC) described a vision of smart grid as: A strong power grid that takes advantage of modern information technology, that fully supports a digital economy, that enjoys automation, and that allows interactions between the network and the demand. In the same time SGCC published a staged implementation plan of SGCC smart grid. In 2010, the Chinese government followed an ambitious research plan of smart grid, focusing on the interconnection of renewable energy and electric vehicles. In addition, two demonstration projects are under construction. The first one, Jinghai City Smart Grid Project, was initiated in the fall of 2009. Upon completion, 24.62% of electricity consumptions of this mid-size town in Tianjin (with a population of about 350,000), will be supplied by green power. This grid will also be integrated with cable television, IP telephone, realizing remote control, remote measuring, and remote information collection. Several advanced technologies, including energy storage systems, on-line equipment monitoring, smart building, electrical vehicles, etc., will be tested and exhibited. Jinghai Smart Grid is also expected to realize self-healing power supply to local customers. The second demonstration project is located in Yangzhou, a city nearby Shanghai.

In Zhejiang University, we have been working very hard, with the financial support of several entities including Fuji Electric, on a number of challenging tasks. Our goal is to develop practical solutions to microgrid, virtual power plant, and grid-friendly load. Take the research on grid-friendly load as an example. An interesting observation we found is that: much of the electrical loads can be temporarily reduced without introducing an essential impact on load performance. A classical example is that of residential air conditioning load. This implies that the characteristics of loads can be made grid-friendly. What is missing here is the information exchange between the network and the load. Therefore, in a smart grid regime, the notion of load participation should include frequency control, emergency voltage stability control, etc. This seems to be a potentially powerful and relatively new concept compared with the traditional demand response programs.

In summary, despite of the confusions and controversies, smart grids are gaining acceptance world wide. It is our view that eventually the core functions of smart grids will be identified and implemented, leading to the development of a much more efficient infrastructure, a win-win solution to both power suppliers and customers.

† Professor, School of Electrical Engineering
Zhejiang University
‡ Professor, Zhejiang University

Present Status and Future Outlook for Smart Communities

Kenzo Sugai † **Naoto Kobayashi** † **Jimpei Kuwayama** †

ABSTRACT

The development of smart communities that provide low-carbon, highly convenient urban infrastructures are a global trend enabled by the adoption of smart power grids, efficient energy use, a stable supply of water and the like. Fuji Electric, which specializes in the core technology of power electronics, is working to broaden the range of available smart community products related to public infrastructure. These products have a uniform interface, and are all controlled by an integrated energy management system (EMS) that allows for the simultaneous realization of energy visualization and optimal operation of equipment. The promotion of overseas exports is also under consideration as a way to expand the smart community business further.

1. Introduction

In recent years, with the rapid industrialization and population growth in the emerging nations of China, India and elsewhere, demand has increased for primary energy, including crude oil and natural gas, and the resulting higher prices and supply instability have led to problems. On the other hand, in the developed nations of Japan, Europe and North America, in addition to the popularization of electric vehicles and the expanded usage of solar power and wind power, "smart grid" technology that combines electric power grids with information technology to dramatically increase the power supply capability and usage efficiency is becoming a strategic technology for enhancing international competitiveness.

With the widespread usage and interconnection to power grids of distributed power sources and electric power storage systems among end-users, the flow of power, rather than being unidirectional from the power plants of electric power companies to end-users, is becoming a bidirectional flow or is flowing back and forth among end-users. A smart grid is a power grid provided with a function for performing optimal supply/demand control of electric power.

Moreover, with a smart grid, since the grid is distributed at the regional level and is able to accommodate distributed power sources providing large amounts of regional power resources such as solar, wind and biomass power, the regional energy independence can be enhanced significantly. Thus, the benefits of a smart grid are that in the event of an earthquake or other regional disaster, the risk of damage to the energy infrastructure is distributed, and the supply of energy to important regional sites can be restored rapidly by using diversified local energy sources.

Furthermore, by incorporating the smart grid concept, expanding the utilization of various types of energy, and through utilizing buildings having a highly efficient energy savings function, highly efficient transportation systems and stable and safe water supply systems, urban development and urban regeneration projects are being planned and being carried out as "smart communities" for realizing a low-carbon and highly convenient urban infrastructure.

In projects related to such smart communities, IT companies are active participants. Moreover, because smart communities involve national energy policy and growth strategy, the advancement of smart communities has expanded into a global movement.

In Japan, since 1980, in initiatives led by the national government or electric utility companies, various technical measures have been developed for improving power supply reliability and expanding usage of renewable energy, and various efforts have been advanced for improving the sophistication of power grids. Furthermore, in response to recent global trends, various national projects are being advanced, including national smart community demonstration projects targeting energy infrastructure exports to foreign countries, and investigations of urban infrastructure construction in emerging countries.

Through previous efforts, primarily through collaborative development with domestic Japanese power companies to develop automation systems for distribution systems and remote meter reading systems for power meters, Fuji Electric has accumulated products, technology and know-how relating to the advanced operation of power grids. Moreover, Fuji Electric participated in the "Demonstrative Project of a Regional Power Grid with Various New Energies" conducted by the New Energy and Industrial Technology Devel-

† Fuji Electric Co., Ltd.

opment Organization (NEDO) for a period of 5 years beginning in 2003, and has amassed a proven track record for developing and evaluating "microgrid control technology" that balances the supply and demand of energy within a regional grid consisting primarily of renewable energy sources such as solar power, wind power and biomass power.

Combining its accumulated advanced power grid technology with end-user power savings technology and public system technologies such as transportation and water environment technologies, Fuji Electric is currently participating in national demonstration projects and research projects relating to smart communities, and by integrating its in-house resources for various fields, Fuji Electric is helping to advance the development and expand the lineup of smart community products and technologies.

This special issue reports on Fuji Electric's support of these demonstration projects, product development for more advanced power grids and more highly sophisticated energy utilization by end-users in order to realize smart communities, and efforts to establish elemental technologies.

This paper describes the smart communities envisioned by Fuji Electric and their associated challenges, as well as the systems for technologies and products in Fuji Electric's smart communities. For further details, please refer to the individual papers that follow this one.

2. Trends Toward Smart Communities

2.1 Smart grids and the mass adoption of solar power generation and wind power generation

With the aim of realizing a low carbon society, the increased adoption of solar power and wind power is being promoted worldwide.

These unstable sources of energy, with the exception of small power supply applications such as in remote areas, are directly connected to power grids. In general, if the mass adoption of solar and wind power exceeds about 10% of the power grid supply capacity, the frequency and voltage of the power grid will become unstable and power quality problems will arise. Additionally, depending on the load pattern of the power grid, it can be expected that surplus power will be generated and adversely affect the protection and control functions of the power grid in some cases.

In terms of the capacity utilization ratio of the system, the addition of large-scale equipment to the power grid-side is not always an effective way to compensate for the fluctuations in solar and wind power generation, however. For this reason, the end-user and the power grid must be organically linked by means of information technology, and the control of the user equipment (user's grid) and of the large-scale power grid must be coordinated. A smart grid can realize such coordinated control, and is said to be a means for solving problems when adopting large amounts of solar and wind power.

Figure 1 shows the correlation between Fuji Electric's assumption of the increase in solar and wind power generation and capital investment trends[1]. For the planned global spread of solar and wind power, the need for "user grids" will increase beginning in 2012, and smart grids are expected to come into widespread use as of 2017. Additionally, together with the associated capital investment, smart communities having high-level urban features are also expected to increase.

2.2 From smart grids to smart communities

The populations of Asia and Africa are to increase dramatically in the future. In these regions, industrialization is progressing rapidly, especially in nations with emerging economies such as India and China, and large investments are being made for the development of industrial parks and urban development, as well as the accompanying construction of public infrastructure

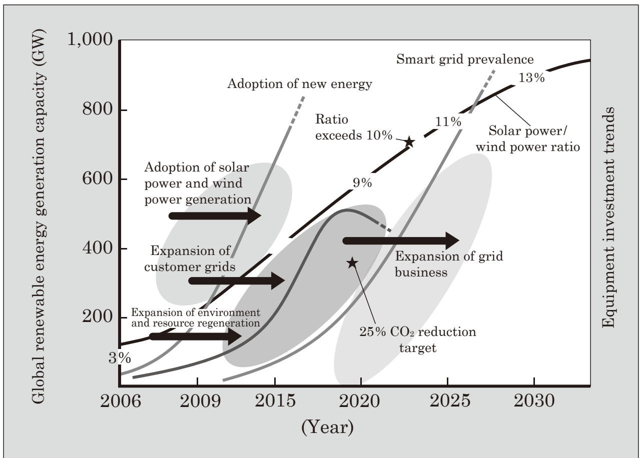
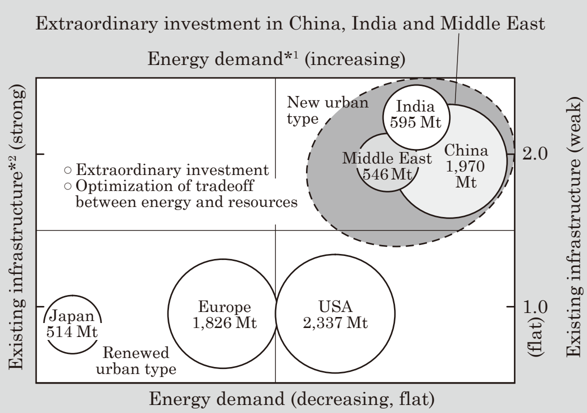


Fig.1 Smart grid equipment investment trends



*1 Energy demand: Million tons of oil equivalent (shown by area size, 2007)
Growth rate (Vertical axis, 2030/2007 ratio)
(Source: WORLD ENERGY OUTLOOK 2009)
*2 Strength of existing infrastructure: Energy and environment business strategy
(Source: Mitsubishi Research Institute, Sep. 2009)

Fig.2 Energy infrastructure portfolio

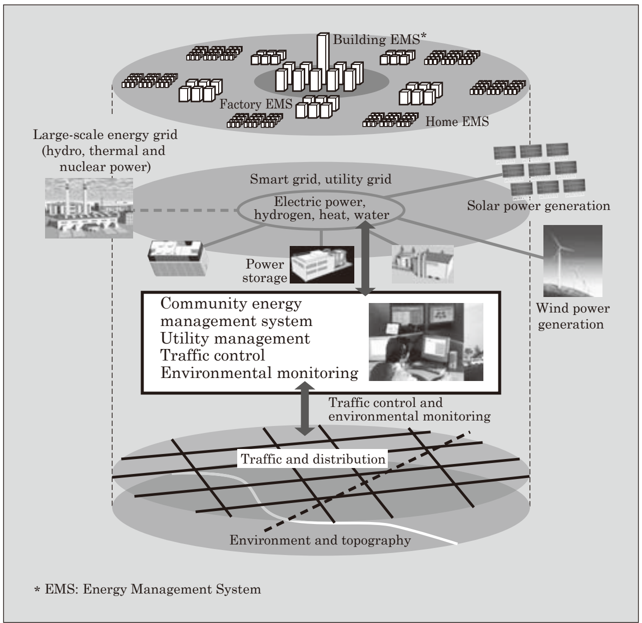


Fig.3 Overview of smart communities

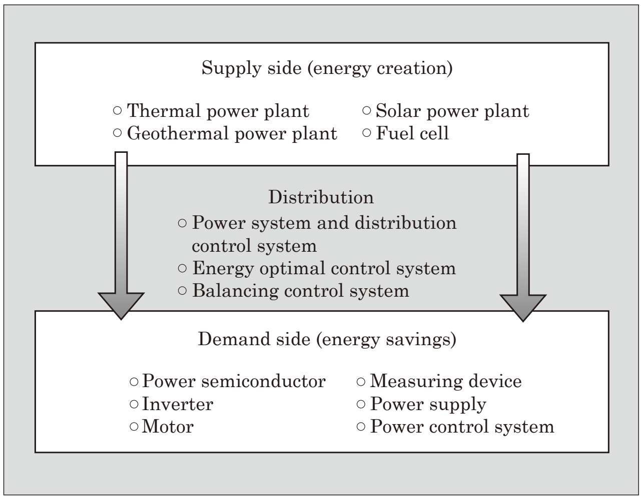


Fig.4 Fuji Electric's business areas

for supplying energy and water, and for transportation, distribution and the like.

In Japan, Europe, the United States and other developed nations, energy demand is flat and in some cases may decrease in the long-term due to a declining population and an overseas shift of production bases. In these countries, infrastructure investment is expected for renewal of the energy infrastructure developed during times of economic growth and to successively update that infrastructure into smart grids.

Figure 2 shows a portfolio of "new urban" and "urban renewal" type infrastructure.

Currently, more than 300 urban development and urban renewal projects are underway throughout the world. Not limited to providing power grids with smart functionality, these concepts have been expanded to the creation of eco-friendly urban spaces that combine water supply, transportation, distribution and energy infrastructure, i.e. smart communities (Eco-cities). (See Fig. 3.)

Smart communities can be defined in various ways according to various issues such as a particular country's energy policy, energy security and so on.

The Eco-city projects in the Middle East will be powered entirely by renewable energy, and aim to create the world's first carbon neutral and zero waste eco-friendly cities. Moreover, China is moving forward with 13 national eco-city projects, and has posted performance indicators for 32 items including a renewable energy usage of greater than 30%, a daily waste detoxification rate of greater than 70%, and a sewage water recycling rate of greater than 30%.

3. Fuji Electric's Activities for Smart Communities

3.1 Fuji Electric's business areas

The main markets for smart communities are new urban development in emerging nations and urban renewal in industrialized nations. Rather than provide individual elemental technologies, what is needed is a one-stop business scheme capable of constructing and operating a continuous energy supply chain, from an energy infrastructure consisting of energy supply and energy distribution functions to the effective utilization of energy on the user side (user's grid). Additionally, functions for water supply, waste disposal, transportation, distribution and the like are also requested of the developers of comprehensive social systems.

Figure 4 shows the business areas in which Fuji Electric is involved with smart community projects. Based upon high-performance power semiconductor technology, and with power electronics capable of "freely controlling energy" positioned as a core technology, Fuji Electric has established a product lineup that ranges from products for supplying energy to a smart community to products for the user's grid. These products aim to achieve integrated operation through the use of an integrated energy management system (EMS) platform, which is a mechanism that coordinates shared information.

3.2 Energy supply-side products

Fuji Electric possesses plant technology relating to large-scale thermal power, hydropower, and geothermal (flash) power generation. Fuji Electric also supplies distinctive energy supply-side products such as binary generators that are able to utilize low temperature geothermal energy, lightweight and flexible amorphous solar cells, industrial-use phosphoric acid fuel cells and so on. Additionally, Fuji Electric also has a lineup of products for power substation and protection systems for safely connecting the above supply-side products to a power grid, power stabilizers that smooth solar and wind power fluctuations and supply stabilized power to power grids, and so on.

3.3 Distribution and demand-side products

Figure 5 shows Fuji Electric's envisioned structure of a smart community.

At Fuji Electric, "smart communities" are positioned as a type of public infrastructure that encompasses smart grids, transportation systems, water and sewage management, and the like. The smart grid structure is divided into five layers, with the core components of "power devices" forming the first layer, followed by "power electronics equipment" and "user's grids" for performing power conversion and power control, "microgrids" used as regional grids, and "smart grids" as the energy infrastructure. Energy and information flow in both directions between each of these layers to realize optimal energy operation in smart grids and smart communities.

(1) Power devices and power electronics equipment

Fuji Electric supplies power electronics equipment such as uninterruptible power supplies (UPS) and high-current DC power supplies for which Fuji Electric has a high market share worldwide, powertrains for electric vehicles, transport and conveyance systems, etc. Additionally, a new 3-level conversion circuit that uses Fuji Electric's proprietary reverse blocking IGBT (RB-IGBT) has been developed, and achieves 30 to 40% lower loss than a conventional circuit.

Power electronics in smart communities is applied over a wide range of fields including, for example, power conditioners for solar power generation systems, power storage systems for the effective utilization of surplus renewable energy, reactive power compensators and voltage regulators for maintaining the power grid voltage at a proper level, etc.

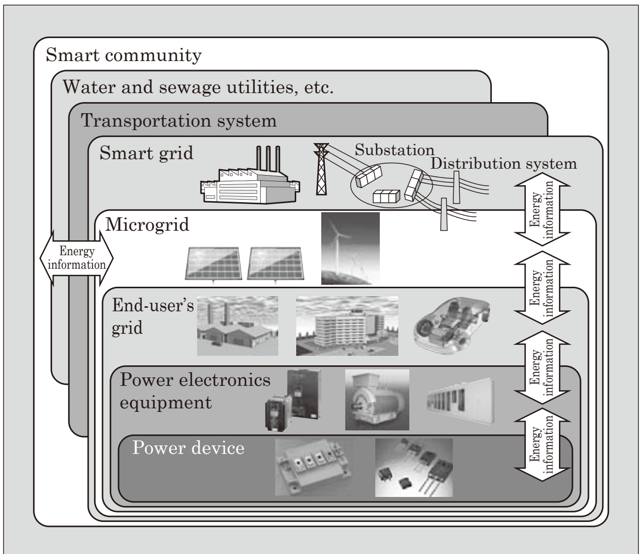


Fig.5 Structure of a smart community

(2) User's grids

The key role of a smart community is considered to be the achievement of energy savings in the household, industry and transportation fields and the like.

Targeting the end-users of plants and buildings, Fuji Electric installs and deploys EMSs for energy visualization, analysis and evaluation, and the overall optimized operation of equipment. Fuji Electric also applies power electronics to develop "green navigation" and provide a total solution for energy savings.

In addition, for Internet data centers (IDC) where the energy demand density has increased as servers have become more highly integrated, green IDC solutions centering on ultra-efficient uninterruptible power supplies and local air conditioning systems are being proposed. Moreover, targeting convenience stores and distribution businesses, one-stop integrated solutions are also provided for the construction of energy-saving stores.

With a smart grid, these EMSs and an upper-layer community EMS are hierarchically linked on the same information platform.

A two-way interconnection with an upper level EMS or power company is realized via "smart meters" installed in homes and at other small-scale end-users. A smart meter, in addition to having a conventional real-time metering function of the cumulative power consumption, also has an information display terminal that continuously exchanges information with an upper level EMS, and implements a demand response function, which according to the supply and demand status of power companies, varies the selling price of electricity and induces load control for the end-user.

(3) Microgrids

For the introduction and evaluation of microgrids on remote islands, many projects are planned or are underway, both in Japan and overseas.

At present, a large number of diesel generators are used for supplying power to remote islands, and mitigating the high generation cost resulting from fuel transportation costs and reducing the environmental load are challenges. The remote island demonstration projects aim to resolve, through the coordinated operation of existing diesel generators and power storage systems, the problem of supply/demand imbalance and to maintain the power quality of the power grid when solar power, wind power, or other type of renewable energy is adopted in large quantities.

In 2009, Fuji Electric delivered a total of nine microgrid demonstration systems to remote islands in the Kyushu and Okinawa regions.

(4) Smart grids

As a participant since 2010 in the "Next-Generation Energy and Social Systems Demonstration Project" of the Japanese Ministry of Economy, Trade and Industry, Fuji Electric is working on the development and demonstration of a cluster energy management system (CEMS).

Figure 6 shows the characteristics of the CEMS that Fuji Electric is working on. Targeting the exporting of new urban energy infrastructure to emerging nations, this demonstration project evaluates the utilization of renewable energy and local industrial resources, the potential contribution to large-scale interconnected power grids, as well as the usefulness and profitability thereof. Additionally, for local end-users to contribute to supply/demand operational management for energy, leading research of demand response, various incentives, and the like is also planned.

Furthermore, since 2009, in NEDO's "Smart Power Network Research," Fuji Electric has also been involved in the development and demonstration of component devices and distribution control systems for next-generation distribution systems.

(5) International standardization strategy

In international standardization activities concerning smart grids and smart communities, Europe and North America have a slight lead at present. The global deployment of distinguished domestic technologies is an important part of the international standardization strategy. Focusing on power electronics, smart meters, and the EMS field, Fuji Electric is increasing its participation in various standardization activities, including the Japan Smart Community Alliance established by the Japanese Ministry of Economy, Trade and Industry and NEDO.

4. Future Challenges

The main markets for smart community public infrastructure projects exist in urban development and urban regeneration projects overseas. As a supplier of component and system products, Fuji Electric is expected to face the following challenges in expanding its business.

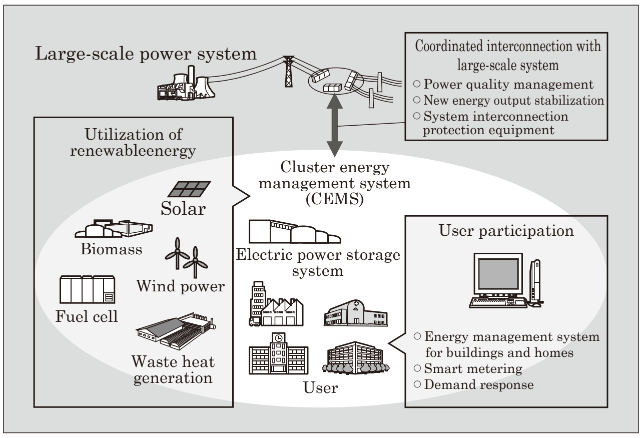


Fig.6 Characteristics of cluster energy management

4.1 Engineering, procurement, construction (EPC) skill

A smart community project, especially when exporting infrastructure, requires a business scheme for providing total solutions, from planning to construction and operation. Accordingly, as the project structure, collectives consisting of suppliers, developers, engineering firms, constructors, operators and maintenance workers, finance companies and the like are expected to be increasingly formed and advanced by domestic Japanese companies and regional overseas companies.

In order for Fuji Electric to play a major role in these collectives, the "EPC skill" level must be enhanced so as to provide a one-stop solution capable of aggregating the resources of the group companies and performing the engineering, procurement and construction work for the energy infrastructure.

4.2 Safety and security in the construction of public infrastructure

A smart community oversees the efficient operation of not only the energy infrastructure but also the public infrastructure, which includes water, sewage and waste treatment systems, transportation systems and so on, for an entire city and requires robustness as a lifeline for city functions in the case of a disaster, and also requires know-how for incorporating substantial safety and security features.

Possessing technology and know-how relating to the protection and control of power distribution equipment and large-scale plants, Fuji Electric positions these safety and security technologies as important distinguished items in its lineup of smart community products.

5. Postscript

Smart communities are mostly still in the planning and demonstration stages. As solar cells and electric vehicles come into widespread use in the future, the construction and operating costs for smart grids will become comparable to those of large-scale power grids, and the full-scale launching of the smart grid market is expected.

Aiming to provide a safe and secure low-carbon energy infrastructure, Fuji Electric intends to strive for further technical innovation and thanks all concerned parties for their guidance and cooperation.

References

(1) World Energy Outlook 2008, International Energy Agency.

Fuji Electric's Efforts Involving Next-generation Energy and Social Systems

Yutaka Fueki † **Jimpei Kuwayama** †

ABSTRACT

In order to realize the "Fuji Smart Network System" as a next-generation energy and social system, Fuji Electric aims to realize power stability, energy savings and reduced carbon emissions in a targeted area by employing geographical distribution, and to construct a system that does not affect power transmission systems. The system aims to resolve energy-related problems within each region by addressing, through region-wide initiatives, increased voltage resulting from the adoption of large amounts of solar power, energy conservation by direct and indirect load control using smart meters, and the interchange of heat and gas or other energy sources. Fuji Electric is participating in planning for Kitakyushu City and Keihanna Science City in Japan, and having been commissioned by NEDO, is conducting a basic survey for overseas.

1. Introduction

To achieve a low carbon society, the adoption of renewable energy, electric vehicles (EV), energy saving homes, zero-emission buildings, and the introduction of high efficiency equipment in factories have been studied extensively. Recently, in addition to the introduction of stand-alone energy-saving and energy-creating equipment, efforts aiming to utilize bidirectional communication, such as with a smart meter, in order to utilize energy effectively throughout a region have been attracting attention.

In Japan, region-wide optimal energy management that includes electric utilities, companies that generate renewable energy, and consumers, the effective utilization of not just electrical energy, but also heat, gas and the water environment, as well as demonstration projects for creating eco-friendly urban spaces and transforming consumer lifestyles are being promoted. Overseas, infrastructure improving projects for electric power, heat, gas, the water environment, transportation and the like are actively being carried out for cities and industrial parks.

Fuji Electric is participating in projects to construct a next-generation energy and social system in Japan in order to create a smart community that is an eco-friendly city, and is also actively conducting a survey of overseas smart communities.

2. Next-Generation Energy and Social Systems

Below, definitions of a smart grid and smart community are presented, and national initiatives and demonstration projects for next generation and energy and social systems, as well as Fuji Electric's participation in demonstration projects are described.

2.1 Definitions

(1) Smart grid

To resolve the power quality-related issues that accompany the large-scale introduction of renewable energy, a smart grid provides an information network for controlling power and performs real-time adjustments of the supply and demand of energy, and the following benefits can be obtained as a result.

(a) Stable utilization of power is ensured and the risk of a large-scale power outage is reduced

(b) Energy savings and efficient energy utilization are promoted integrally with customers

(c) Optimization of electric power facility maintenance and management

(2) Smart communities

A smart community is a new type of "city planning" that aims to achieve a low carbon footprint as well as increased convenience for its residents and to foster urban renewal. Smart communities are next-generation type local communities and are built using the latest technologies, such as smart grids. Smart communities are formed by creating living spaces that achieve both improved comfort and energy savings through the effective utilization of energy, the introduction of renewable energy, and the renovation of transportation systems, and the information networks that link these smart communities also play an important role.

2.2 Fuji Electric's vision of next-generation energy and social systems

Fuji Electric aims to build a geographically-distributed type next-generation energy and social system that achieves power stabilization, energy savings and a smaller carbon footprint for a target region, and that

† Fuji Electric Co., Ltd

does not negatively affect the power distribution system.

The next-generation energy and social system aims to resolve energy-related problems within each region by addressing, through region-wide initiatives, the increase in voltage resulting from the adoption of large amounts of solar power, and to realize energy conservation by direct and indirect load control using smart meters, and the interchange of heat and gas or other energy sources.

Figure 1 illustrates Fuji Electric's concept of a geographically-distributed type next-generation energy and social system. This concept is fundamental to the "Fuji Electric Smart Network System," to be described later, and is applied to smart grids and smart communities.

2.3 National initiatives and demonstration projects

Japanese national initiatives include the mass adoption of renewable energy centered mainly on solar power (targeting 28 GW of solar power generation and 4.9 GW of wind power generation by 2020), direct and indirect load control through bi-directional communication using smart meters (targeting installation in all homes by 2020), the application of storage cell technology as represented by electric vehicles, and the support of the overseas exporting of infrastructure based on the new technologies acquired here. In June 2006, for the purpose of demonstrating these technologies, a "Regional Energy Management Development and Complex Storage System Technology Development Project" was made public, and demonstration projects of the next-generation energy and social system were decided to be carried out for 5 years beginning in 2010 in Kitakyushu City, Keihanna Science City, Yokohama City and Toyota City.

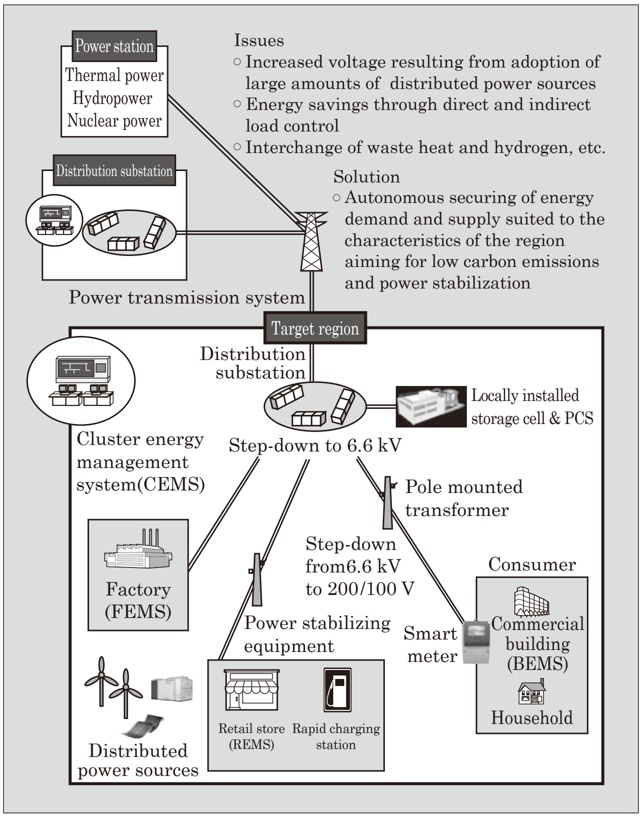


Fig.1 Fuji Electric's regionally distributed next-generation energy and social system

2.4 Fuji Electric's participation in demonstration projects

Sharing a vision of the future with national and local governments, Fuji Electric is participating in demonstration projects and offering various proposals to promote development both in domestic and global scale.

Fuji Electric has participated in the following recent demonstration projects.

(1) Smart grid-related demonstration projects
- (a) Kyushu and Okinawa isolated island micro-grid demonstration system (2009)
- (b) Next-generation optimizing control technique experimental project for energy transmission and distribution systems (2010)
  Voltage control of centralized-type next-generation power distribution automation system
- (c) Fuel cell system for commercial buildings in a US-Japan smart grid demonstration project in New Mexico (2010)
- (d) Demonstration of effect of introducing load balancing equipment (2011)
  Indirect and direct load control using smart meters

(2) Smart Community-related demonstration projects
- (a) Next-generation energy and social system demonstration (2010)
  - (i) Kitakyushu city
    - ○ Regional energy management system development project
    - ○ Complex storage cell system technology development project
  - (ii) Keihanna Science City
    - ○ Complex storage cell system technology development project
- (b) Study of feasibility of introducing smart community technologies to an industrial park in Java, Indonesia (2010)

3. Fuji Electric's Efforts

The targeted scale, power quality, energy management and local production for local consumption are four essential perspectives for next-generation energy and social systems. Based on these perspectives, Fuji Electric's technologies that contribute to lower carbon emissions and improved power stabilization are described, and demonstration projects, both in Japan and overseas, that apply these technologies are introduced below.

3.1 Four perspectives and the corresponding technologies

Fuji Electric has been involved in developing and delivering next-generation energy technologies and social systems for many years. These technologies have included, for example, distribution automation systems, power system control systems, energy management systems (EMS), distributed power sources, balancing control, power quality stabilization, power instruments, power distribution equipment, and inverters, converters and the power conditioners (PCS) to which they are applied.

In recently requested social infrastructure-related projects in Japan and overseas, in addition to higher efficiency and optimization through managing, monitoring and controlling the entire energy supply chain, from supply to delivery to the consumer, the information networks that provide support have also become essential elements.

Fuji Electric is approaching the next-generation energy and social systems from the following four perspectives.

(a) Targeted area

Various sizes exists, but compact cities, industrial complexes, industrial parks, islands, and non-electrified areas are targeted.

(b) Power quality

So as not to adversely affect the power transmission system, fluctuations in voltage and frequency caused by distributed power sources that have been installed in a targeted region are to be absorbed within the targeted region to stabilize power.

(c) Energy management

Through the efficient utilization of electric power and heat by consumers, i.e., households, charging stations, stores, commercial buildings and factories, and the utilization of information networks to acquire information in real-time, energy management aims to cross-utilize energy within a region.

(d) Local production for local consumption

Energy control of a target region is implemented in collaboration with the power transmission system, regional cogeneration system, distributed power source system and the like, and aims to achieve local production for local consumption.

Based on these four perspectives, Fuji Electric's technology to be utilized in the next-generation energy and social system is classified as carbon emissions-lowering or power stabilizing as shown below.

(1) Carbon emissions-lowering technologies

(a) Cluster energy management systems (CEMS) that manage entire energy in the targeted region

(b) Retail, building and factory energy management systems (REMS, BEMS, and FEMS) that target the consumer

(c) Smart meters and wireless multi-stage relay technology provided with customer power usage prehension, stop and release, guidance display and response input functions

(d) Technology relating to distributed power sources such as lightweight flexible film-type solar cells, commercial 100 kW phosphoric acid fuel cells, micro tubular turbines for low-head hydropower generation, and binary geothermal power generation that efficiently converts low-temperature

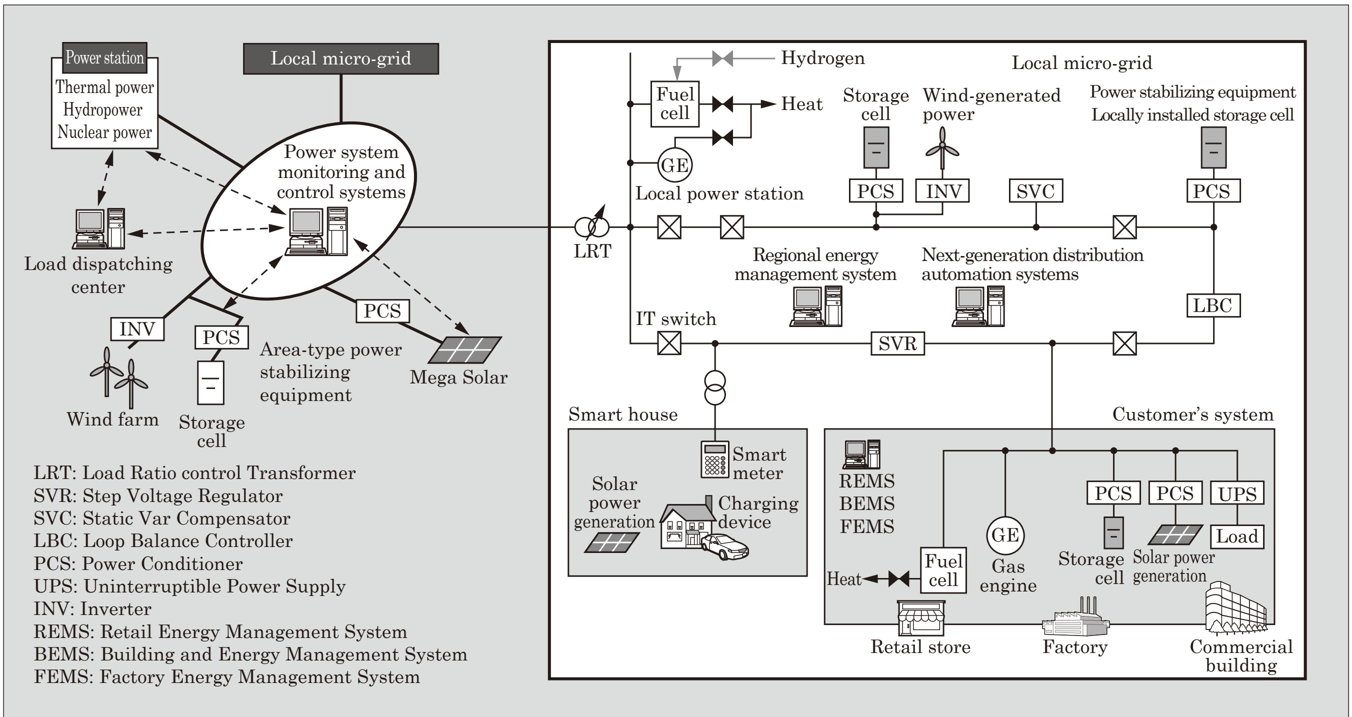


Fig.2 Overall view of the "Fuji Smart Network System"

thermal energy into electrical energy

(2) Power stabilizing technologies

(a) Next-generation power distribution system technology provided with functions for fault point detection and recovery, power flow monitoring, and voltage and frequency adjustments.

(b) Technology relating to high-efficiency power conditioners (PCS) and power stabilization equipment to control the discharging and charging of locally installed storage cells as equipment for implementing power control within a grid

(c) Technology relating to load ratio control transformers (LRTs), IT switches, static var compensators (SVCs), step voltage regulators (SVRs) and uninterruptible power supplies (UPSs) which, as distribution equipment, aim to stabilize the on-grid power quality

(d) Micro-grid technology and balancing control technology for performing high-speed optimized control of energy supply and demand in a closed grid as in the case of isolated islands

The linking of these technologies is shown in the overall view of the Fuji Smart Network System in Fig. 2.

Fuji Electric has developed essential products and technologies for realizing the Fuji Smart Network System, and is conducting field demonstrations in Japan and overseas. The results of these projects are incorporated into a compact "Social Infrastructure Package Focused on Electric Power," and application is being promoted to: (1) environment friendly cities and smart communities, (2) industrial complexes where high levels of energy integration exist, and (3) isolated islands and non-electrified areas where there are low levels of energy integration.

3.2 Demonstration projects in Japan

(1) Next-generation energy and social system demonstration projects

(a) Regional energy management

Fuji Electric is participating in the development of a "regional energy management system focused on regional energy-saving stations" in Kitakyushu-city, and is promoting urban development that aims to achieve lower carbon emissions in the Higashida district of Kitakyushu-city.

This district is an advanced model district for energy supply and demand, and aims to become a local community in which energy saving behavior is incorporated into daily life and business activities.

The relevant technologies for reducing the carbon footprint and controlling all the energy utilized

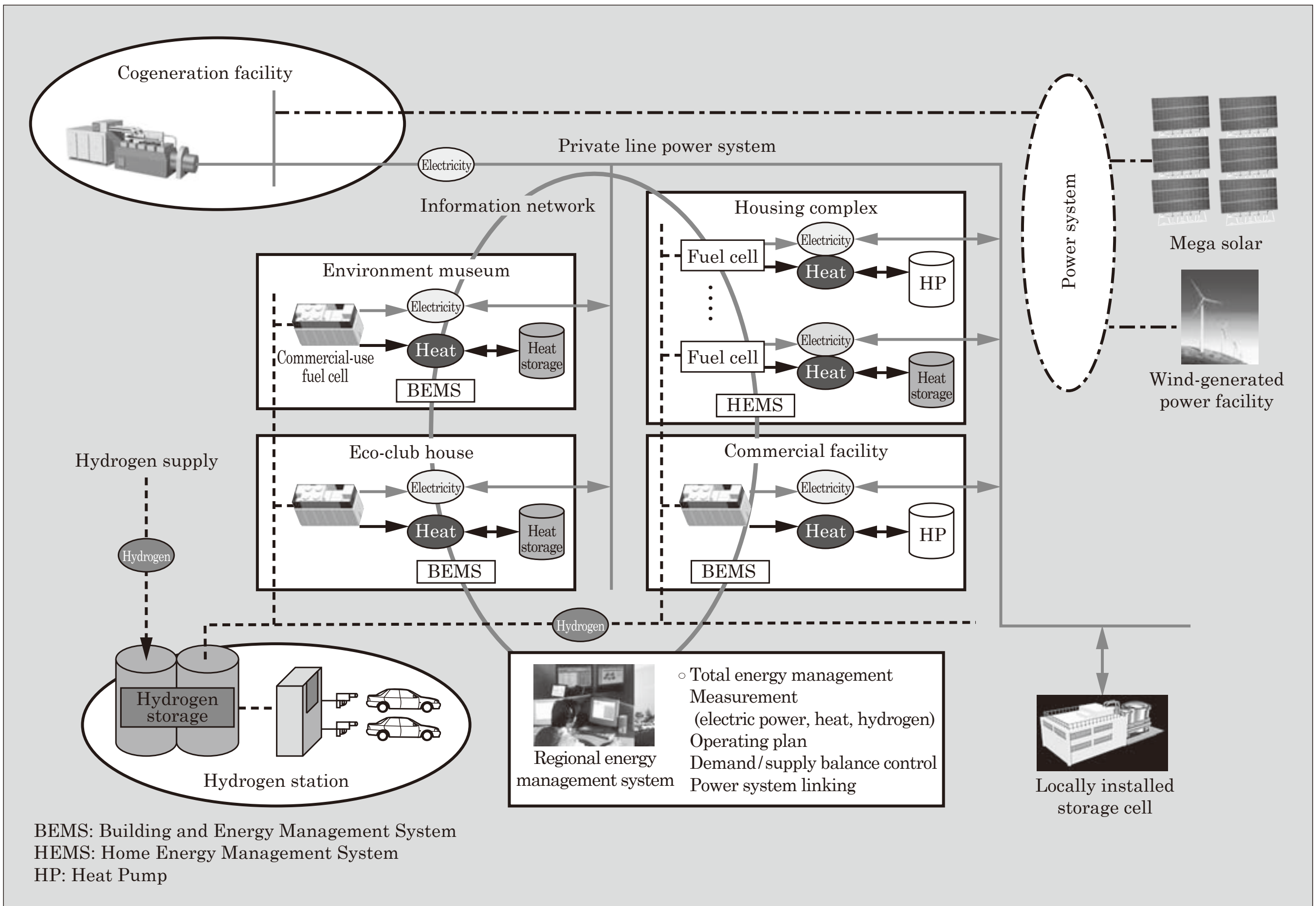


Fig.3 Overall view of Kitakyushu City next-generation energy and social system

in the district include linking technology for renewable energy and cogeneration systems, technologies for supplying power to electric vehicles and for utilizing power from discharging electric vehicles, power stabilizing technology that utilizes locally installed storage cells, technology for visualizing the energy consumption of each consumer, and demand suppression measures based on dynamic pricing and an eco-point system. In the demonstration project, as shown in Fig. 3, energy suppliers and consumers in the targeted region are connected to an information network, and a regional energy management system measures the supply and demand of electric power, heat and hydrogen, creates an operating plan, controls demand and supply, and incorporates the power systems. The results of this demonstration project, in terms of comprehensive energy management, are expected to be used as a model case of an environment-friendly compact city that will be deployed overseas in the future.

The regional energy management system being developed to reduce carbon emissions in this demonstration project has the following three characteristics.

(i) The system acquires, through a dedicated line or general acquisition procedure, and centrally manages comprehensive energy data required for regional energy management according to the need (high-speed response, frequency, etc.) for that data.

(ii) Multiple independent systems can be installed, according to requirements of the targeted region, in order to implement control requiring real-time performance such as for power generation, charge and discharge commands, ascertainment of energy utilization for each consumer, and business processes such as energy demand and supply planning

(iii) Acquired information is provided to an external service provider so that new services can be created.

Table 1 lists the main functions and Fig. 4 shows the system configuration of a regional energy management system.

Table 1 Functions of a regional energy management system

	Regional energy management system
Functions	Comprehensive energy management for an entire region, combining energy demand forecasting and weather forecasting, power system control at the time of adoption of new energy, storage cells and EVs
	Stabilization through coordinated operation with the power system
	Real-time ascertainment of energy usage status for each customer
	Demand-side management through customer load control and dynamic pricing
	Standard procedure for connecting to customers and energy equipment
	Creation of new services by utilizing energy consumption and CO_2 visualization data

(b) Demand-side energy management

In support of the next-generation energy and social system for consumers, Fuji Electric is participating in the "development of an energy controller for a facility grid" in Keihanna Science City, and is advancing demonstration projects for technologies that lower carbon emissions of complex buildings, including rental offices, halls, hotels and restaurants.

This demonstration project has the following two objectives.

(i) By installing storage cells, solar cells, fuel cells and smart meters within a complex building, which is considered to be a single closed grid, and utilizing the storage cells, fuel cell and heat pumps efficiently, the project aims to achieve the effect utilization of the renewable energy and heat within the building.

(ii) By promoting energy savings and reduced carbon emissions through indirect load control, and enhancing the environmental awareness of tenants and other building users, the project aims to contribute to the goal of achieving zero emissions for the entire complex building.

Fuji Electric is also moving forward with verification of the control method for achieving the specified target value of demand through linking information with the regional energy management system for Keihanna Science City.

Demand-side energy management is realized by installing a compact building-use energy controller in a complex building. This controller directly controls energy devices such as storage cells and fuel cells in a complex building, and through a smart meter, also

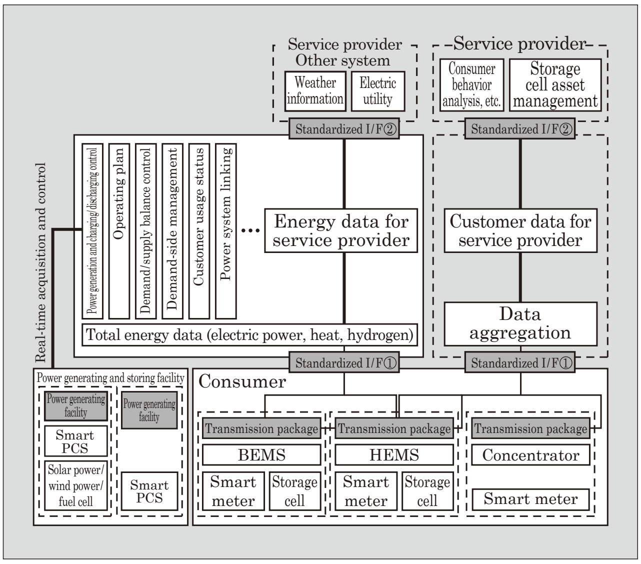


Fig.4 Configuration of a regional energy management system

performs indirect load control for the tenant. Through linking to building management systems centered on conventional monitoring or visualization, the energy usage within a building can be made even more efficient. Table 2 lists the main functions of building-use energy controllers, and Fig. 5 shows a system configuration.

(2) Demonstration project of optimal control technology for next-generation power transmission and distribution systems

One technical challenge for smart grids is how to prevent a voltage increase when many distributed power sources including solar cells are connected to the power distribution system. To overcome this challenge, Fuji Electric has for many years advanced the development of equality control for voltage suppression with solar power generation and the like. Next-generation distribution automation systems overcome this challenge by utilizing centralized control of power conditioners connected to voltage regulators and solar cells from the central monitoring and control systems.

In the power distribution sector, as preparation for the introduction of a large number of distributed power sources, next-generation distribution automation systems provided with a centralized control function for voltage regulators, and distributed generator-use power conditioners equipped with power stabilizing, reactive power adjustment and power storage functions will be utilized both in Japan and overseas. Fig. 6 shows a comprehensive view of optimal voltage control technology.

Table 2 Functions of an energy controller for buildings

	Energy controller for buildings
Functions	Load leveling with storage cells (peak cut, peak shift)
	Control and operation of storage cells (power) and heat pumps (heat)
	Indirect load control via smart meters at customer sites
	Charging control based on EV operating plans
	Utilization of waste heat from fuel cells
	Coordinated control with air conditioning
	Achievement of targeted demand with regional energy management

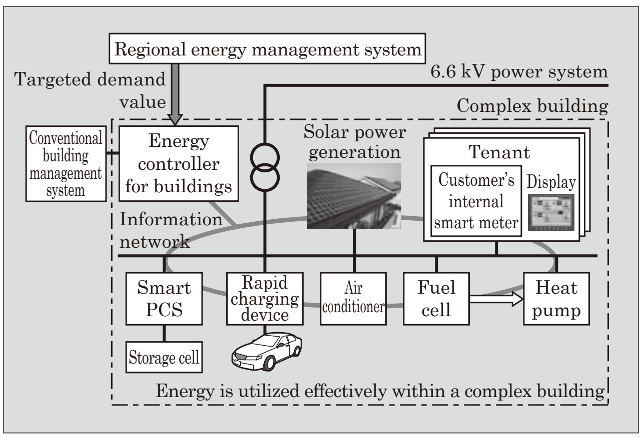


Fig.5 Configuration of demand-side energy management system for complex buildings

3.3 Demonstration projects overseas

Fuji Electric, Sumitomo Corporation, Mitsubishi Electric and Tokyo Electric Power Services Co., Ltd. have been commissioned by the New Energy and Industrial Technology Development Agency (NEDO) to conduct a basic survey of power infrastructure exports that utilize smart technology and that target Southeast Asian industrial parks where a high level of energy integration exists and where greater energy savings and lower carbon emissions are anticipated.

Industrial parks in Southeast Asia are experiencing an influx of Japanese companies and have the following characteristics.

(a) Power quality at a level equivalent to that of Japan is requested for stable manufacturing
(b) Compared to Japan, the energy management of plants has much room for improvement in terms of energy conservation and reduction of carbon emissions
(c) The amount of contracted electrical power corresponds to the amount of power managed by a single power distribution substation, and is similar in scale to that of the district targeted for energy management

In light of these three characteristics, among the smart grid technologies being developed for next-generation energy and social system demonstration projects, the technologies for lowering carbon emissions and improving power stability listed in Table 3 are thought to be applicable to Southeast Asian industrial parks.

Aiming to reduce carbon emissions and improve power stability of Southeast Asian industrial parks, Fuji Electric intends to apply these smart grid technologies to build an industrial park power supply infrastructure.

Fig. 7 shows a system model in which smart grid technology has been applied to an industrial park.

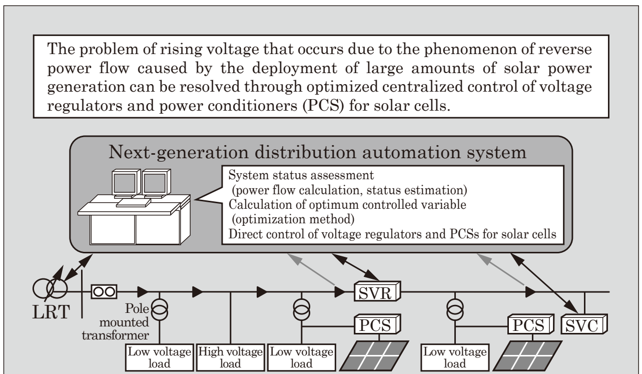


Fig.6 Overall view of optimal voltage control technology

feature issue: Smart Community

Table 3 Smart grid technology suited for industrial parks

	Carbon reduction technology	Power stabilization technology
Factory	Factory energy management Peak-cut/demand control Direct/indirect load control Automatic measurement with smart meters Changeover to high-efficiency equipment Renewable energy equipment Inverter control, air conditioner control Information network within the factory	Uninterruptible power supply (UPS) Emergency in-house power generator Static var compensator (SVC) Step voltage regulator (SVR) Power capacitor
Industrial park	Regional energy management Peak-cut/demand control Direct/indirect load control Renewable energy equipment Information network within the industrial park	Emergency power supply system Power quality stabilizer Static var compensator (SVC) Step voltage regulator (SVR) Distribution automation system within the industrial park

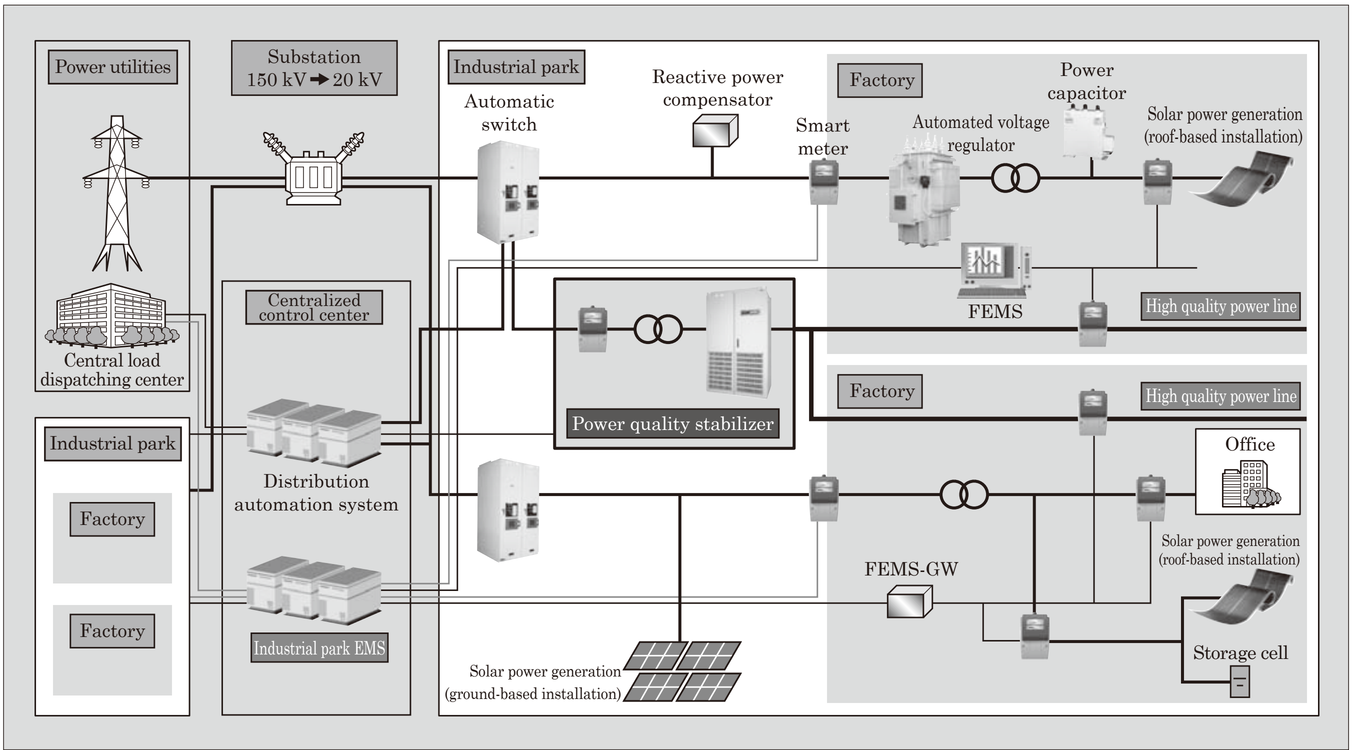


Fig.7 System model of smart industrial park

This model assumes that the district targeted for regional energy management is the entire industrial park, and with an energy management system, stabilizes power for the entire industrial park, saves energy and cuts peak power demand. The two main technologies utilizes are listed below.

(a) A “power quality stabilization device” installed at the industrial park supplies a high quality power source to multiple factories

(b) An “industrial park EMS” performs centralized control of factory demand restraint and energy management

4. Future Challenges

The ongoing demonstration projects described in section 3 are all component elements of the Fuji Smart Network System, and this system will be completed initially by leveraging the results of Japanese and overseas demonstration projects. The net result is the compilation of a next-generation energy and social system that aims for lower carbon emissions and improved power stabilization for consumers and targeted regions.

Fuji Electric will develop this system for consumers who are seeking energy savings and more effective utilization of electricity and heat energy, and also for designated energy districts and local governments possessing a vision of new energy utilization. For power companies, with the aim of improving stability and increasing the quality of power, Fuji Electric is promoting the introduction of next-generation distribution automation systems to meet year 2020 targets (solar power generation of 28 GW, wind power generation of 4.9 GW, and smart meters installed in all homes).

Overseas, Fuji Electric is aiming to develop this system as a “social infrastructure package focused on electrical power” that combines carbon-lowering technology and power stabilization for smart communities, industrial parks, islands, as well as the power distribution sector. The infrastructure for a smart community is required to consist of not only an energy infrastructure, but also a water environment infrastructure, an infrastructure for electric vehicles including the capability to control the status of charging device and the like, and an information infrastructure. Fuji Electric will proceed to construct this system by linking it to water treatment systems and retail store systems that have been developed over many years.

Moreover, because the business areas targeted by next-generation energy and social systems are new service areas, the profitability of companies that have a next-generation energy and social system and companies that operate and maintain systems are important, and Fuji Electric intends to participate from the business feasibility study and basic planning stages.

5. Postscript

In the future, it is expected that solar cells and smart meters will be used in many homes, distributed power sources and high efficiency devices that aim to reduce carbon emissions will be encouraged and electric vehicles will become widespread. Fuji Electric possesses many technologies relevant to the smart grids that will be utilized in Japanese society in the near future. In response to social requests concerning smart grids and smart communities, Fuji Electric will expedite the commercialization of the results of technical development and demonstration projects of the next-generation energy and social systems, and intends to contribute to the establishment of a social infrastructure for developing environment friendly cities and regions, adopting large amounts of renewable energy, and popularizing electric vehicles.

Microgrid System for Isolated Islands

Takehiko Kojima † **Yoshifumi Fukuya** †

ABSTRACT

There are many inhabited isolated islands throughout the world and most of these operate with independent power systems. Because such power systems located on small isolated islands are small in size and their generators have low inertial energy, they are sensitive to fluctuations in the output of renewable energy. To solve this problem, Fuji Electric has studied the configurations of microgrid systems for isolated islands and the challenges for isolated systems when introducing a large amount of renewable energy, and also has examined ways in which to best address those challenges. This paper describes the challenges and solutions for the application of microgrid systems to small isolated islands and also presents an overview of demonstration projects being carried out on six islands in Kyushu and three islands in Okinawa.

1. Introduction

To address global environmental issues including the reduction of greenhouse gas emissions, the creation of a framework and the setting of goals on a global scale are being examined. In this context, the adoption of renewable energy is considered to be effective both for resolving environmental issues as well as fostering new industries, and future developments are expected.

Meanwhile, the mass adoption of renewable energy raises concerns about possible deleterious effects on the power system.

Since the latter half of the 1990s, countries of the European Union (EU) have advanced the adoption of large quantities of wind power in order to tackle global environmental issues, but various system problems have become evident and a solution is urgently needed.

Since 2009, Fuji Electric has studied microgrid system configurations for isolated islands, the issues involving independent systems when large amounts of renewable energy are introduced, and methods for resolving those issues.

This paper presents an overview of the control functions and the types of equipment that are installed when applying these microgrid systems to isolated islands.

2. Application of Microgrids to Island Power Systems

2.1 Microgrid system

A microgrid system uses multiple distributed power sources and operates a power supply system while maintaining a regional balance between power demand and supply. A microgrid system has the following characteristics.

(a) Applicable to special regions where multiple consumers exist
(b) Configured from distributed power sources and a small-scale power supply network
(c) Onsite power supply system capable of operating separately from a pre-existing large-scale power supply system
(d) Configured as either a system linked-type that is linked to the power system, or an independent-type separate from the power system
(e) Typically uses Information and Communication Technology (ICT) for integrated control of multiple distributed power sources and loads

As an interchange power supply system that uses renewable energy, this type of small-scale system is an environment friendly power system that, because it contains equipment for storing energy and heat, is able to absorb the fluctuations in demand and output arising from renewable energy within the region, and is expected to come into widespread use as a system that is compatible with existing systems and that does not negatively affect pre-existing power sources.

2.2 Goals and issues in the application of microgrids to isolated islands

An isolated island microgrid system is a specialized small to medium-sized independent power system that inherits the original microgrid characteristics and that aims to maintain the quality and to ensure the reliability of power in an independent system when large amounts of renewable energy are introduced.

Countless inhabited islands exist worldwide, the majority of which are supplied with electric power by independent systems. Japan has the largest number of isolated-island independent power systems of any country.

† Fuji Electric Co., Ltd

In independent power systems for isolated islands, due to problems with operational constraints and the like, power is typically supplied from internal combustion power generators, which use fossil fuel and have a relatively large CO_2 emission factor. Additionally, the transportation of fuel to remote areas adds to the cost of power generation, and economic efficiency is an issue for isolated islands.

The mass adoption of renewable energy, without requiring fossil fuels, by isolated islands is thought to provide the solutions of both reduced environmental load and improved economic efficiency.

The mass adoption of renewable energy, however, leads to a decrease in power quality and supply reliability of the power system, and measures to reach a solution are needed. The challenges when renewable energy is adopted by an isolated island are listed in Table 1.

The introduction of a microgrid system provides an effective resolution for the various issues of concern in the case of a mass adoption of renewable energy at an isolated islanded.

Table 1 Challenges for adopting renewable energy on isolated islands

Item	Challenge
Supply/demand operation management	Balance between supply and demand must be maintained at all times (allowable fluctuations are within range of the governor following capability for pre-existing generators)
Frequency and voltage sustainability	Renewable energy and load fluctuations cause large and instantaneous changes in frequency and voltage
Reserve power	Reserve power is extremely low (because the generator unit capacity is small)
Economic feasibility	If sufficient reserve power (increased margin) is provided to compensate for the amount of fluctuation in renewable energy, the diesel generators will operate at a point of low output and the fuel efficiency will decrease.

3. Isolated Island Microgrid Systems

3.1 Basic configuration

Figure 1 shows the basic configuration of an isolated island microgrid system.

The system, which consists of an existing internal-combustion power generation system and renewable energy and electric power storage systems, measures with a sensor the generated power and power quality assessment items (frequency, reactive power, etc.) and sends the measured values via a high-speed transmission path to a microgrid control system.

A small-scale system operates mainly with small capacity internal combustion generators having low inertial energy and is susceptible to decreases in power quality due to instantaneous fluctuations in frequency or the like caused by outages or abrupt changes in the output of renewable energy. The control device (governor control) of an existing system is unable to follow such abrupt changes, and unless countermeasures are implemented, the frequency may deviate from the pre-

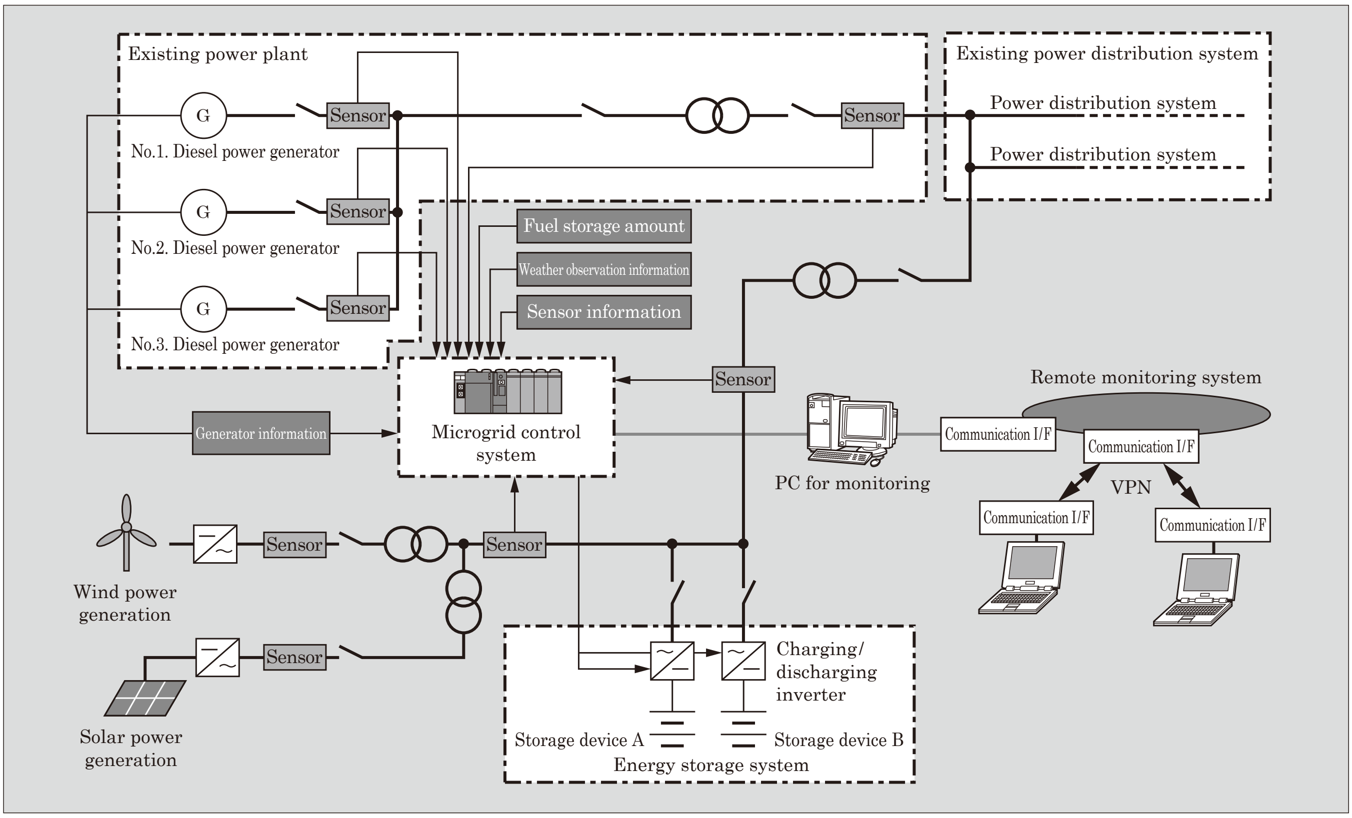


Fig.1 Basic configuration of isolated island microgrid system

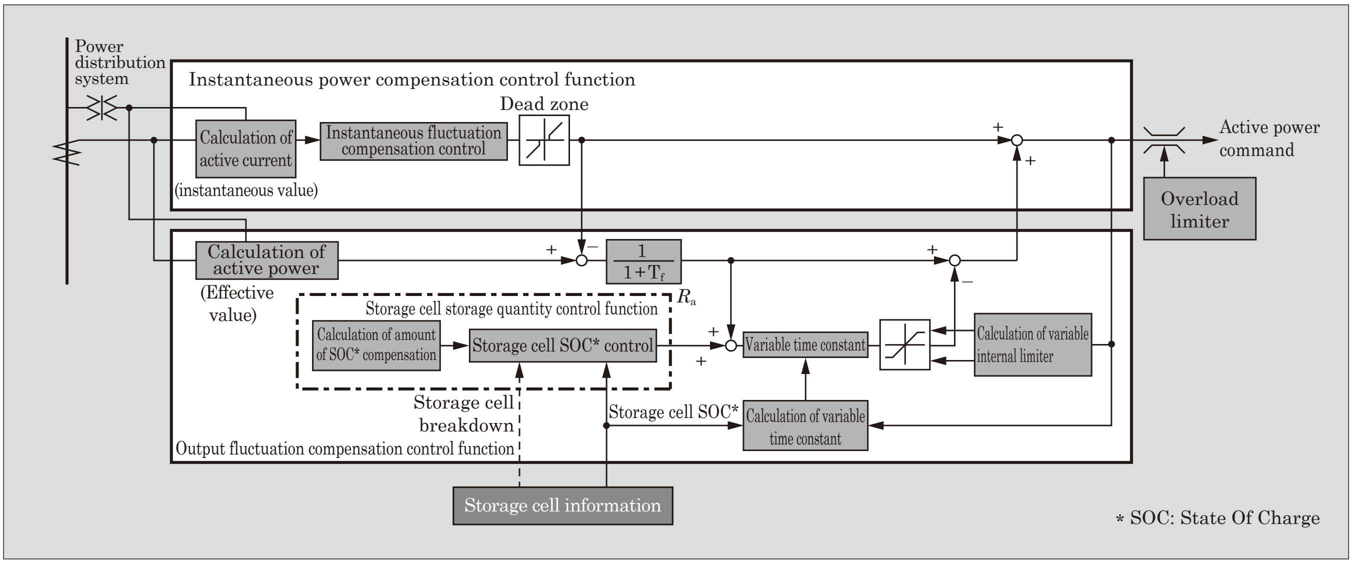


Fig.2 Configuration of control function for a small-scale isolated island system

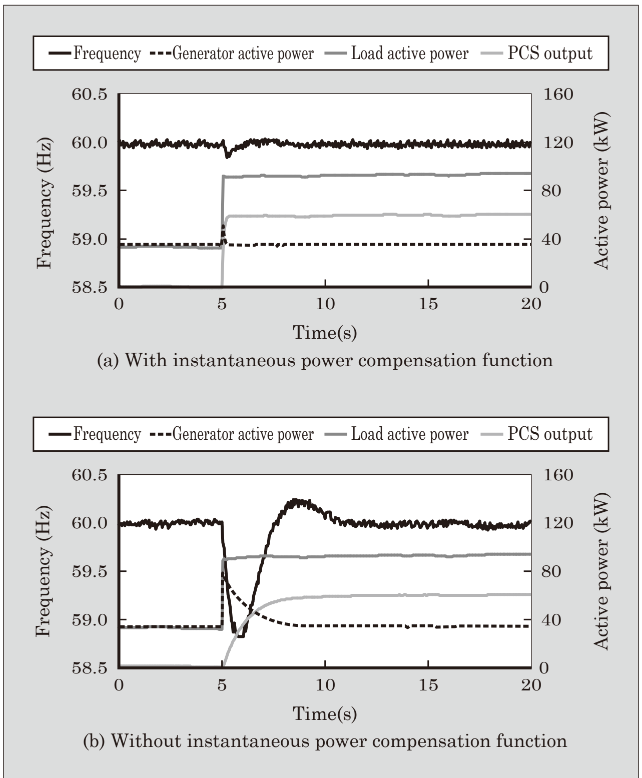


Fig.3 Suppressive effect of frequency fluctuation by instantaneous power compensation

scribed value and the power quality of the system will deteriorate.

In the case of an isolated island system of about several hundred kW, these instantaneous frequency fluctuations tend to become noticeable, and a high-speed function for compensating for these fluctuations is needed. Furthermore, on a small-scale isolated island, the number of generators in operation is few, and the operation can only be adjusted over a small range. Thus, if the percentage of power generated by renewable energy increases, stable operation within the operating range of the existing generators will be difficult to maintain, and measures such as peak shifting by controlling the output of the renewable energy, adding redundant electric power storage systems and increasing capacity are needed.

Additionally, in the case of an isolated island system of about 1,000 kW (a medium-scale isolated island system), the system operates mainly by controlling multiple internal generators, and a wide operating range can be set if there is a sufficient margin of reserve power. Thus, a microgrid system is able to realize the most economical system configuration within the control range of pre-existing generation equipment.

3.2 Control functions in a small-scale isolated island system

Fuji Electric has commercialized its “UPS 8000 G” series of uninterruptible power supplies that are equipped with an absorber function for assisting the load-following performance when a load is applied to a high-efficiency gas engine generator. These uninterruptible power supplies sense instantaneous fluctuations in the load and are able to provide instantaneous fluctuation compensation of approximately several milliseconds to 10 ms. In addition, a demonstration tests for stabilization equipment that aims to suppress output fluctuations of wind farm has been underway since 2008 at the Nishime Wind Farm operated by Win-power Co., Ltd. (a wholly owned subsidiary of Fuji Electric).

As a result of the demonstration tests, stabilization technology and technology for the operation and management of storage devices has been established. Based on these technologies, a microgrid control function for small-scale isolated island systems was developed.

Figure 2 shows the configuration of a control function for a developed small-scale isolated island system. This control function enables control to be implemented in response to instantaneous fluctuations due to wind turbine cut-out, outages of photovoltaic power conditioner and the like, without deviating from the system frequency. Fig. 3 shows the results of simulations comparing the cases with and without the instantaneous power compensation function.

3.3 Control functions in a medium-scale isolated island system

In a medium-scale isolated island system where multiple rotating-type electric power generators are operating at all times, a certain amount of transient fluctuation is absorbed by the inertial energy of the generators. In such a system, the generators are able to operate over a relatively wide range, and the selection of suitable storage devices and reduction of generator capacities are important factors to consider so that the installation of equipment will be economical.

Furthermore, as the scale of the system increases, there will be a greater number of installed sites of renewable energy, and fluctuations in the output of the renewable energy will become more difficult to detect. In such cases, fast frequency compensation for the system, including demand fluctuation, is effective.

3.4 Selection of storage devices

When configuring a microgrid, the selection of storage devices is important in terms of both operation and economic efficiency. Fuji Electric, with the help of storage device manufacturers, has conducted validation testing of nickel metal hydride batteries, high-cycle lead-acid storage batteries and electric double-layer capacitors at the Nishime Wind Farm.

As a result of this validation testing, Fuji Electric has developed a storage device management function that considers the allowable depth of discharge and cycle life characteristics for each device.

The different types of storage devices have different characteristics as shown in Fig. 4. The selection of storage devices must consider, in addition to these characteristics, the cycle life, required space for installation, and the economic efficiency.

In general, for load balancing purposes, such as peak shifting, larger capacity storage devices are required, and storage cells having a relatively high volumetric energy density are advantageous.

On the other hand, for fluctuation compensation purposes, various storage devices are considered for application. As a stabilization measure for relatively short-period fluctuations lasting several minutes or less, a capacitor is advantageous in terms of cycle life and volumetric power density. Moreover, for the compensation of long-period fluctuations lasting several tens of minutes or more, various types of storage cells, including new batteries such as lithium ion batteries and the like, are applied.

Fuji Electric has verified the application of these various types of storage devices and has also promoted the joint development of storage devices. Lithium ion capacitor modules for power converters are products that were jointly developed by Fuji Electric and FDK Corporation. These lithium ion capacitor modules can be used for nearly the same purposes as electric double-layer capacitors and are smaller and lighter weight than electric double-layer capacitors of the same capacitance.

The external appearance of a lithium ion capacitor

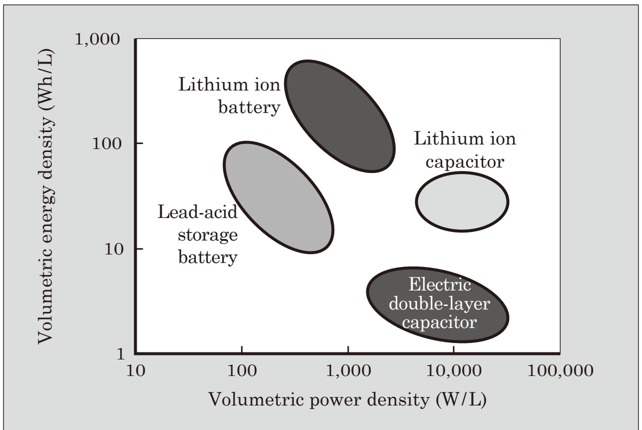


Fig.4 Storage device type and performance

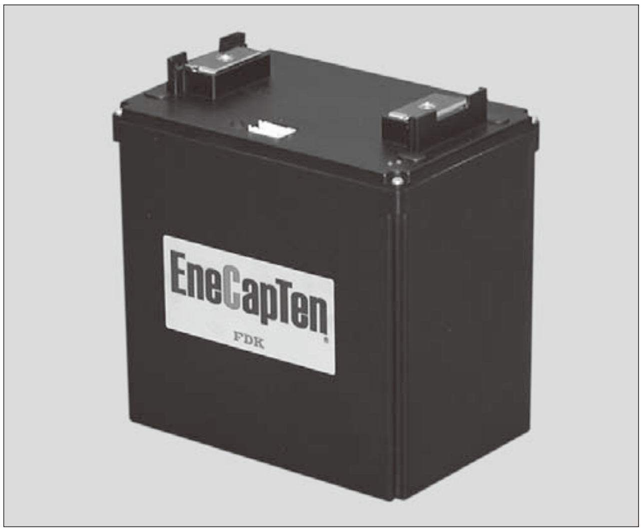


Fig.5 Appearance of lithium ion capacitor module

Table 2 Specifications of lithium ion capacitor module

Item	Specifications
Rated power	DC45 V (27 to 45 V)
Initial static capacitance	200 F or higher (for 1 A discharge)
Initial internal DC resistance	19 mΩ or less (for 100 A discharge)
Charge and discharge current (rated)	20 A
External dimensions	W203×D134×H193 (mm)
Mass	6 kg

is shown in Fig. 5, and its specifications are listed in Table 2.

3.5 Fast frequency detector

Frequency detection in the microgrid provides not only an indicator of the power quality, but is also an important indicator for assessing the balance between the supply and demand of power within a microgrid that includes internal combustion generators.

In order to achieve coordinated control over the entirety of an independent power system on an isolated island, the microgrid control must function effectively in response to instantaneous frequency fluctuations that pre-existing control devices are unable to follow.

The principle of system frequency detection is based on, for example, the number of times that the system AC voltage transitions from a negative voltage to a positive voltage within a certain period of time, and a method[1] for computing the time of an AC cycle from the time required for N transitions, or the like is used. In this case, the frequency detection requires a detection time ranging from several hundred milliseconds to ten seconds.

Using the system AC voltage as a signal source, and a proprietary error compression algorithm and an optimized characteristics filter, Fuji Electric has developed a fast-frequency detector that achieves a frequency-following performance of approximately 30 ms for frequency fluctuations in an actual power system, and has applied this fast-frequency detector to fast-frequency fluctuation compensation as part of the microgrid control function. Fig. 6 shows an example of actual measurement results obtained with the newly developed fast-frequency detector.

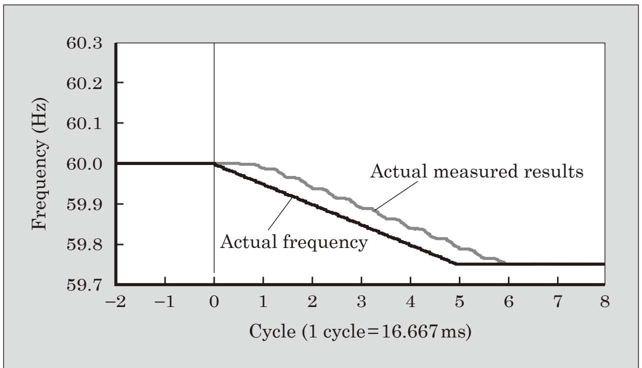


Fig.6 Example measurement results of fast frequency detector

4. Demonstration tests of Isolated Island Microgrid System

4.1 Demonstration tests in small-scale isolated island system

Fuji Electric has delivered isolated island microgrid-related equipment to the Kyushu Electric Power Co., which has received an "Island Independent-type New Energy Demonstration Project Grant" from the Japanese Ministry of Economy, Trade and Industry. A summary of the equipment installed is listed in Table 3.

The amount of new energy adopted in relation to the scale of the system varies by approximately 10 to 30% depending on the island, but exceeds 50% of the minimum demand occurring during an intermediate

Table 3 Overview of equipment to be installed (small-scale isolated island system)

Name of isolated island \ Equipment to be installed	Solar power (kW)	Wind power (kW)	Lead-acid batteries (kWh)	Lithium ion batteries (kWh)
Kuroshima	6.0	10	256	66
Takeshima	7.5	—	—	33
Nakanoshima	15.0	—	80	—
Suwanosejima	10.0	—	80	—
Kodakarajima	7.5	—	80	—
Takarajima	10.0	—	80	—

Fig.7 Appearance of storage containers

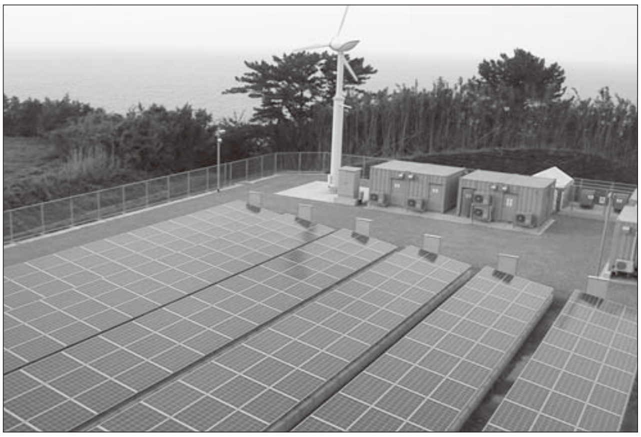


Fig.8 Overall view of system (Kuroshima)

Table 4 Overview of equipment to be installed (medium-scale isolated island system)

Equipment to be installed / Name of isolated island	Solar power (kW)	Electrical power storage system	
		Converter capacity (kW)	Capacitor capacity (kWh)
Taramajima	250 (25)	300	7.2
Yonagunijima	150 (15)	200	4.7
Kitadaitoujima	100 (10)	100	2.9

Note: Values enclosed in parentheses show the capacity of Fuji Electric's film-type amorphous solar cell "FWAVE"

Fig.9 Overall view of system (Taramajima)

period such as the Spring or Autumn. Storage cells, consisting of high-cycle life lead-acid storage batteries and lithium ion batters, are used for fluctuation compensation, peak shifting and other smoothing purposes. Because these islands are far from the mainland and the transport constraints are severe, electrical products such as interconnecting equipment and inverters are all installed and wired in small storage containers on the mainland, and are then shipped in order to streamline the onsite construction work.

Figure 7 shows the external appearance of storage containers and Fig. 8 shows the overall view of the system.

4.2 Demonstration tests in medium-scale isolated island system

Fuji Electric has also delivered isolated island microgrid-related equipment to the Okinawa Electric Power Co., which has received an "Island Independent-type New Energy Demonstration Project Grant" from the Japanese Ministry of Economy, Trade and Industry. A summary of the equipment installed is listed in Table 4.

In this system, the abovementioned lithium ion capacitor module was applied to system stabilization for the first time in the world. Capacitors for each type of equipment were designed so as to be able to smooth the steep output fluctuations occurring in the system within the response range of pre-existing control equipment. Additionally, the control apparatus employs fast-frequency control that utilizes a fast-frequency detector, and for fluctuations in the system frequency, is provided with a function that aims to stabilize the frequency prior to the response of the governor-free function of a pre-existing power generating system. Fig. 9 shows an overall view of the installed system.

5. Postscript

This paper has introduced Fuji Electric's characteristic products and application technology for isolated island microgrids. In the future, with system standardization and the completion of packaging, Fuji Electric plans to pursue economic efficiency, and streamlined transportation and execution with an eye on overseas markets.

Finally, the authors wish to thank all the relevant individuals from the Kyushu Electric Power Co., Okinawa Power Co., and Okinawa Enetech Co. for their tremendous cooperation and guidance regarding the adoption of equipment for the demonstration projects and their cooperation in providing materials for this manuscript.

References

(1) IEEE 61000-4-30 Electromagnetic compatibility (EMC) – Part 4-30: Testing and measurement techniques – Power quality measurement methods. p.25.

Cooperative University-Industry Research with Zhejiang University: Toward the Creation of Smart Grid Related Business

Yun Lei † Kimihisa Kaneko † Naoto Kobayashi †

ABSTRACT

In China, the economy has continued to grow and the market has continued to expand since the year 2000. To develop and produce products that meet the needs of customers in China, Fuji Electric has established cooperative relationships with several Chinese universities and is engaged in cooperative research in university-industry partnerships. Specifically, Fuji Electric and Zhejiang University have entered into a comprehensive agreement and are advancing a unique partnership that aims to advance research work for the creation of new products and new business and also to promote activities that will contribute positively to society. Building upon the prior development work and field testing of systems that comply with GB standards (Chinese national standards) for power quality measurement in a distribution system, this collaboration will endeavor to expand smart grid related business to the field of power stabilization technology.

1. Introduction

In the 1990s, as a result of China's policies of reform and opening-up, many foreign companies decided to move into China. With the launching of a new base for motor manufacturing, Fuji Electric also began to move into China.

In the 2000s, market in China has expanded as its economy has developed, and in preparation for the 2008 Beijing Olympics, infrastructure development has been advanced at a rapid pace. Under these circumstances, in order for foreign companies in China to expand their business into the Chinese market, not just low cost manufacturing, but also product development and manufacturing suited to the needs of Chinese customers have come to be strongly required. In response, Fuji Electric is establishing cooperative relationships with many Chinese universities, and has entered into a comprehensive partnership with Zhejiang University. This paper introduces the university-industry partnership between Fuji Electric and Zhejiang University, and efforts to create business opportunities relating to smart grids.

2. Characteristics of Universities in China

Owing to their political, national, cultural and historical backgrounds, universities in China have the following characteristics.

(a) Close relationship with government
(b) "Old boy" network cultivated through dormitory life
(c) Contributor to Chinese company research
(d) Research and development supported by an abundance of graduate students
(e) Active business management and university-industry collaboration

There is an active exchange of personnel between universities and governments/administrative authorities. As a result, networks closely connected with industry, government, academia and research institutions are formed and have a significant impact on government policy.

All university students live in dormitories, and this student lifestyle fosters a strong sense of camaraderie that continues even after graduation. Eighty-four percent of graduates find jobs with private companies, and corporate ties using "old boy" networks are utilized extensively. Also, 14% of graduates find jobs in the government sector, further strengthening the ties between one's alma mater and industry, government and academia.

Thirty-five percent of corporate research and development expenditures in China in 2008 were outsourced to universities, a high percentage that is approximately 12 times greater than that of Japan, and is an indication of the active collaborations between industry and academia. The research outsourced from companies is performed mostly by graduate students under the guidance of professors. The number of these graduate students is about 13 times that of Japanese universities.

Many examples exist of universities themselves managing companies, and there is a strong entrepreneurial mindset. The total revenue obtained from corporate management by the top 20 Chinese universities in 2009 was 120 billion yuan (approximately 1.48 trillion yen).

In this way, Chinese universities exert a much greater influence on domestic industry than Japanese universities.

† Fuji Electric Co., Ltd

3. University-Industry Partnership With Zhejiang University

In Japan, some companies also utilize research at Chinese universities as one part of their research and development base[(1)]. These university-industry partnerships, in addition to being an efficient use of research and development funds, are also reported to be advantageous for forming networking contacts, acquiring expertise in areas of academic research, and so on. On the other hand, the need to manage intellectual property carefully and to pay close attention to compliance with the laws of Japan and China has also been reported.

Fuji Electric, having fully analyzed and considered such advantages and disadvantages in conjunction with its relevant departments and affiliates, is developing university-industry partnerships as part of its business expansion in China.

In 2004, Fuji Electric entered into a university-industry partnership with Zhejiang University, and began research and development work. Then, in April 2006, Fuji Electric and Zhejiang University entered into a comprehensive collaborative agreement, establishing the "Zhejiang University – Fuji Electric Systems Research and Development Center" at Zhejiang University, and expanding their university-industry collaboration over many fields. Building upon the positive results obtained from specific activities over four years, and in order to strengthen cooperation for the creation of additional business, Fuji Electric founded the "Zhejiang University – Fuji Electric Innovation Center" in April 2010 to enlarge the scope of collaboration and to promote various collaborative activities.

3.1 Individual research

Fuji Electric and Zhejiang University have maintained a certain relationship at the researcher level since the 1990s. To further expand business in China, in 2004, Fuji Electric conducted a feasibility study in the power supply field.

3.2 Zhejiang University – Fuji Electric Systems Research and Development Center

In the research and development of basic and applied technologies in China, in addition to conducting individual research in specific technical fields as in the past, from the medium and long-term perspective, there is a need for collaborative activities and close cooperation in many technical fields in order to advance research. For this purpose, Fuji Electric Systems Co., Ltd.*1, the principal operating company of the collaborative research project with Zhejiang University, established and operated the "Zhejiang – Fuji Electric Systems Research and Development Center" for a period of 4 years, beginning in April 2006.

At this Center, more than 10 research projects were initiated in electrical and other fields, and research and development as well as demonstration experiments were carried out, resulting in patent applications, published papers, and so on.

One activity of this Center is to foster personnel exchanges and educational cooperation, and technical exchange meetings were held for specific technical fields, such as power electronics, to promote mutual understanding in academia and industry. Additionally, Zhejiang University professors also held educational activities for employees of Fuji Electric's base in China, and the collaboration was expanded to include technical exchanges with relevant affiliates. The diverse range of activities over these 4 years resulted in a closer partnership and greater mutual trust by both sides.

3.3 Zhejiang University – Fuji Electric Innovation Center

Based on the mutual trust cultivated with Zhejiang University, and in consideration of the benefits of cooperation in a wider range of fields and the need for activities that emphasize new business creation in addition to new product development, Fuji Electric has decided to adopt a collective approach as entire group. Accordingly, in April 2010, Zhejiang University and Fuji Electric Holdings Co., Ltd. established the "Zhejiang University – Fuji Electric Innovation Center" in the Zhejiang University campus.

Global warming and climate change are becoming serious problems at the global level and in order

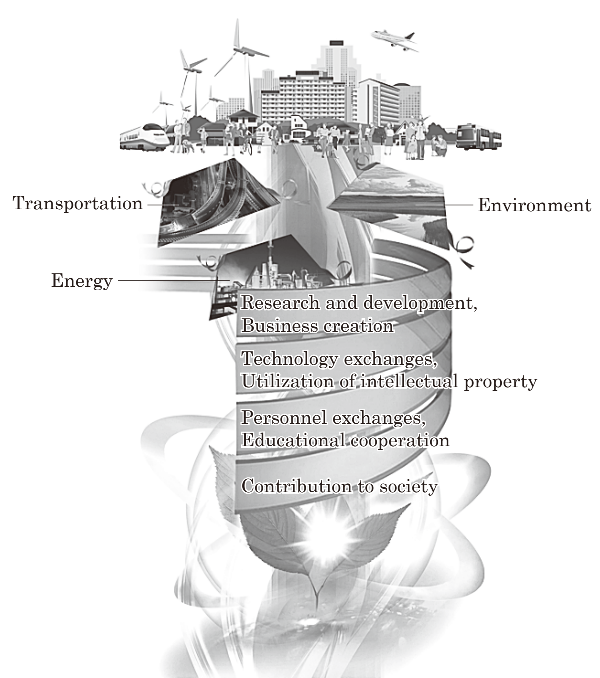


Fig.1 Key business areas and activities

*1: Fuji Electric Systems Co., Ltd.: Merged with Fuji Electric Holdings Co., Ltd. in April 2011 to create the present Fuji Electric Co., Ltd.

to contribute to solving these problems Fuji Electric is focusing on the "energy and environment" business field, and intends to expand businesses globally in this field. For this purpose, the technology and human resources of Zhejiang University and the technology and business experience of Fuji Electric are leveraged to strengthen business creation activities primarily in the "energy and environment" field.

Efforts at the Center, mainly in the three business fields of energy, environment and transportation, are concentrated on the four activity areas of research and development and business creation, technological exchanges and utilization of intellectual property, personnel exchanges and educational cooperation, and partner cultivation and societal contributions (see Fig. 1).

4. Initiatives in smart grid-related fields

In the field of power systems, one of the fields in the energy business sector, university-industry partnerships are expanding through a three-tier frame work (see Table 1), whereby a feasibility study of the power system business in China was conducted first, then product development and demonstration projects were carried out, and at present, smart grid-related business creation is being expanded. Table 2 lists items implemented in the power system field, and details are presented below.

Table 1 Framework of university-industry partnerships

Organization	2004 to 2005	2006 to 2009	2010 to 2013
Individual research	Chinese power supply business feasibility study		
Zhejiang University – Fuji Electric Systems Research and Development Center		Product development and demonstration projects	
Zhejiang University – Fuji Electric Innovation Center			Smart grid-related business creation

4.1 Chinese power system business feasibility study

From 2004 to 2005, Fuji Electric conducted a feasibility study of the power system business in China.

With its rapid economic growth, the demand for power in China increases day by day. As the capacities of large-scale power facilities are increased, improvements in power transmission and distribution systems are also expected. Having acquired power system development and automation experience during periods of high growth in Japan, Fuji Electric's power system monitoring and control technology is considered to be essential for China. To expand Fuji Electric's business opportunities in the electric power field in China, the first step was to conduct a feasibility study of the power system business in China.

Fuji Electric's proprietary technology was analyzed and studied with regard to its applicability and business potential in the Chinese market in the following seven areas: energy management systems (EMS), distribution management systems (DMS), automatic meter reading (AMR), power quality (PQ) measurement and countermeasures, energy conservation, new energy, and electricity trading market. The results indicated that, in the near future, power infrastructure in China will require DMS effective for reducing the annual downtime and increasing the efficiency of power distribution equipment investment, PQ measurement and countermeasures effective for assessing the power quality, i.e., high frequency harmonics, instantaneous voltage drops and the like, and EMS and AMR effective for increasing the efficiency of supply-demand balance control, including energy conservation.

Fuji Electric has identified the following three areas as high-priority technical fields, and is moving ahead with research and development for the Chinese

Table 2 Implemented items in the electric power system field

Power-related cooperation phase	Items implemented	Achievement
Chinese power system business feasibility study	Of the technology owned by Fuji Electric, adaptability in the Chinese market was analyzed for 7 fields	Identification of 3 high-priority technical fields (a) DMS field (b) PQ field (c) EMS field
Product development and demonstration projects	Development in the identified fields: ○ Localization of distribution automation system ○ Field trial of wide-area PQ* measurement system, Development of complex PQ* countermeasure devices ○ Development and application of system-wide VQ* control algorithms	○ Acquisition of certification for wide-area PQ* measurement system ○ Practical application at power utilities
Smart grid-related business creation	○ Demonstration of smart grids ○ Development of system-related simulation models, etc.	○ Business creation

* PQ : Power Quality
* VQ : Voltage Q (reactive power)

market.

(a) DMS field
(b) PQ field
(c) EMS field

4.2 Product development and demonstration projects

From 2006 to 2009, at the Zhejiang University – Fuji Electric Systems Research and Development Center, product development and demonstration experiments were carried out for the three technical fields identified in the feasibility study.

In the DMS field, the many proven DMS solutions of Japanese power companies were additionally developed and localized so that the capability to interface with other systems, the accident recovery sequence and so on would accommodate the operational management rules and structure of Chinese power companies.

In the PQ field, power measurement terminals that comply with GB standards (Chinese national standards) were developed, and field trials of a wide-area PQ measurement system (Fig. 2) that uses an actual power company system and its information infrastructure were carried out. Typical problems with the power quality in China were analyzed and power electronics devices were researched and prototypes were developed in order to realize complex PQ countermeasures. Additionally, system-wide VQ (Voltage Q (reactive power)) control algorithms were developed to control voltage and reactive power throughout the entire system, including the power transmission and distribution system, and a certain power company has applied these algorithms.

In the EMS field, electric power load prediction and how to control limited power supply facilities so as to best accommodate load fluctuations are major challenges. Fuji Electric has researched and analyzed various load leveling control methods, such as the use of power pumped-storage power generation and chiller cooling systems to shift power utilization to low-load (nighttime) hours.

Through such specific research and development activities, the characteristics and technical challenges of power systems in China have come to be understood. In addition, by carrying out demonstration trials at power companies, the adaptability of Fuji Electric's proprietary technology to the Chinese market was confirmed. The results of these activities led to the acquisition of certification of a wide-area PQ measurement system, which directly tied to business opportunities.

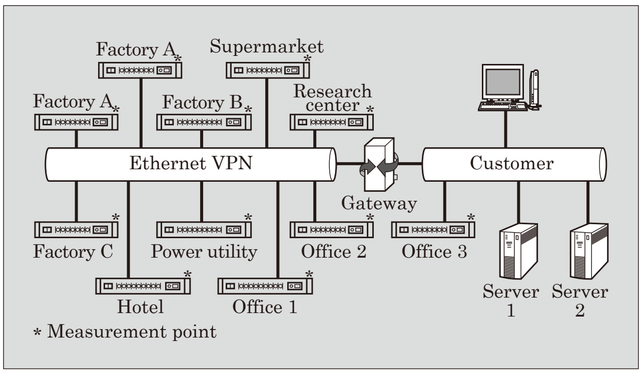


Fig.2 Overview of wide-area PQ measurement system

4.3 Creation of smart grid-related business

From 2010 to 2013, the Zhejiang University – Fuji Electric Innovation Center is endeavoring to create smart grid-related business opportunities.

Since the global financial crisis, in order to prevent global warming and as economic policy, smart grids have attracted attention as a way for realizing more efficient power systems and to help popularize new type of energy. Several national key projects (National High-tech Research and Development Programs) have been conducted at Zhejiang University so far. Especially noteworthy is the recent involvement in a national key project for conducting demonstrations related to smart grid usage on remote islands. Based on established power system monitoring control technology and a business infrastructure, Fuji Electric is endeavoring to create new smart grid-related business that will fully utilize power electronics, an area of technical strength of Fuji Electric.

This Center is advancing smart grid demonstration projects, including the development of new energy system interconnection simulation models and the localization of power system stabilization technology, for systems that strive to achieve a renewable energy system that combines safe, reliable energy with environmental technologies and a self-sufficient balance system.

5. Postscript

Energy policy is being reviewed as a consequence of the Great East Japan Earthquake of March 11, 2011. As renewable energies such as solar and wind power become widespread, and load leveling by storing electric power and power system stabilization is needed increasingly, those trends will expand globally, and such needs will increase further in China as well. Fuji Electric, based on its wealth of accumulated technology, intends to create smart grid related business opportunities in China in order to contribute to economic development and to help resolve environmental problems in China.

References

(1) Jianmin Jin. Japanese Enterprises and R&D Activities by Multinational Enterprises in China. Fujitsu Research Institute. Reserch Report. No. 270, July 2006.

System Technology that Supports Next Generation Electricity Delivery

Satoru Takahashi † Yasuhisa Kanazawa † Tatsuo Suzuki †

ABSTRACT

When a large amount of solar power is introduced into a system, reverse flow and voltage fluctuations occur. Moreover, this is feared to affect the demand/supply control, since net demand cannot be ascertained. To solve this problem, Fuji Electric optimized the placement and setting values of voltage control equipment, and is developing a centralized control method. Devices models for analysis, a method of predicting solar power output and a demand/supply control function are also being developed.

To replace aging facilities, a unit replacement-type protective relay using a new IED (Intelligent Electrical Device), and in support of the diversifying operating modes of power companies, IP network devices, middleware for wide-area distributed power, and a disaster prevention and crisis management system are being developed.

1. Introduction

As power consumption increases due to continued economic growth, power companies and manufacturers have been endeavoring for many years to realize a stable supply of power, which is the primary goal of power distribution, and to streamline their operations with the aim of increasing economic efficiency. Systems that support power distribution include centralized monitoring control systems that use computer technology, protection and control systems that prevent the spread of system faults in the event of system trouble, and so on, and these systems have been utilized to realize a high degree of supply reliability.

In the future, with the aim of achieving a low-carbon society, the mass adoption of distributed power generation predominately consisting of solar power generation and wind power generation is anticipated. Additionally, there will be a need for the renewal of aging protective relay equipment that had been delivered more than 20 years prior and for increasing the efficiency of power system operation. These types of challenges and Fuji Electric's efforts in the power distribution field are described below.

2. The Power Distribution Field: Present Status and Challenges

In the power distribution field, Fuji Electric has developed and delivered various types of support systems, including power system control systems, distribution automation systems, remote supervisory control system, protection and control systems, system analysis simulators and power demand prediction systems. Figure 1 shows the main products that Fuji Electric has developed and delivered in the power distribution field.

Challenges related to the mass adoption of distributed power generation, as well as challenges involved in the renewal of aging equipment and efforts to increase the operating efficiency are described below.

2.1 Challenges relating to mass adoption of distributed power generation

(1) Challenges of power distribution systems

In the mass adoption of distributed power sources, such as in the case of solar power generation, the occurrence of voltage rises due to reverse flow and voltage fluctuations on the distribution line due to abrupt output fluctuations are problems associated with power distribution systems. At present, power

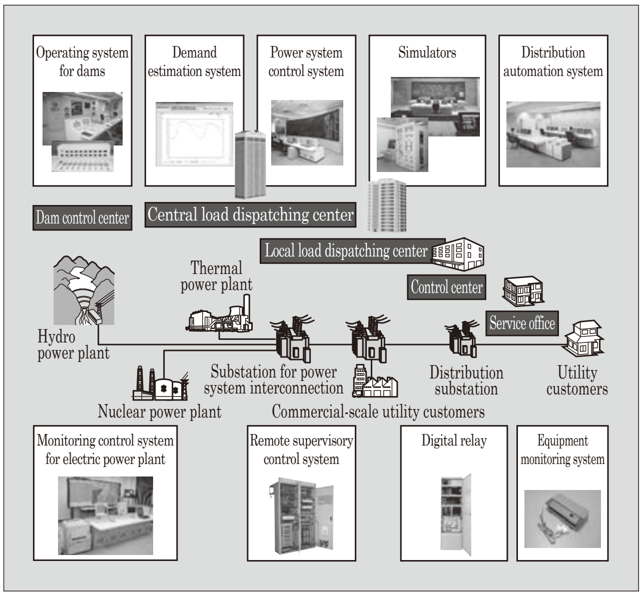


Fig.1 Fuji Electric's power distribution products

† Fuji Electric Co., Ltd

regulating devices such as on-load tap-changing transformers (LRT: load ratio control transformers), automatic voltage regulators (SVR: step voltage regulators) and static reactive power compensators (SVC: static var compensators) are used at distribution substations with the aim of realizing a suitable system voltage in a power distribution system. However, the regulating ability of a voltage control method based on the effect of individual voltage regulating equipment is limited, and solutions for anticipated problems are needed.

(2) Challenges in supply/demand operational management

In the case of the mass adoption of solar power generation in homes, the generated power output will not be measurable in real-time. The power companies will be unable to ascertain the net demand for power, and therefore must, in order to maintain the power system frequency, implement supply/demand operational management based on predictions of solar power generation output. Moreover, to accommodate the absorption of surplus electricity at the load side and increased loads due to sudden fluctuations in the weather, a storage cell optimization control function, a reverse flow detection function and the like are necessary.

(3) Challenges in power system analysis

In the future, to demonstrate the effect of the installation of newly-developed distributed power sources and the effect of control systems on the power system, analytical models for distributed power sources must be designed to be easily and rapidly introducible into a systems analysis simulator.

2.2 Next-generation support of aging protective relay equipment

Due to the aging of equipment and an accelerated replacement cycle for major equipment components, renewal work for protection and control systems in Japan will increase in the future. Protective relays utilize electronic components having a short improvement or elimination cycle, and device configurations that allow for easy updating by unit replacement are the mainstream. Moreover, so that protection and control systems can be connected easily to equipment made by different manufacturers, i.e., so as to realize a multivendor system, monitoring control systems and protective relay systems will converge further, aiming for an all digital system.

2.3 Improvement of operating efficiency

In order to reduce the operational management cost of power systems, the trend toward consolidation of multiple operational management organizations such as load dispatching offices and service offices provided with distribution automation systems has been accelerating in recent years. For this purpose, construction technology for monitoring and control systems capable of responding to changes in the operating mode is needed.

Moreover, the workload on the operator increases as monitoring and control is performed over a wider range, and remedial measures are needed.

3. Fuji Electric's Efforts in the Next-Generation Power Distribution Field

3.1 Measurers for the mass adoption of distributed power sources

(1) Measures for distribution systems

(a) Power distribution system voltage fluctuation suppression technology

As voltage fluctuation suppression technology for next-generation power distribution systems that support the mass adoption of distributed power sources, Fuji Electric is using state estimation, power flow calculations and optimization methods to develop planning support for optimally arranging voltage regulating devices, and a voltage control method for controlling the voltage in distribution systems to suitable levels. Fig. 2 shows an overview of the distributed voltage control developed by Fuji Electric.

(i) Optimal arrangement of voltage regulating devices

To streamline the operation to plan for installation or relocation, optimization techniques are used to calculate the SVR installation location at which the deviation rate from upper and lower voltage limits is smallest throughout the year.

(ii) Optimization of voltage regulating device set points

In order to minimize the operating frequency of the SVRs, optimization techniques are used to calculate the combination of set points for multiple SVRs at which the deviation rate from upper and lower voltage limits is smallest throughout the year.

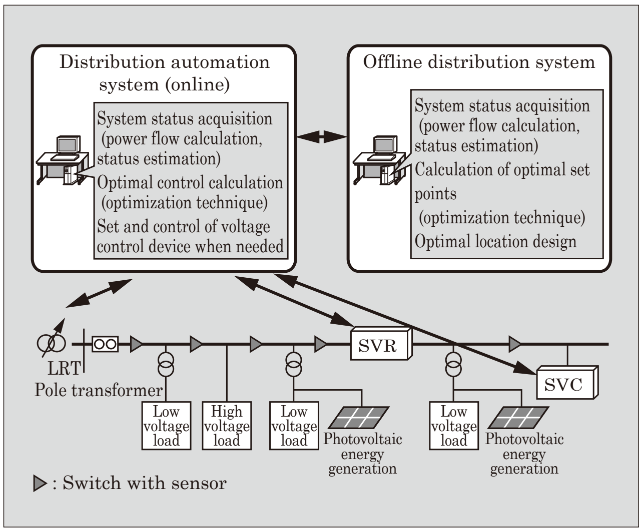


Fig.2 Overview of distribution voltage control

(iii) Centralized control of voltage regulating devices

So that the voltage throughout an entire distribution bank incorporating large quantities of solar power generation remains within an appropriate voltage range, based on measurement information from switches with sensors, tap values for load ratio control transformers (LRTs) and SVRs on a distribution system, and optimal static var compensator (SVC) voltage command values are calculated, and are centrally controlled in real-time.

(b) Next-generation optimizing control technique demonstration project for power transmission and distribution systems

To establish voltage fluctuation suppression technology, Fuji Electric is participating in the “Next-generation optimizing control technique demonstration project” sponsored by the Japanese Ministry of Economy, Trade and Industry. Aiming for the mass adoption of renewable energy such as solar generation by 2020, this project will conduct, with twenty-eight participating entities including Tokyo University, a three-year development and demonstration experiment for an optimized control method for demand-side devices, a system voltage control method for distribution systems, and the like in order to solve the problems shown in Fig. 3. Fuji Electric is participating in the “voltage suppression technology for distribution systems development” sub-working group of the project.

(2) Measures for a supply/demand operational management using a demand forecasting system

Fuji Electric has delivered power demand estimate systems that use neural network technology to power companies. Using this technology, meteorological forecast information such as the amount of solar radiation is used to predict and estimate the effect on solar power generation, and research is being carried out to reflect those results in system-wide demand estimates. Fig. 4 shows an overview of a demand estimate system for solar power generation. The amount of solar power generation at certain locations is estimated by calculating the amount of solar radiation from numeric cloud cover data based on Grid Point Value (GPV) forecasts by the Japanese Meteorological Agency, and in consideration of longitude-latitude information and temperature forecasts. Fuji Electric plans to apply this

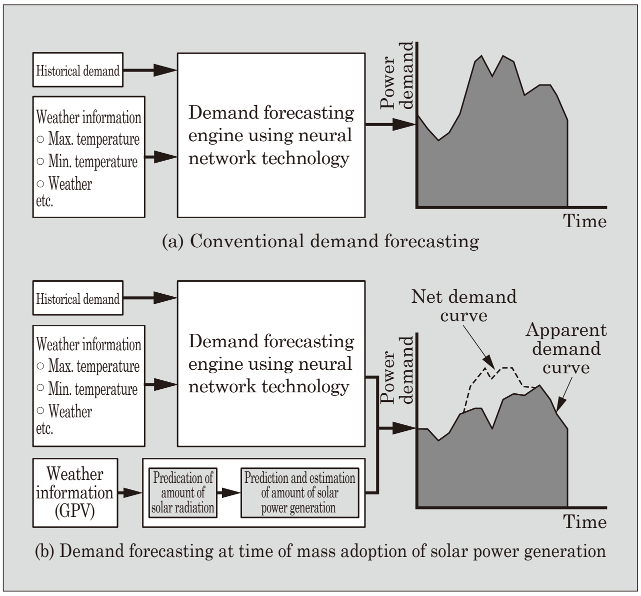
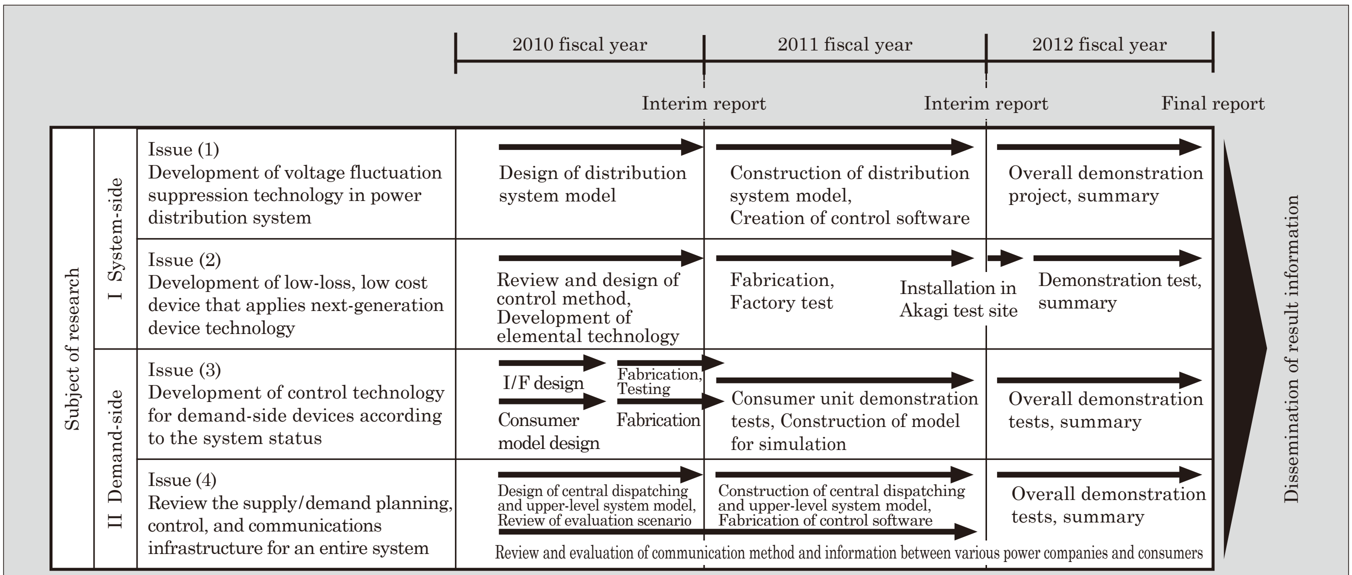


Fig.4 Overview of demand prediction system in consideration of solar power generation



(Source: Next-generation optimizing control technique demonstration project for power transmission and distribution systems document)

Fig.3 Schedule of next-generation optimizing control technique demonstration project for power transmission and distribution systems estimation technique to smart community demonstration projects.

Additionally, in a remote island micro-grid demonstration project, Fuji Electric has developed and applied a supply/demand operational management planning function, an economic load allocating function and a load frequency control function. As the mass adoption of distributed-type power sources and the adoption of electric vehicles (EV) progresses, power companies are expected to implement supply/demand operational management in smaller regional units than at present. For this purpose, Fuji Electric intends to apply its technical expertise acquired through demonstration projects to the power distribution field.

(3) Measures for power system analysis

A power system analysis simulator is configured from an equivalent reduced model of system component devices, and is used to analyze the power flow, steady-state/dynamic-state stability, and power system resonance phenomena, simultaneous faults, and the like.

Fuji Electric has delivered analog-type power system analysis simulators, capable of the real-time analysis from surge phenomena of several micro seconds to economic load allocating that lasts several hours or more, primarily to power companies and universities. An analog-type power system analysis simulator performs calculations with continuous quantities, and therefore has an advantage in that the divergence occurring in digital calculations due to the operation time interval and numeric solutions is less likely to occur. In recent years, to analyze the effect on a power system of the adoption of large-scale renewable energy generation from massive solar power stations, wind stations and so on that is associated with output fluctuations, Fuji Electric has developed models of solar power generation and wind power generation, and has supplied these as device models.

Among such efforts, there is increased utilization of analog-type power system analysis simulators in the analysis of high-level application technology of future power systems, such as next-generation power distribution systems, smart communities and the like.

Analog-type power system analysis simulators support the research and development of future methods for power system device location and control, such as studies of the operating method and point of optimum location of electric power storage systems installed on a power distribution system, including assessment of the effect on power quality due to the mass adoption of solar power generation and wind power generation.

Fuji Electric has begun development of a next-generation hybrid-type power system analysis simulator that combines conventional analog technology with the latest digital processing technology.

3.2 Next-generation substation protection and control systems

At present, Fuji Electric is moving forward with the development of a new intelligent electrical device (IED) that conforms to the IEC 61850 international communication standards. While retaining the environmental performance, reliability, lifespan and the like required of protective power-use relays in Japan, the new IED is positioned as a successor to Fuji Electric's existing protective relays and measurement units, and is a highly reliable controller suitable for use in protection, control, measurement and communication terminal applications. Fig. 5 shows an example configuration of the new IED. The combination of a basic unit and an expansion unit allows the optimal configuration to be provided for individual equipment application. Fuji Electric is also considering application to all-digital substations in the future, including application to protection and control systems.

Moreover, based on the assumption of modular replaceable units, Fuji Electric is also advancing the development of a main unit for digital relays. Fig. 6 shows an example of unit replacement-type protective relay. By integrating the main processing part, the input/output part and the power supply part of a

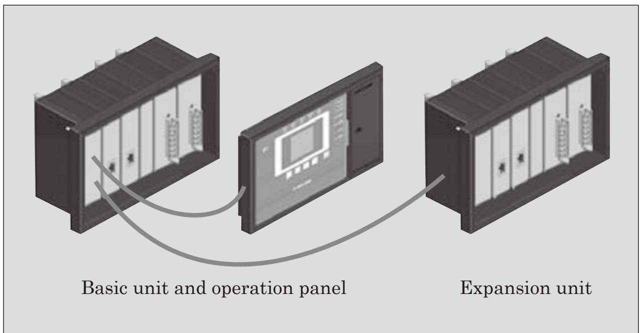


Fig.5 Example configuration of new IED

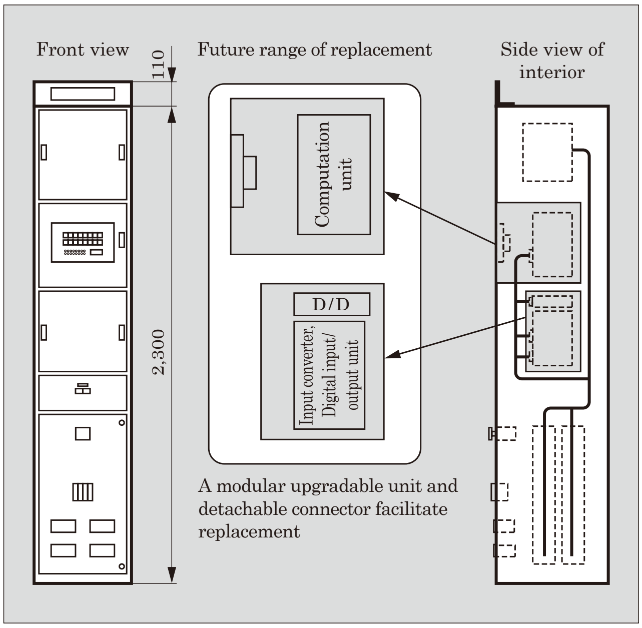


Fig.6 Example of unit-replacement type protective relay

feature issue: Smart Community

protective relay into a single unit, the structure can be upgraded simply by replacing each single unit.

3.3 Technology for realizing improved operational management

Fuji Electric has been providing technologies that support the realization of operational management systems configured in various forms, such as for ensuring the reliability of information transmission. These technologies are outlined below.

(1) IP network support

In the case where multiple operational management organizations are to be consolidated, ensuring a route for the transmission of information to a substation and guaranteeing the reliability of that transmission of information are challenges. Fuji Electric applies the JEMA industrial protocol known as protocol for mission critical industrial network use (PMCN) to ensure data ordering and real-time performance, and to provide an IP network terminal that supports 2-route transmission and 1:N transmission. While maintaining a conventional level of reliability, these terminals support the different operating systems of various power companies.

(2) Middleware for wide-area distributed power systems

The different power companies have various system configurations. Fig. 7 shows an example configuration of a wide-area distributed system. In this system, a single server is centrally positioned at one location and clients only are installed at the other various locations. Other systems include a backup system for a server positioned among multiple locations, and a system capable of monitoring the respective systems at adjacent locations.

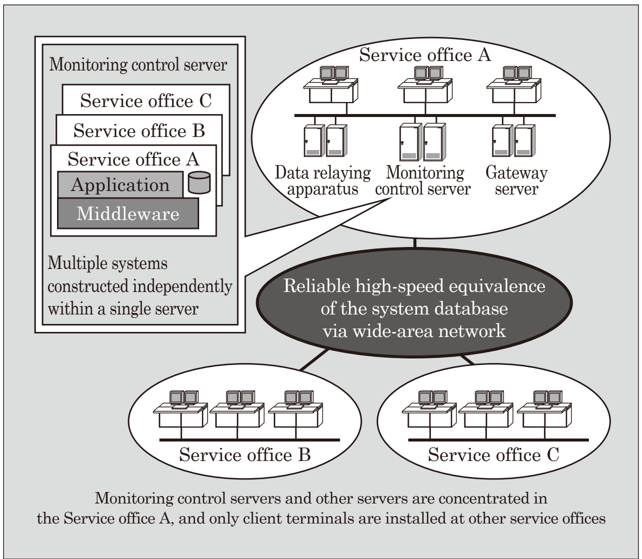


Fig.7 Example configuration of wide-area distributed system

To realize these configurations, the distributed servers must be constantly monitored for application startup/response, database high-speed equivalence, and server status, and for this purpose, Fuji Electric uses middleware for wide-area distributed power systems.

This middleware has been realized by extending the conventional middleware for power systems to wide-area distributed power systems. Thus, the extension of an existing in-use system to a wide-area system involves little risk of the need for significant software modifications and the installation of new applications.

(3) Support for disaster crisis management

When operational management organizations are merged, the operator burden increases not only for usual business operations, but also in the response to natural disasters such as earthquakes, typhoons and so on. Consequently, Fuji Electric has developed a "Disaster crisis management support system." This system provides an integrated display, which shows load dispatching information, map information, weather forecast information and disaster prevention information for each layer, and makes a preliminary estimate of risk based on the weather forecast and disaster prevention information, and supports operations to avoid that risk. If a real disaster were to occur, the system will provide subsequent recovery support.

4. Postscript

In addition to systems for the power distribution field, Fuji Electric has also delivered many dam control systems, including pumped-storage power generation stations, water control systems, gas control systems, and so on.

As the range of operation expands from microgrids to smart communities, which aim to increase efficiency and optimally operate all forms of energy, including electricity, heat and water, Fuji Electric, based upon its prior experience with social infrastructure, intends to contribute to stabilizing the supply of electric power and to improving the efficiency of its usage.

Power Electronics Technology that Supports Smart Grid

Shinsuke Nii † **Masaki Kato** †

ABSTRACT

A smart grid is a system that reduces the effect that the mass adoption of renewable energy has on the total power system. Because the generated power output from renewable energy is generally difficult to control, a power supply system capable of implementing high-speed and high-accuracy control is needed for the mass adoption of renewable energy in the system. Power electronics technology plays an important role in realizing such control. The main power electronics applied technologies are charging/discharging control technology and demand/supply control technology. Devices suitable for use in a smart grid include power electronics devices for power distribution, smart PCS and new energy packages, and the deployment of these devices to the "Fuji Smart Network System" is targeted.

1. Introduction

The adoption of renewable energy is being promoted as a measure to help mitigate the problem of global warming. The generated power output from renewable energy, however, is often difficult to control, and if adopted in large quantities, may cause frequency fluctuations throughout the entire power system and local voltage fluctuations may occur. A smart grid is a system that reduces the effect on the entire power system from the mass adoption of renewable energy, and ensures a stable supply of electrical power. By simultaneously controlling the generation, distribution and consumption of energy, the efficient use of energy can be achieved. With a smart grid, a compensating high-speed high-accuracy power supply system must be used to connect renewable energy, for which the generated output power is difficult to control, to the power system, and power electronics technology plays an important role in the realization of such a system. In particular, many types of distributed power sources generate DC power, and power electronics technology for performing power conversion is one of the most important technologies for smart grids.

This paper discusses the role, functions and devices of power electronics required in smart grids, and also describes application examples and initiatives for the future.

2. Trends in Power Electronics Devices for Smart Grids

The power electronics devices used in smart grids are required to have a function that is capable of accommodating fluctuations in frequency or voltage, as well as a function for safely interconnecting with a power system. This section describes the requirements and technical trends of recent power electronics devices.

2.1 Functions and technical trends of power system interconnection

(1) Low voltage ride through (LVRT)

As an example of a function necessary for power supply interconnection, the LVRT function is described below. LVRT is a function that enables a device to continue outputting without parallel off*[1], even when the system voltage drops. In the case where only a small amount of renewable energy is introduced into a power system, even if a distributed power source disconnects due to a drop in the system voltage, the effect on the overall system will be minor and non-problematic. In the case where a large amount of renewable energy is introduced into a power system, however, if the distributed power sources disconnect from the power system all at once, an imbalance will occur between the amount of power generation and the amount of load, and the frequency stability of the system will decrease as a result. If the amount of simultaneous parallel off is large, then in order to maintain the power supply frequency, the load must be dropped. Accordingly, the following three characteristics are sought in order to connect distributed power sources to a power system.

(a) To accommodate frequency changes

(b) To connect to the power system and supply power to the extent possible, even when the voltage drops

(c) To connect to the power system and supply power as soon as the system voltage is restored

† Fuji Electric Co., Ltd.

*1: Parallel off: Disconnection of electric power generating equipment or the like from a power system following a parallel off

(2) Isolated operation detection function

An isolated operation detection function is essential for connecting to a power system. Isolated operation is the state in which an isolated system that has been disconnected from the power system is supplied with electricity from the output of a distributed power source only. In the isolated operating state, there is the possibility of electric shock or equipment damage, and this state must be detected as soon as possible and the relevant distributed power sources must be disconnected. (See explanation on page 152).

The method used to detect isolated operation is either passive or active. The passive method detects sudden changes in voltage phase, frequency and the like resulting from imbalances between the generated output power and the load during the transition to isolated operation, while the active method continuously applies voltage and frequency fluctuations and utilizes the fact that the fluctuations become noticeable during transition to isolated operation. Presently, in power distribution systems, the load is larger than the generated power, and therefore the passive method operates reliably even when there is a transition to isolated operation. However, if the number of distributed power sources increases and the balance between the generated power and the load is realized within the power distribution system, then system fluctuations will be smaller when transferring to isolated operation, and detection of isolated operation based on the passive method may not be possible. In the past, the passive method had provided the main protection, and the active method had been used as a backup. However, because of the risk of being unable to detect isolated operation with the passive method when a large number of distributed power sources are introduced, in recent years, the active method has been considered as the main protection.

At present, especially for small-scale photovoltaic power generation, unification toward an active method that is free of mutual interference is underway. Also, the trend of isolated operation of medium and large capacity power conditioning systems*2 (PCS) must be watched closely.

2.2 Function for accommodating power generation fluctuations and power system fluctuations

In the past, generators have been controlled to absorb load fluctuations and to stabilize frequency. If the amount of renewable energy generated fluctuates, however, a balance between supply and demand is difficult to achieve with only generator control. For this purpose, the output at the renewable energy side must be adjusted to minimize the effect on the system. A power storage device is used to implement this function, and depending on the period of fluctuation, the power storage method may need to be changed to storage cells, lithium ion batteries, electric double-layer capacitors, and the like, and appropriate discharge control technology for the storage method is also needed.

If the fluctuation in renewable energy power generation is to be adjusted with individual power stabilizers, then the same number of stabilizers as power generators (or power plants) will be needed. In contrast, an area-type stabilizer allows the fluctuation to be averaged to that the total equipment capacity can be reduced, and is more economically efficient than the individual approach. This area-type stabilizer controls the amount of power generation, including the amount of renewable energy, over a wide area (such as a town, city, prefecture or larger). For this purpose, the capacity of the stabilizer must be increased by expanding the individual device capacity of the inverters used in power storage systems and arranging them in parallel configurations.

Additionally, in small-scale power systems at remote islands and the like, the generators have low inertia constant, and disturbances are likely to occur when a supply-demand imbalance arises due to a power fluctuation. Such unstable states can be stabilized with a power storage device, and for this purpose, high-speed and high-precision control are required of the inverter.

3. Usage of Power Electronics in Smart Grids

Recently, power electronics products incorporating the above technologies have become possible to manufacture, and the applicable range of power electronics technology has expanded. Additionally, complex control has become easier to implement in the distribution of energy, enabling more efficient utilization of the public infrastructure.

Figure 1 shows a conceptual diagram of a smart power distribution supply chain in a smart grid being promoted by Fuji Electric. In Fig. 1, sensors and smart meters monitor the system information, and power generation, distribution and consumption are optimized so that the system will operate more efficiently. Fuji Electric has experience with many such examples for this purpose. Of the power electronics technology that may be used in a smart grid, implementation examples involving power generation and distribution are introduced below.

3.1 Usage of power electronics technology in power generation

The power stabilizer is introduced below as an example application of power electronics for power generation.

The generators in a power system are mainly rotary-type generators, and this is essentially the same

*2: Power conditioning system: Device for converting generated electric power from a photovoltaic cell, storage cell or the like into system power .

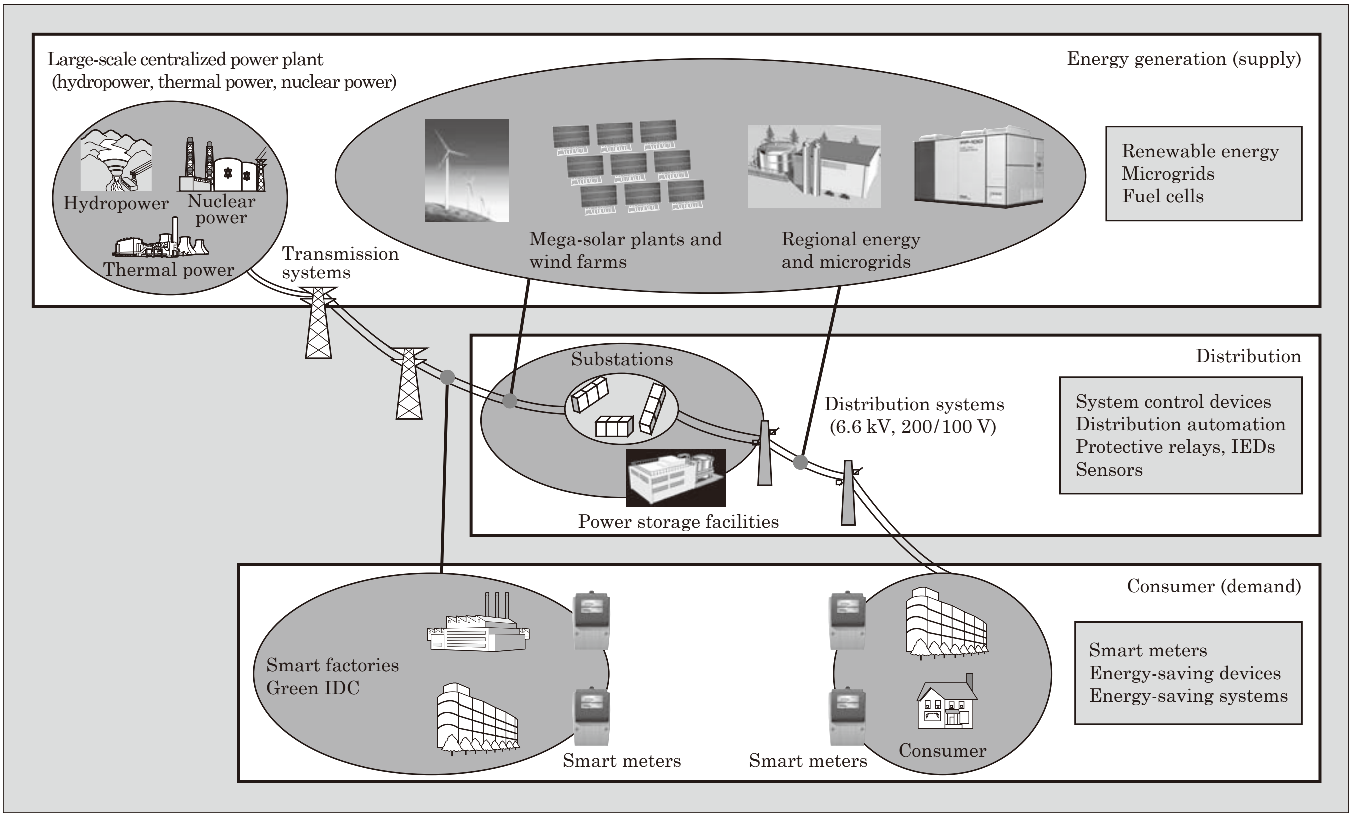


Fig.1 Conceptual view of a smart power distribution supply chain

for smart grids as well. As described above, however, when generating equipment that uses renewable energy is introduced in large amounts to a power system, the frequency control of the system will be affected due to the instability of the power generation. By using a power storage device to compensate for the power generation instability and by implementing control so that the output of the generating equipment is stable, stable power can be supplied to the system. Figure 2 shows the configuration of this power stabilizer. Figure 2 shows the case of wind power generation, but the same configuration could also be used for photovoltaic power generation.

Power stabilizers charge and discharge storage cells so as to compensate for the corresponding output fluctuation of renewable energy, thereby smoothing the combined outputs at points of interconnection with the power system. Charging and discharging can be performed according to bidirectional inverter control.

The purpose of smoothing is to stabilize the power system voltage and frequency. To stabilize the voltage, active power control and reactive power control are performed. To stabilize the frequency, governor-free (GF) control for short-duration fluctuations, load frequency control (LFC) for long-duration fluctuations, economic load dispatching control (EDC) for long-period fluctuations, and the like are performed. Each control method requires a different power storage capacity. Battery capacity has a significant impact on facility costs, and therefore, the smallest possible capacity is desired.

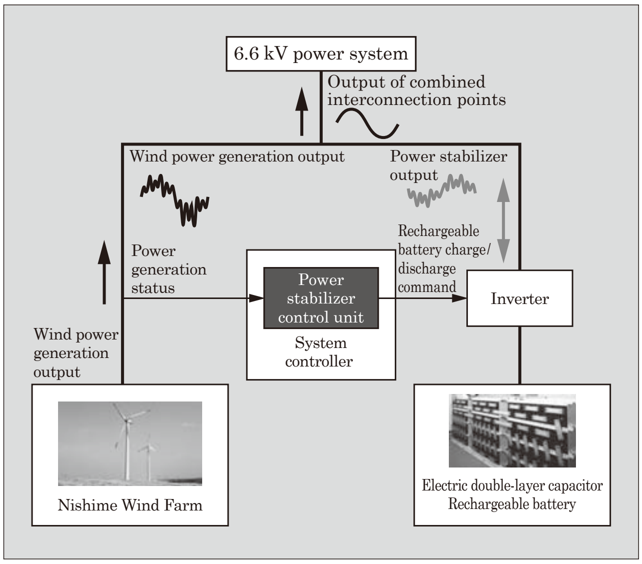


Fig.2 Overview of power stabilizer

Fuji Electric has installed this power stabilizer at the Nishime Wind Farm which is operated by Win-power Co., Ltd., an affiliated company, and has conducted an experimental study. The results of that study confirmed that a power stabilizer does have a stabilizing effect on the output of wind farms, and established a charge/discharge control method that realizes the required functionality with the minimum equipment capacity.

3.2 Usage of power electronics technology in power distribution

The area-type stabilizer described in section 2 attempts to stabilize power over a wide area. The "Demonstrative Project of a Regional Power Grid with Various New Energies, Kyoto Eco-Energy Project" (2003 to 2007) conducted by the New Energy and Industrial Technology Development Organization (NEDO) is introduced below as an example where supply/demand is adjusted and power stabilization is performed in a relatively narrow area.

An overview of the Kyoto Eco-Energy Project is shown in Fig. 3. In this demonstration project, biogas, photovoltaic and wind power generating facilities were established, and control to achieve a balance between demand and supply (5 minutes balancing control) was performed at specified times between several preselected end-users and a power plant where these renewable energies are used to generate power. The demonstration project was conducted as joint research among four companies and two government entities, and Fuji Electric participated mainly in the development of the control system.

In this system, sensors detect the generated output of photovoltaic power and wind power, and send monitoring information to a control center via a communication line. The control center calculates the rechargeable battery output to compensate for fluctuation, and issues an output command to the rechargeable battery via the communication line. As a result, fluctuation in the generated output of photovoltaic power and wind power is absorbed. The processing from data measurement and aggregation until the issuance of command value is completed in a time of approximately 20 seconds, and therefore compensation and demand/supply adjustment are possible for power generation fluctuations on the order of several tens of seconds. Because a general-purpose wide-area network (ADSL or ISDN) is used for monitoring and control, the measurement and control targets can be chosen without regard for distance. The realization of a large-scale supply/demand adjustment system at low cost is anticipated.

Additionally, when performing balancing control with this system, adjustment corresponding to the amount of load fluctuation is performed basically with a gas engine generator. In cases where the load fluctuation per unit time is large and difficult to track with a gas engine, adjustment corresponding to the amount of load fluctuation can be implemented as compensation by a rechargeable battery.

The demonstration project aims to achieve balancing control accuracy within 3% error in five minutes, and the results obtained mostly satisfy this aim. As a result, the project verified that high accuracy can be maintained even with control implemented via a general-purpose communications network. Moreover, the effectiveness of rechargeable batteries as a means for controlling supply and demand in a smart grid was confirmed.

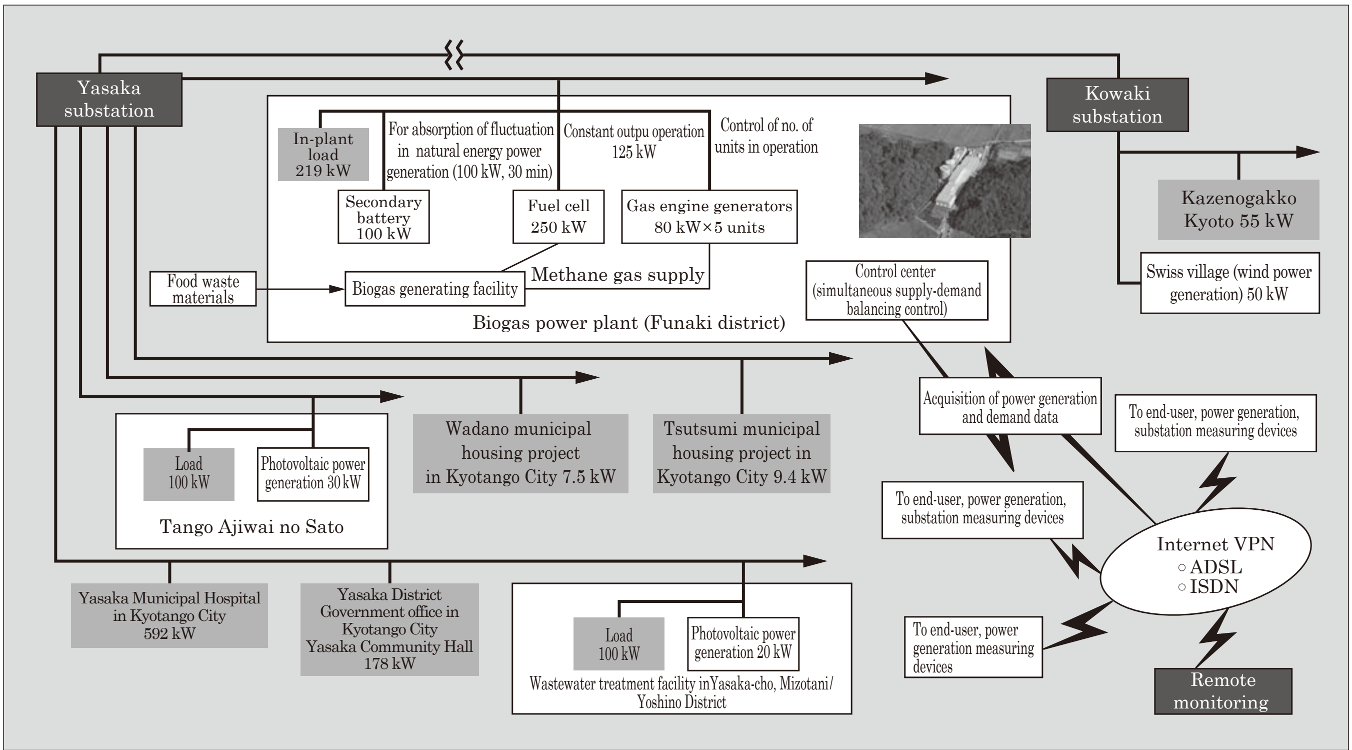


Fig.3 Overview of Kyoto Eco-Energy Project

4. Power Electronics Devices in Smart Grids and Fuji Electric's Future Initiatives

Fuji Electric is advancing various initiatives aimed toward constructing smart grids, and is also advancing the development of new technology for power electronics devices. This section describes technology essential for developing smart grids in the future.

4.1 Power electronics devices for power distribution

In power systems, large-scale centralized power generation plants are responsible for power generation, transmission and distribution equipment are responsible for power distribution, and the end-users are responsible for consumption. Electric power flows from large-scale centralized power plants toward end-users, and power systems have been constructed assuming a one-way flow of power from upstream to downstream.

In recent years, end-users have generated power by using home-use solar power generators and the like, but if they were to install a large amount of distributed power sources, the flow of power, at least in the distribution system, will not be unidirectional (see Fig. 4). Additionally, because the amount of power produced by generation from renewable energy cannot be controlled, new methods will be needed to manage the distributed power sources, and specific areas or wide areas in order to control the frequency, voltage or power flow.

Examples of power electronics devices used to solve these types of power distribution system problems are the self-commuted static var compensator for distribution and a distribution line loop balance controller (LBC). For power electronics distribution devices to become widespread, they must be compatible with outdoor and pole-mounted installations, provide maintenance free operation, have a low price, and so on.

To support outdoor installation, power electronics devices must meet specifications for environmental resistance, and the heat exhaust of the system, sealing technology and the like are also important factors. For pole-mounted installations, a light weight is essential, and the future development of technology that enables direct connections to high-voltage systems and eliminates the necessity for a transformer is needed. A fanless implementation is also needed for maintenance-free operation and to reduce cost. To develop equipment that fully satisfies the functional requirements of power distribution devices, the commercialization of next-generation devices made from silicon carbide (SiC) or the like is considered to be necessary, and therefore some time will be needed before such devices can be used in practical applications.

4.2 Smart PCS

The DC-side of a PCS is connected to solar panels, rechargeable batteries, capacitors (including electric double-layer capacitors), etc. In the case of solar panels, a photovoltaic PCS is connected; for rechargeable batteries, a power storage device is connected and in the case of a capacitor, a static var compensator is connected. The inverters used have many common parts in their configurations. A smart PCS is a multi-function inverter provided with the required communication capability and a system interconnection function, and has a configuration suitable for multi-purpose applications.

Standardization of the PCS communication specification is being advanced by the Japanese Ministry of Economy, Trade and Industry (METI), and standards for the communication interface, protocols and the like are expected to be established in the future. Fuji Electric plans to move ahead with the development of a PCS equipped with these standardized functions and that is suitable for multi-purpose applications.

System interconnection functions include an LVRT

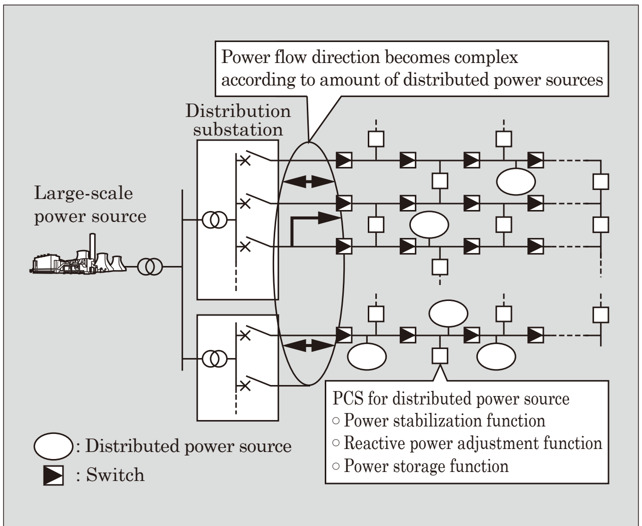


Fig.4 adoption of renewable energy in a power distribution system

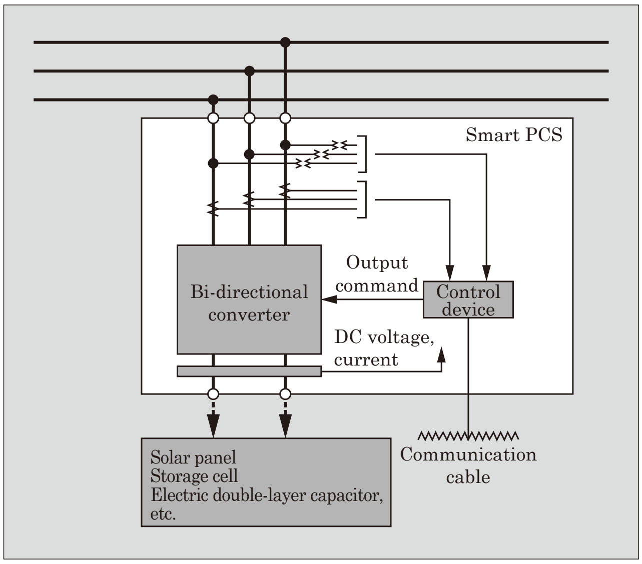


Fig.5 Overview of smart PCS configuration

function, an isolated operation detection function, an interconnection protection function, and so on, and through incorporating these functions and standardizing the equipment, various types of standardization will be supported (see Fig. 5).

4.3 New energy power supply package

Aiming to expand the utilization of renewable energy, and in order to facilitate the adoption of new energy, a new energy package constructed so as to combine a power generator and a power storage device is desired.

In the METI system forum final report concerning smart communities, power system types were compared by classifying them into the five categories shown in Table 1.

If relatively small-capacity power supply devices that use renewable energy can be packaged and applied for various purposes regardless of the power system configuration or type of renewable energy, then renewable energy will become easier to use. By using the same power supply package configuration regardless of the power system type, i.e., advanced country type (US, Europe), developing country type (urban type, rural type), or isolated island type, and by changing the control method according to the application target, power supply devices will be easily configurable, and will be applicable to many systems without changing their hardware specifications. For this purpose, scalability, safety and security, and maintainability (maintenance-free operation) must be realized.

Scalability is the ability to expand system capacity according to demand, and in addition to increasing device capacity, the ability to connect various power sources and to achieve system-wide harmonization easily are required. Safety and security are the ability to operate safely at all times and in various locations, even when operated by persons lacking experience with electricity. Good maintainability means to have a low failure rate, and to be easily serviceable in the case of a failure.

The new energy power package incorporates a

Table 1 Power system characteristics

Power system type	Operating method
Advanced country type (US) Advanced country type (Europe) Developing country type (urban type)	The distributed power sources are connected to a strong power system. In this case, maintenance of the frequency and voltage may depend upon the power system, and efficient operation of the distributed power sources becomes important.
Developing country type (rural type)	Since there is no pre-existing power system, the distributed power sources themselves constitute the core power supply. For this reason, the distributed power sources are responsible for constantly maintaining the frequency and voltage, and the ability to absorb fluctuations in the load as well as output fluctuations from other distributed power sources is essential.
Isolated island type	The distributed power sources are connected to a weak power system. In this case, the output of the distributed power sources may affect the power system. Accordingly, the state of the power system must be evaluated while operating the distributed power sources.

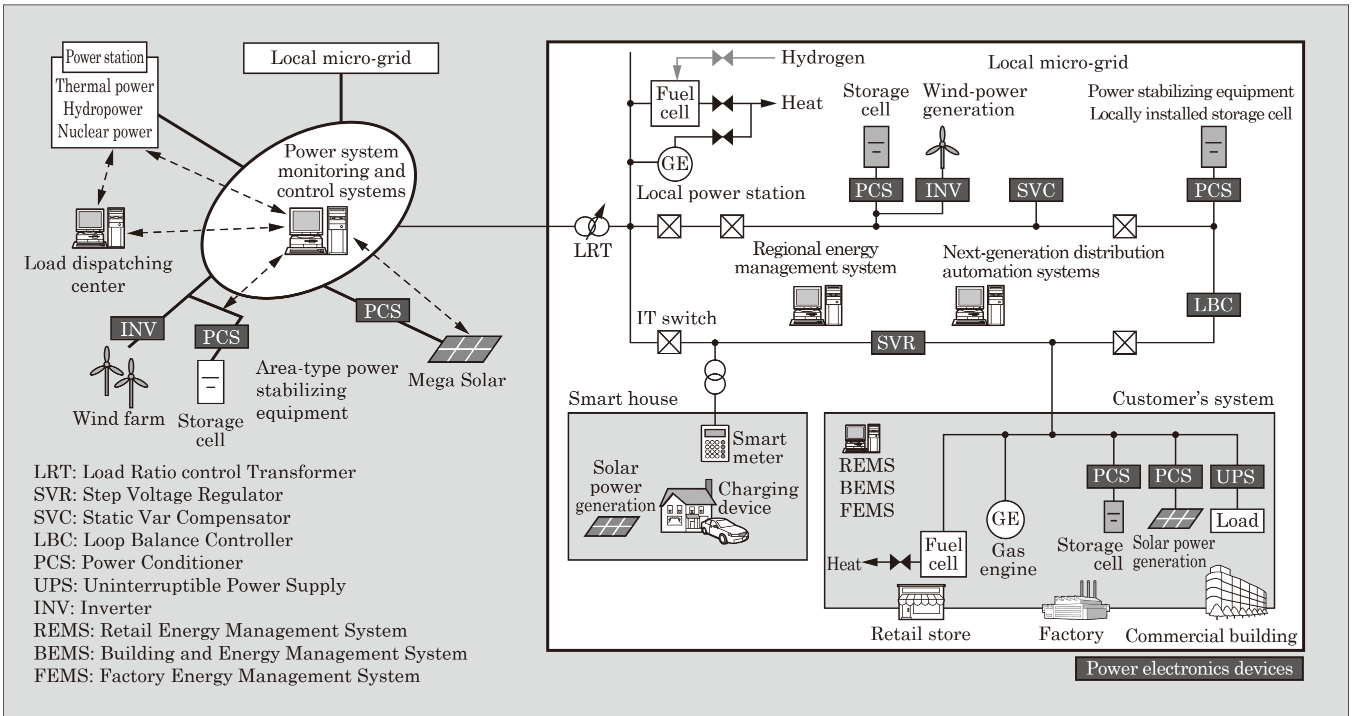


Fig.6 Areas of applied power electronics technology in the "Fuji Smart Network System"

PCS for photovoltaic power generation and a PCS for storage cells into the same package, and is optionally configurable as a system compatible with small-scale hydropower, wind power or the like.

Fuji Electric plans to develop a new energy package suitable for multi-purpose applications and to use this with smart grids.

4.4 "Fuji Smart Network System"

Figure 6 shows the areas of applied power electronics technology in the "Fuji Smart Network System." With the Fuji Smart Network System, in both the industrial and consumer sectors, end-user microgrids are constructed, and hybrid power supply equipment that combines photovoltaic power generation systems, storage cell PCS, fuel cells and the like is introduced to the system. Moreover, in the distribution system, regional microgrids are configured by combining conventional load ratio control transformers (LRTs) and step voltage regulators (SVRs) with reactive power compensation equipment for voltage stabilization, loop balance controllers (LBCs) for power flow control, power stabilizers to absorb fluctuations in renewable energy, and the like. Additionally, in the power transmission system, an area-type stabilizer is installed to stabilize the supply of power within a region.

With the Fuji Smart Network System, information from smart meters and from IT devices in the distribution system is collected by an energy management system (EMS), which monitors and controls the entire system. The EMS issues control commands to devices in order to achieve energy efficiency, and the power electronics devices respond to the commands quickly and accurately to support the realization of high efficiency.

5. Postscript

Smart grids are a part of the public infrastructure and assure energy security by incorporating a diversified range of power supplies to eliminate a dependency on fossil fuels, which traditionally had been the primary source of energy. Additionally, the transition to use of a smart grid entails not only modification of the power system, but also asks the question, in regard to energy generation and consumption, of what is the ideal grid configuration in which users can participate.

Aiming to protect the global environment, the stage is now being set for the creation of a sustainable energy system for future generations. In order to realize such an energy system, the capability of fine control of energy is prerequisite. Such capability can be achieved with power electronics technology, and the role of power electronics technology in smart grids will continue to increase in importance. With the goal of expanding usage of smart grids, Fuji Electric intends to continue to improve power electronics technology.

Integrated Energy Management System Platform

Hiroshi Horiguchi † Kenichi Ishikawa † Yoshikazu Fukuyama †

ABSTRACT

Fuji Electric has developed an integrated energy management system (EMS) platform that can visualize energy consumption and integrate energy-saving controls in various fields such as iron and steel production, general industries, retail distribution, water treatment, regional communities and so on to provide energy management functions expeditiously and at low cost. The platform is compatible with models of various energy types such as electric power, gas, water and heat energies and can realize optimal energy-saving control even with renewable energies. Various web screens support local languages, and systems ranging in size from a small single-server system to a system consisting of several tens of servers can be developed easily using the same engineering tools.

1. Introduction

The Japanese government's setting of medium-term targets for cutting greenhouse gas emissions (cutting emissions by 25% from 1990 levels by 2020), revision of the "Law concerning the rational use of energy" (energy saving law), the international standard (ISO 50001) concerning energy management to be issued this year, and the like are measures that address the urgent need to prevent global warming. Additionally, many smart communities, aiming to realize a global sustainable society, are proceeding with efforts to use new forms of energy and to conserve energy. To attain these goals, the entire supply and demand of energy must be integrally managed and operated, and for this purpose, energy management systems (EMS) will have a greater role than ever before.

Fuji Electric has developed various EMS focused on the energy supply chain in the fields of power, iron and steel, water, industry, retail distribution, etc. The functions of a cluster EMS (CEMS), factory EMS (FEMS), building EMS (BEMS), and retail EMS (REMS) have been integrated into a single platform to develop an integrated EMS platform for providing EMS functions that meet various onsite needs, rapidly and at low cost.

2. Configuration and Functions

2.1 Development concepts

The integrated EMS platform is important middleware that forms the core in the construction of an EMS. The development concepts of the EMS platform are listed below.

(a) For various types of energy (electric, gas, water, heat, etc.) facilities, the EMS platform shall have ability to optimize each type of energy and to selectively implement optimization and control functions according to goals regardless of the industrial field

(b) In accordance with the size of a user's energy facility, systems ranging in size from small-scale systems with a single server to large-scale distributed systems with multiple servers, shall be constructible quickly and easily with the same engineering operations

(c) Even during online operation, it shall be possible to conduct system enhancement and evaluations with simulation when adding or renewing energy equipment.

2.2 Software configuration

Figure 1 shows the integrated EMS platform and its peripheral software configuration. The software configuration is the same as that of a typical EMS, and consists of software for various Web screens, performance data management, optimization/control program groups, and driver management that controls communications with field sensors and control equipment and the like. The most prominent features of this platform are the "Fuji Service Bus" high-speed program linking service that can associate various functions, the "Field Connector" high-speed data sharing service and the integrated energy network model that unifies various control targets. As needed, an EMS ranging in size from a small-scale single-server system to a system consisting of multiple large-scale distributed servers can be constructed on the same platform, with the same engineering operations and within a short time.

Functions of the core integrated EMS platform as well as its peripheral functions are described below.

† Fuji Electric Co., Ltd

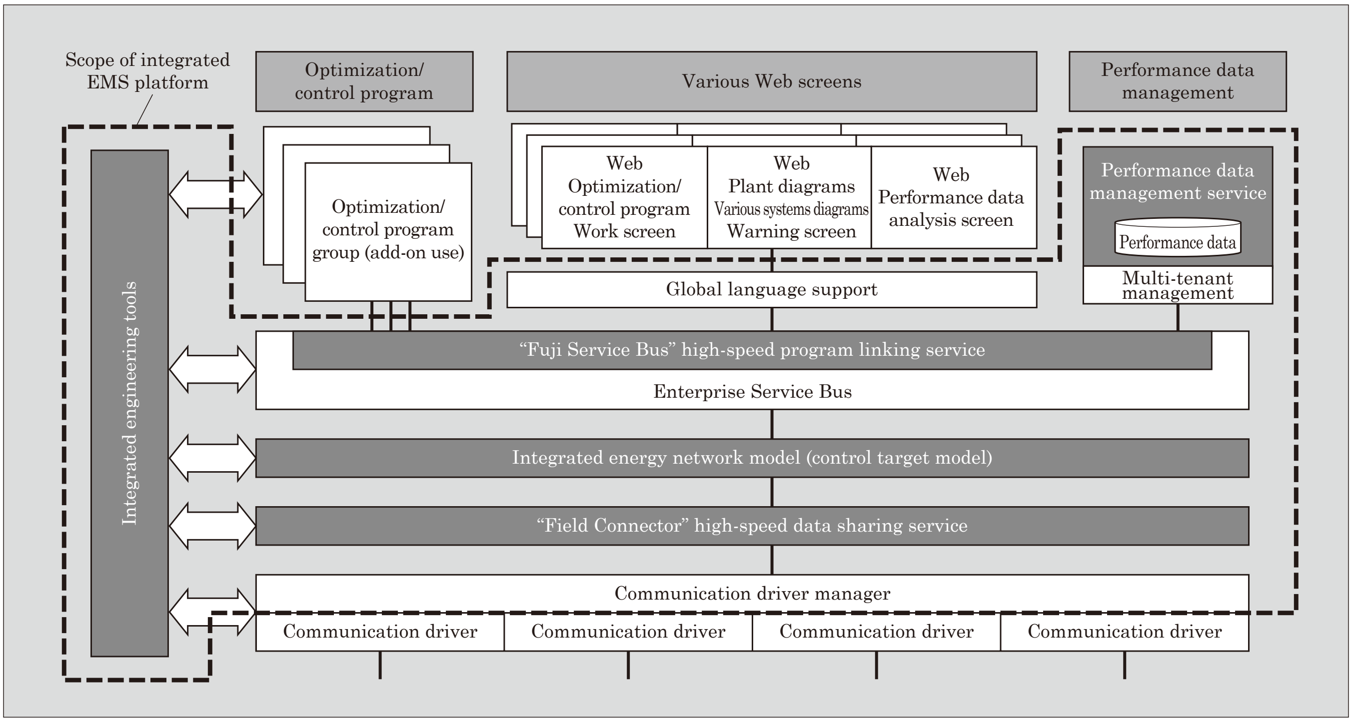


Fig.1 Integrated EMS platform and its peripheral software configuration

2.3 "Fuji Service Bus" high-speed program linking service

According to the size of the control target, the number of required software functions, the monitoring and control cycle, and required server redundancy, an EMS may be constructed as a system ranging in size from a single-server configuration to a large-scale distributed configuration consisting of several tens of servers in a CEMS or the like.

The "Fuji Service Bus" is a mechanism for linking, without awareness of these types of differences in server configurations, the processing among optimization/control programs distributed in each server, and among Web screens and optimization/control programs.

Traditionally, program calls in a distributed environment were implemented as a "program X residing on server Y", with the server allocation information for each program having been defined in advance. For this reason, when adding servers or changing the server configuration due to an increased number of control targets, a system engineer would have to shut down the system, and redefine the server allocation information for each program.

With the Fuji Service Bus, however, rather than requiring server allocation information definitions in advance for programs, the relevant program residing on any server can be called using only the service name (program function name). This is because the Fuji Bus Service exchanges information dynamically and in real-time with the service name list residing in each server.

As a result, with easy operation of integrated engineering tools (to be described later) by the user, the Fuji Service Bus instantaneously acquires the server allocation information for program even when optimization/control programs are newly added or existing optimization/control programs are transferred between servers in accordance with CPU load conditions. Consequently, work tasks can be performed while the system continues to operate.

Moreover, because the optimization/control program groups previously developed for various industrial fields used various different languages (C, C++ and Java), they could not be made to interact easily with each other. The Fuji Service Bus, however, enables mutual interaction regardless of the development language. As a result, Fuji Electric's EMS software assets can be provided seamlessly.

In the future, by linking the Fuji Service Bus with a general Enterprise Service Bus, standard linking with global-standard core software will be realized.

2.4 "Field Connector" high-speed data sharing service

With the Fuji Service Bus, each program is able to interact mutually, regardless of the server on which it is allocated. However, in order for each program to perform actual operations and control, an environment in which each program, regardless of the server on which it is located, is able to reference online data and issue control instructions is necessary. This capability is realized with a mechanism known as the "Field Connector."

The Field Connector manages online data with TAG management (data management method using a TAG name such as "TAG0001" and a corresponding

TAG value). In contrast to a typical TAG value that only accommodates a single integer or floating-point value, the Field Connector TAG value is a string of variable length. As a result, TAG values can be stored by handling 30-minute power generation planning values and other continuous numeric data as comma-separated character string data. For example, TAG management can also be used effectively for linking data (24-hour continuous data in units of 30-minute intervals) among programs in the sequence shown below.

(a) Power demand forecasting program
(b) Optimal power generation planning program for each generator according to the power demand forecast value
(c) Generator control program conforming to optimal generated plan

Additionally, because Field Connectors on all servers are mutually linked and the Field Connector on each server performs TAG value management for all the servers, programs that reference and update TAG values can run without problem regardless of the server on which they reside.

In addition to use for data linking among programs, Field Connectors also are provided with a function for connecting to field devices via a communication driver manager. The online data obtained through communications with field sensors and control devices is managed as TAG values, and TAG values set by control programs can also be output directly to the field devices.

Thus, with a Field Connector, data can be shared among various programs from any server, online data of the entire system can be referenced, control signals can be output, and a system that meets various needs can be configured and built easily.

A Field Connector is able to manage 500,000 TAG values system-wide.

2.5 Integrated energy network model

An energy network model defines how electricity, gas, water, heat and other forms of energy are converted and transmitted by each device.

To optimize energy and control the balance between supply and demand, the various optimization/control program groups must be commonly aware of the energy transmission of the control target. Previously, with optimization/control programs in various fields, different types of model representation methods were applied in order to process calculations with the highest efficiency. As a result, models had to be defined with engineering tools that differed for each optimization/control program that was applied[1].

On the other hand, to simplify the engineering work to be performed by users, the representation method and data structures were prescribed so that an intuitive easy-to-understand common integrated energy network model, which does not depend on the optimization/control program to be applied, could be realized. As a result, energy network model definitions can be made with the same engineering operations, regardless of the type of optimization control program to be applied.

Fig. 2 shows an example representation of an integrated energy network model.

With this model representation scheme, equipment is placed at nodes, and connections between equipment are represented with a node-branch model that connects branches to the nodes. Additionally, definitions of energy conversion characteristics (efficiency, etc.), maximum output power, TAG names for obtaining the real-time status of field equipment, TAG names for control output destinations, and the like are defined as properties in the nodes. Integrated management is performed in advance to control which types of properties are required for each of the various node devices. The model definitions are output as xml data, and prior to use, are converted into the model representation format used by the optimization/control programs in each field.

For the creation of power system models, a function that converts between the common information model (CIM) of IEC 61968 and IEC 61970 and an integrated energy model network model is being developed to facilitate the incorporation of existing power system equipment data.

2.6 Performance data management service

The performance data management service is a feature that periodically extracts TAG values from the Field Connector, accumulating and managing those values as performance data. Through the use of an energy analysis function, provided as a standard feature, the energy usage status can be analyzed in an easy to understand manner.

With the performance data management service, performance data is linked in advance to an equipment hierarchy consisting of, for example, business office and plant, building, line and device levels, so that energy across an entire company or at an arbitrary hierarchical layer can be tallied instantaneously. As

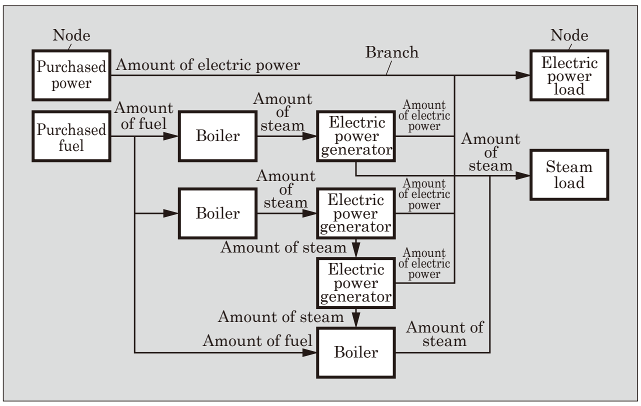


Fig.2 Example representation of integrated energy network model

a display method, a configuration graph of energy type (gas, heavy oil, coal, electric power, etc.) and a configuration graph of energy application (power, air conditioning, lighting, etc.) can be indicated with equivalent amounts of t-CO_2 (carbon dioxide equivalent tons) or crude oil. Moreover, arbitrary measurement data can be combined and displayed graphically, or may be output to spreadsheet software for the user to perform their own analyses.

In actual energy analysis, the production quantity, operating time and the like are important considerations. The performance data management service is able to associate and manage a variety of data in addition to energy data in the equipment hierarchy, and energy analyses can be performed horizontally across the hierarchical equipment locations (see Fig. 3).

The performance data management service also has a multi-tenant management function. This function, if incorporated into a software as a service (SaaS) environment, allows even a single server to provide the performance data management service to multiple companies (tenants) simultaneously.

This service is provided in order to visualize energy data acquired from the various homes, buildings and companies in a smart community, and is an effective means for raising awareness of energy conservation.

2.7 Integrated engineering tool

The integrated engineering tool was developed so that users could construct a system easily, and by positioning user screens and work functions as in Windows Explorer, screen programs and optimization/control programs are positioned automatically for each server. Figure 4 shows an example screenshot of the integrated engineering tool.

First, the network energy models and various work functions (sets of programs combining optimization/control programs and their work screen programs) which are operated for the model as needed are positioned in the function hierarchy column on the left-side of the screen. Then, on the right-side of the screen, function settings are made for the various work functions, and the servers at which the optimization/control programs should be positioned are specified. This completes the engineering work.

The integrated engineering tool automatically positions the screen programs and the optimization/control programs in each server according to the content of the function settings.

2.8 Simulation environment

In the screenshot of Fig. 4, the model and various work functions are positioned under "ONLINE," but simply by pasting the models and the various work functions under "SIMULATION," operation can be verified under a simulated environment that differs from the ONLINE environment.

The purpose of the simulation verification is to evaluate the effect of adding a new energy facility to the model, or to evaluate the validity of energy saving control output based upon a change in the control parameters, or the like.

So that simulations can be realized, the Fuji Service Bus, Field Connector and performance data management service are each provided with two different environments, online and simulation. As a result, various verification tests can be performed while online operation continues.

Especially with the simulation environment of the Field Connector, the control output to TAG management is limited to the TAG value setting, without being linked to the actual control devices, and is recorded as control performance data in the simulation environment and displayed graphically so that the validity of control commands can be verified.

3. Application to Community Energy Management Systems

An example system configuration when this EMS is applied to a cluster energy management system (CEMS) is shown in Fig. 5.

The servers in a CEMS all use a redundant con-

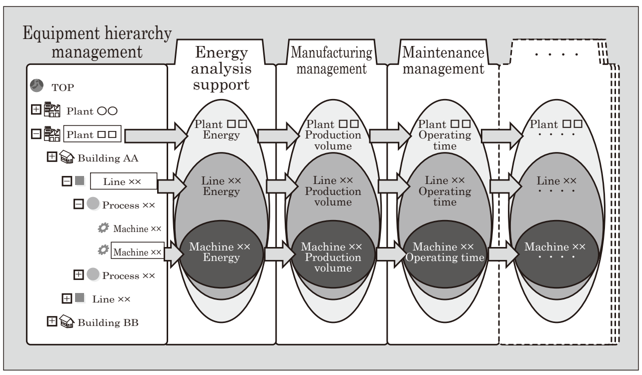


Fig.3 Energy management centered on equipment hierarchy management

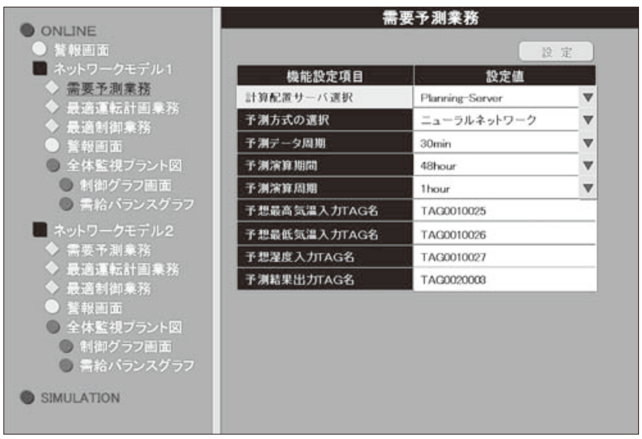


Fig.4 Integrated engineering tool screen example

feature issue: Smart Community

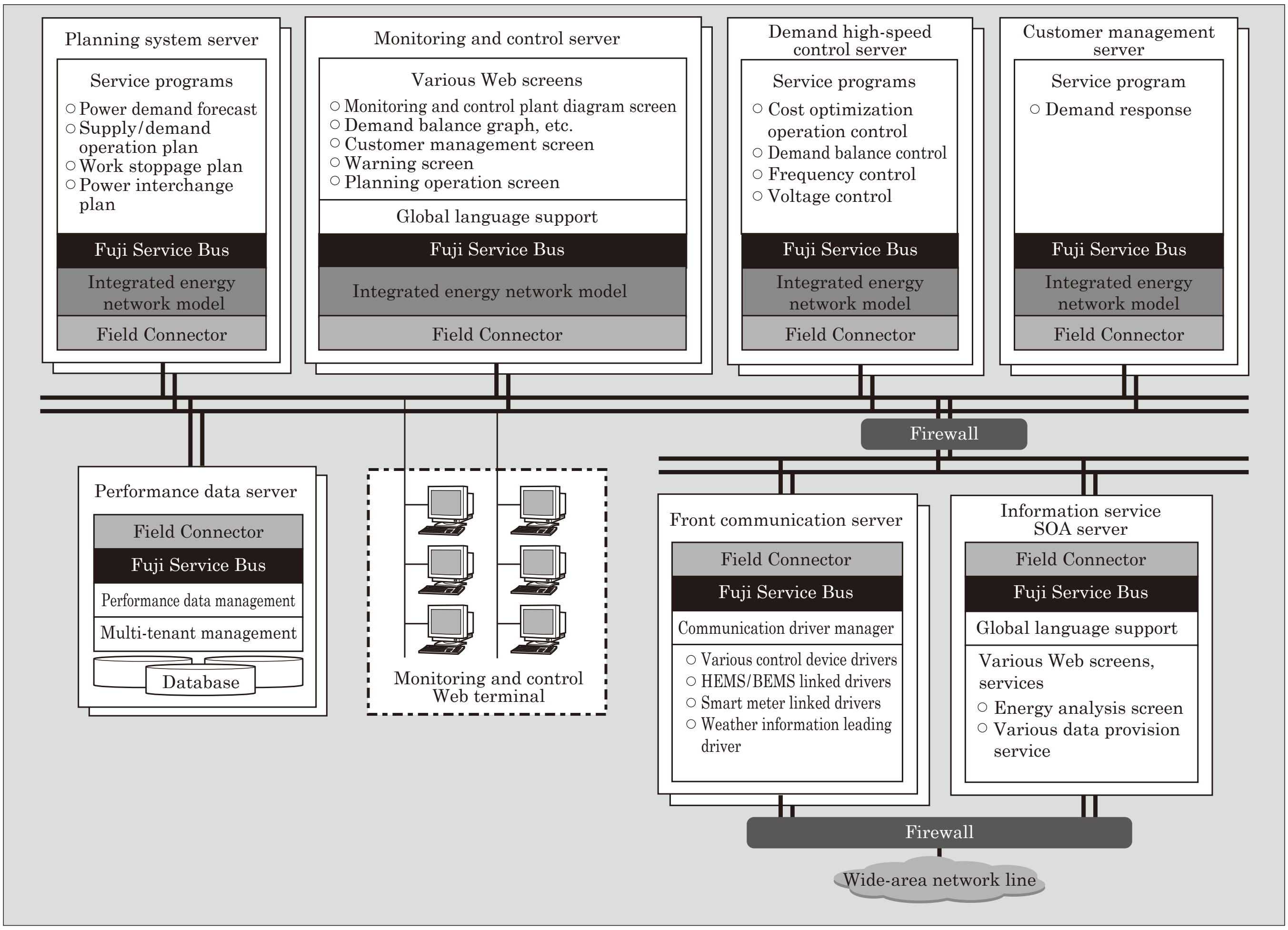


Fig.5 Example CEMS configuration with integrated EMS platform

figuration in order to improve reliability. The monitoring and control servers are provided with server functions for all Web screens, and the performance data server manages the database. Various other servers are configured as independent servers in order to distribute the CPU load. In the future, front communication servers that communicate with the field and information provision SOA servers that provide energy visualization services to homes and building managers can be added according to the number of connected communication targets and the increase in number of concurrent accesses.

By mounting a Field Connector in each server, the on-site TAG values received by the front communication server can be referenced by each server. Moreover, by writing data to the field TAG, the monitoring and control server, demand/supply and high-speed control server, and the end-user management server can implement control via the communication driver in the front communication server. Additionally, the optimal generator operation planning value calculated with a planning server is sent to the demand/supply and high-speed control server as a TAG value, and is used as the balance control target value.

The various optimization/control programs are distributed to each server for the purpose of load distribution. These programs can be called from any server via the Fuji Service Bus, and their locations can be changed according to the system operating load.

Thus, with the powerful distribution-supportive platform of the Field Connector and Fuji Service Bus, a large-scale EMS can be constructed easily and quickly.

The newly developed EMS platform is slated for evaluation as part of the “Next Generation Energy System and Public System Demonstration” being promoted by the Japanese Ministry of Economy, Trade and Industry in Kitakyushu City and elsewhere.

4. Postscript

This paper has introduced Fuji Electric’s integrated energy management system (EMS) platform. The EMS is evolving from discrete optimization to total optimization. This EMS platform, with which the overall EMS status can be acquired and controlled from any server, is effective in realizing more advanced total operation. Fuji Electric intends to continue to enhance engineering tools further, to provide EMSs that are easy to use and have an impact in terms of their performance and pricing, and to contribute towards the realization of sustainable society.

References

(1) Fukuyama,Y., et al. "Development of an optimal operational planning system for energy plants in steelworks", Proc. of IFAC World Congress, 2008-7.

Supplemental Explanation

Isolated operation detection method

Typically, during a power system outage, distribution line circuit breakers are open and the distribution line is in a no-voltage state, but in a distribution line to which distributed power sources such as solar power generation are connected, if operation continues while not disconnected from the power system, the region that should be in a no-voltage state becomes charged. Thus, in a power system that has been disconnected from a commercial power supply, isolated operation is the state in which only the power supplied from the distributed power sources causes electricity to flow through the distribution line.

During isolated operation, there is the risk of serious effects on human body and equipment, such as: (1) electric shocks to the general public, (2) equipment damage, (3) adverse effect on firefighting operations, (4) electric shocks occurring during the search for fault locations and during removal operations. In addition, expansion of the damage at the fault location or a delay in recovery may disrupt the supply of power. Therefore, when connecting distributed power sources to a power system, isolated operation prevention measures are mandatory, and they must detect, either directly or indirectly, the isolated operating state using a protective relay or the like, and then rapidly disconnect distributed power sources from the power system.

There are two methods for detecting isolated operation, and detection is implemented using both of these methods in combination.

(a) Passive method

The passive method detects sudden changes in the voltage phase or frequency caused by an imbalance between the generated power output and the load during the transition to isolated operation.

(b) Active method

The active method continuously applies fluctuations in voltage and frequency via a power conditioner control system and an externally attached resistance, and detects noticeable fluctuations during the transition to isolated operation.

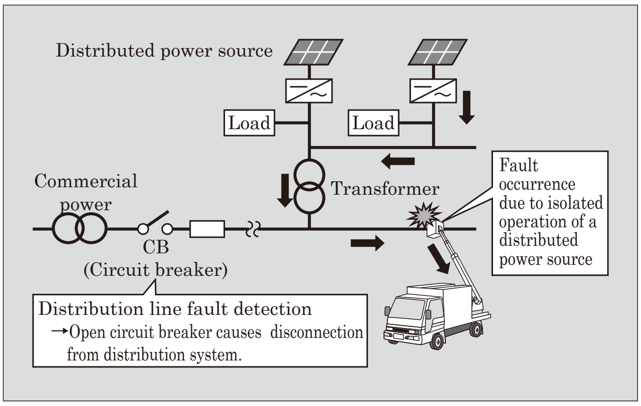


Figure: Failure due to isolated operation

Overseas Subsidiaries

North America

Fuji Electric Corp. of America
Marketing, installation and repair of electrical machinery, control systems and electronic components

Tel +1-732-560-9410
URL http://www.fujielectric.com/fecoa/

EU

Fuji Electric Europe GmbH
Marketing, installation and repair of electrical machinery, control systems and electronic components

Tel +49-69-6690290
URL http://www.fujielectric.de/

Fuji Electric France S.A.S
Manufacture and sale of measuring and control devices

Tel +33-4-73-98-26-98
URL http://www.fujielectric.fr

East Asia

Fuji Electric FA (Asia) Co., Ltd.
Marketing of power distributors and control equipment

Tel +852-2311-8282
URL http://www.fea.hk/

Fuji Electric Dalian Co., Ltd.
Manufacture of low-voltage circuit breakers

Tel +86-411-8762-2000

Fuji Electric Taiwan Co., Ltd.
Semiconductor devices, power distribution and control equipment, sales of control, drive and rotating equipment

Tel +886-2-2515-1850

Fuji Electric (China) Co., Ltd.
Marketing of locally manufactured or imported products in China, and export of locally manufactured products

Tel +86-21-5496-1177
URL http://www.fujielectric.com.cn/

Fuji Electric (Shenzhen) Co., Ltd.
Manufacture and marketing of photoconductive drums

Tel +86-755-2734-2910
URL http://www.szfujielectric.com.cn/FUJIWebSite/index.html

Wuxi Fuji Electric FA Co., Ltd.
Manufacture and marketing of inverters in China

Tel +86-510-8815-2088

Fuji Electric Hong Kong Co., Limited
Sales of semiconductor devices and photoconductors

Tel +852-2664-8699
URL http://www.szfujielectric.com.cn/hkeng/company/index.htm

Shanghai Fuji Electric Switchgear Co., Ltd.
Manufacture and sales of switching equipment, monitoring and control appliances and related facilities

Tel +86-21-5718-1234
URL http://www.csfuji.com/

Fuji Electric Motor (Dalian) Co., Ltd.
Manufacture of motors

Hoei Hong Kong Co., Ltd.
Marketing, installation and repair of electrical machinery, control systems and electronic components

Tel +852-2369-8186
URL http://www.hoei.com.hk/eng/index.php

Fuji Electric (Changshu) Co., Ltd.
Manufacture and sales of electromagnetic contactors and thermal relays

Tel +86-512-5284-5642
URL http://www.csfe.com.cn/

Fuji Electric FA Korea Co., Ltd.
Sales of power receiving and distribution/control equipment and drive control equipment

Tel +82-2-780-5011
URL http://www.fujielectric.co.kr/

Shanghai Fuji Electric Transformer Co., Ltd.
Manufacture and sales of molded case transformers

Tel +86-21-5718-7705
URL http://www.csfuji.com/

Southeast and South Asia

Fuji Electric Asia Pacific Pte. Ltd.
Marketing, installation and repair of electrical machinery, control systems and electronic components

Tel +65-6533-0010
URL http://www.fujielectric.com.sg/

Fuji Electric Philippines, Inc.
Manufacture of semiconductor devices

Tel +63-2-844-6183

Fuji Electric (Malaysia) Sdn. Bhd.
Manufacture of magnetic disks

Tel +60-4-403-1111
URL http://www.fujielectric.com.my/

Fuji Electric Semiconductor (Malaysia) Sdn. Bhd.
Manufacture of semiconductor devices

Tel +60-4-494-5800
URL http://www.fujielectric.com.my/

Fuji Electric Power Supply (Thailand) Co., Ltd.
Manufacture and sale of small to mid-size UPS and internal electrical parts

Tel +66-0-2909-5998

Fuji Electric India Pvt.Ltd.
Sales of drive control equipments and semiconductor devices

Tel +91-22-4010 4870
URL http://www.fujielectric.co.in

e-Front runners

Printed on recycled paper