Automation for Realizing "Smart Energy"

Katsuyuki Ooike † Kazuhiro Oohashi † Yoshikazu Fukuyama ‡

ABSTRACT

In order to realize stable supply of energy toward low carbon society, "Smart Energy" aiming more efficient, quality and reliable energy usage is eagerly expected. Fuji Electric has challenged these energy issues for many years, and has made positive contributions through technology and product development. With regards to supply and demand control of distributed energy, Fuji Electric has involved in the research and development project of regional supply and demand control that incorporates photovoltaic, wind power and biomass generation. For distributed power supply systems, electric power stabilizers have been developed and used in practical applications. For power system operation, we have realized system stabilization with power flow control, and for energy plants, we have realized optimal operation and visualization. Consequently, in energy field, we have contributed to realization of higher quality energy.

1. Introduction

Global warming, believed to be caused by mankind's increased use of greenhouse gases, has serious implications for natural ecosystems and for humans. The amount of greenhouse gases emitted globally is already larger than the amount that can be absorbed naturally by more than a factor of two, and in consideration of the estimated magnitude and seriousness of this problem, global warming is the most critical problem for the environmental, urging the realization of a low-carbon society.

The global demand for energy consumed, especially with newly added demand from developing regions in Asia, is expected to increase dramatically. In fact, a 45% increase in global demand is forecast by 2030 (compared to 2006 levels)(1). Based on these circumstances, "energy and environment" issues are being addressed by various countries through the United Nations Framework Convention on Climate Change (UNFCCC).

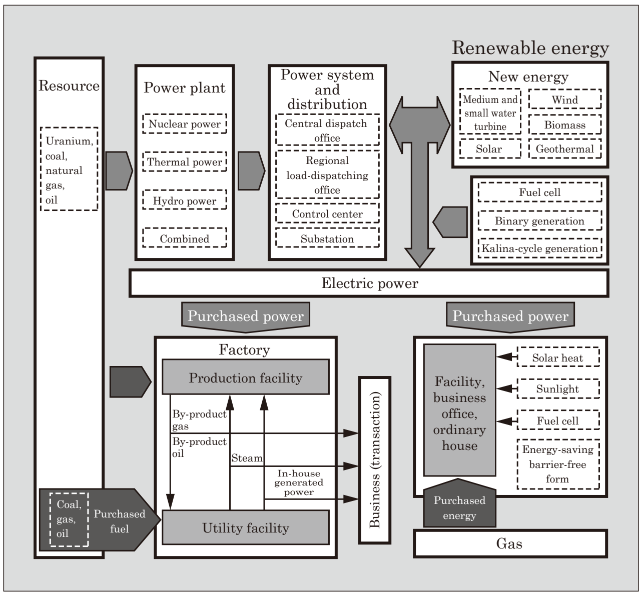
In Japan, to overcome these challenges by realizing a stable supply of energy, conserving the environment and simultaneously attaining an economical balance among the 3Es (energy, environment and economy), the adoption of "smart energy" to increase the sophistication, reliability and efficiency of energy usage is anticipated.

Figure 1 shows an overview of the flow of energy. Fuji Electric is developing automation technology for realizing smarter energy utilization in a wide range of sectors, from the utilization of energy resources such as oil and natural gas, to the overall supply and demand of electric and thermal power. This paper introduces Fuji Electric's automation technology for realizing "smart energy."

† Automation & Solution Business Headquarters, Fuji Electric Systems Co., Ltd.

‡ Technology Development Group, Fuji Electric systems Co., Ltd.

Fig.1 Energy flow overview



2. Needs and Challenges for More Efficient Utilization of Energy

Japan's energy strategy, aiming to attain a balance among the 3Es, is being advanced with the comprehensive approach while clarifying challenges concerning the environmental maintenance, institutions and technology. In particular, the stable supply, effective utilization and reduced consumption of fossil fuels, and the introduction of new forms of energy and the more sophisticated utilization of energy are sought.

Table 1 Requirements for smart energy and technical challenges

Requirements	Technical challenge	
	Equipment/component	System
Higher reliability Higher quality Improved stability	○ More measuring points with sensors and measuring instruments ○ Remaining life assessment, preventative maintenance ○ Semiconductor integration using power electronics, MEMS, etc.	○ Widely distributed backup ○ IP network security ○ Interconnection of distributed generators, power stabilization ○ Rapid response to disturbances ○ Stable supply of various types of energy (i.e., electric, thermal, steam, etc.) in a business
Higher efficiency Higher performance	○ Super critical power generation, combined cycle power, coal gasification at a power plant ○ Improved conversion efficiency with low loss magnetic material ○ Electronic device, optical, superconducting ○ More compact, lighter weight (gas insulation technology) ○ Treatment of aged facilities	○ Reduced transmission/distribution loss: loss minimizing control, higher voltage ○ Optimal operation of various types of energy (i.e., electric, thermal, steam, etc.) in a business ○ Energy savings and energy recovery in the production process ○ Historical management ○ Energy-savings when mining fossil fuel, and maximization of amount mined ○ ISO 50001
Eco-friendliness, safety, security	○ Safety standard compliance ○ CO_2, NO_x, SO_x countermeasures	○ Safety instrumentation ○ Visualization ○ ISO 14001 ○ Installation of distributed generators

More advanced operation and utilization	○ Energy management ○ Smart grid ○ Micro grid ○ Smart factory ○ Smart mining ○ ICT (high-speed and large capacity information communication system, cloud computing)

Fuji Electric has identified the requisite conditions for advancing smart technology as being higher reliability, higher efficiency, and an emphasis on the environment, safety and security. In order to realize smart technology that satisfies such conditions, Fuji Electric is developing customer-oriented comprehensive energy automation technology for applications ranging from equipment and components to systems. The requirements for smart energy are listed in Table 1 and described briefly below.

(1) High reliability and stability

The reliability of equipment and components has improved dramatically as the result of technical advances, and consumers now take for granted the stable supply and ability to utilize energy. Maintaining and improving the level of reliability will continue to be an important topic.

For systems, the attainment of high reliability by monitoring and controlling widely distributed systems via an IP network is important. Moreover, with distributed generators, the introduction of which is being accelerated, power output will fluctuate, and as a result, fluctuations in the power flow and voltage within a power system are expected to increase. For this reason, grid interconnection technology and power stabilization technology will become increasingly important.

When supplying energy to a factory or to a manufacturing plant at a business establishment, it is important that purchased electrical power or energy from a utility facility be supplied corresponding to the fluctuation in consumption of energy, such as electric power or steam power, in each plant.

(2) High efficiency

To increase energy efficiency, energy-saving and recycling technologies, high efficiency energy utilization technology and the like are important. In particular, to achieve energy savings, the application of high efficiency devices and energy-saving devices, and countermeasures based on airflow analysis and the application control technology to each plant, without degrading productivity, are important.

Moreover, to achieve highly efficient energy utilization, the installation of equipment to reduce energy loss, and the development of technology for efficiently extracting and utilizing limited fossil fuel resources without waste are needed. In the electric power sector, system operation based on power flow optimization is important.

(3) Environment, safety and security

An aggressive approach for reducing CO_2, NO_x and SO_x emissions, utilizing renewable energy, and using environmentally suitable materials is needed and must be implemented in consideration of energy security and the entire lifecycle. Safety of energy devices and systems is also being addressed proactively.

(4) Advanced operation and utilization

In recent years, new approaches have gained attention for advancing operation and utilization technology.

In the electric power sector, information and communications technology (ICT) is used in the transmission, transformation and distribution of power from generation facilities at power companies to individual customers (companies, factories, households) to establish a "smart grid concept" that aims to realize advanced operation.

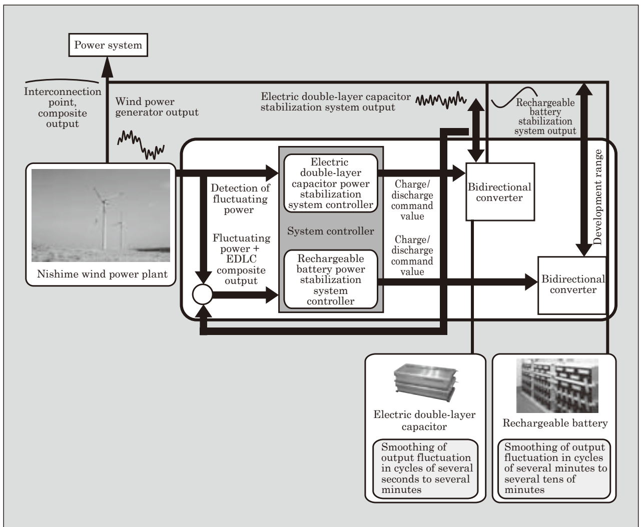
By installing distributed generators and aiming to lower costs and produce power locally for local consumption, efforts to establish micro grids at specific regions such as remote islands and to convert factories to smart factories have been advanced. Also, initiatives for interchanging the waste heat from factories with other factories or with the private sector, diverting thermal energy to certain regions, interchanging power among multiple users, shared utilization and the like have also been advanced.

To realize the above, the establishment of the following two types of technologies is important.

(a) Smart energy-compliant technology
  (i) Next-generation distribution automation system technology for distribution systems
  (ii) Renewable energy coordination technology (power quality measurement/status assessment, power system analysis technology, supply/demand control technology, battery interconnection technology, etc.)
  (iii) Power system interconnection technology for the generation and consumption of thermal, steam or other types of energy
  (iv) Energy management technology for improving energy utilization and supporting power market transactions
  (v) Technology for utilizing "smart meter" network control-type terminals
  (vi) Wide-area multi-point simultaneous measurement technology

(b) Information communication technology
  (i) High-speed, large capacity information communication technology as basic technology
  (ii) Computing system technology

Fig.2 Configuration of hybrid power stabilization system for wind power generation



3. Fuji Electric's Efforts

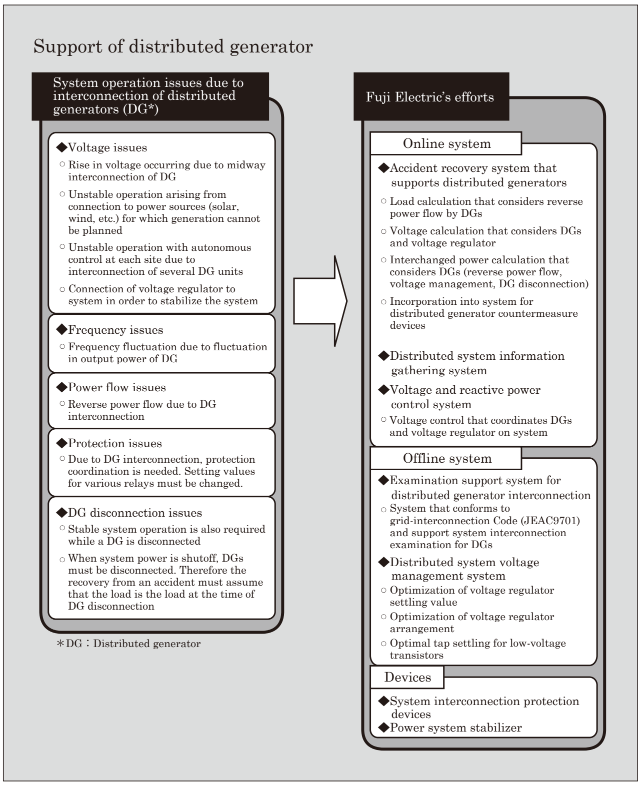
Over many years, Fuji Electric has addressed this challenge of energy utilization, and has made positive contributions through technical and product development. Fuji Electric's automation technology for smart energy, which leverages Fuji's accumulated engineering expertise, is described below.

3.1 Advanced technology in the electric power sector

(1) Supply and demand control technology for distributed energy

For energy systems such as a micro grid consisting of multiple distributed generators, Fuji Electric participates in the "Demonstrative Project of Regional Power Grids with Various New Energies" being carried out by the New Energy and Industrial Technology Development Organization (NEDO), and has developed hybrid technology for stably controlling the supply and demand and for operating and managing natural energy power generations such as solar and wind power, and distributed energies such as biomass generation and rechargeable batteries[(2)]. Fuji Electric has also participated in various regional energy business feasibility studies both in Japan and overseas. Fuji is also working to find solutions to such problems as how to reduce greenhouse gas emissions in developing countries, and supports regional development and vitalization through regional emergent-type distributed

Fig.3 System operation technology that supports the introduction of distributed generators



energy systems.

(2) Power stabilization control

With the objective of using distributed generators as a stable energy source, Fuji Electric has been working on electric power storage technology for over ten years, and has developed stabilization technology using power storage devices such as a super high-speed flywheel power stabilizer, redox flow batteries and so on[3]. Hybrid power stabilization systems have recently been developed using capacitors and storage cells. Power stabilization systems are configured from energy storage systems such as rechargeable batteries, inverters and system controllers, and the energy storage systems are charged and discharged to eliminate fluctuations in the output of distributed generators. Figure 2 shows the configuration of a hybrid power stabilization system, constructed with capacitors and rechargeable batteries, for wind power generation. An optimal charge/discharge control method such as variable time constant control are employed, in verification testing at a wind power generation site of Win-Power Co. For a duration of 20 minutes, the output fluctuation was less than 10% of the maximum output fluctuation range at least 90% of the time when using a power stabilization system at 30% of the wind power rated output ratio.

(3) Optimization of system operation

With distributed generators for renewable energy and the like, planned output control is difficult to implement, and therefore as shown in Fig. 3, various constraints are incurred when connected to a grid. For example, with current systems, trouble such as a voltage rise or reverse power flow may occur midway on the line. In response to such problems, Fuji Electric has developed a high-speed power flow calculation method[4][5] using the backward-forward sweep (BFS) method which enables computations to be performed rapidly with good convergence and is specialized for radial distribution networks, and has also developed proprietary technology such as a state estimation method[6] for estimating the load, voltage and power flow state of an entire distributed system from limited information (such as information from measurement equipment). Fuji has also advanced the development and investigation of the application of distributed generator support systems, such as a recovery system that operates in the event of failure, an optimal reactive power control system, an examination support system for distributed generator interconnection and a voltage control system for distribution systems.

Power flow calculations are used with various distributed generator support systems for state estimation and the like, and because these calculations may be performed several thousands of times in a single process, high speed is necessary. Exploiting the characteristic radial shape of a distributed system, and by alternately performing upstream iterative computations and downstream corrections, BFS method has the advantage of enabling computations to be performed approximately 10 times faster than the Newton-Raphson method which is widely used with high voltage systems.

(4) Smart meters

To enhance energy operation and management, the energy utilization state and energy quality information must be “visible” in real-time.

Since the 1970s, Fuji Electric has been developing automatic meter reading, load control, shutdown/reset processing technology mainly for power meters using wired communications such as power line communication (PLC), telephone lines and optical fiber, and also using wireless communications such as cellular phone networks and short-distance wireless (Bluetooth*1, specified low power radio).

In the future, Fuji Electric intends to use ICT additionally to develop measurement functions and demand response functions for ensuring network stability, and to advance the development of a network control-type meter capable of governing the interface between a distributed system and its customers.

3.2 “Optimization” and “visualization” of energy utilization

To utilize energy resources such as oil and gas more effectively, to efficiently operate and monitor equipment to realize energy savings, and to ensure a stable and secure supply of energy, Fuji Electric has applied various plant control technologies and information technologies to provide a wide range of solutions. Representative examples are described below.

Solutions for the effective utilization of energy resources include the application of high-pressure carbon dioxide injection control technology and oil well head high-pressure valve control technology at an extraction facility to prevent a decrease in the production capacity of natural gas. Fuji is also working to establish a control method for improving the operating efficiency of crude oil pumps, and to optimize well facilities. Other examples of solutions for effective utilization include the application of optimal schedule operation control for the carburetor at a liquefied natural gas site, and control technology for the efficient generation of city gas.

To ensure a stable and secure supply of energy, Fuji Electric has delivered numerous remote monitoring and control systems for pipeline equipment (city gas supply network, natural gas, airplane fuel).

On the other hand, reducing the relatively large consumption of energy at plant facilities and the like is especially important for reducing the emission of greenhouse gases. To attain the minimum cost for produced energy, by-product energy and the purchased energy at a plant, the high-level automated operations described below are being advanced.

---

*1: Bluetooth is a trademark or registered trademark of Bluetooth SIG, Inc.

(a) Boiler control that combusts exhaust gas with ultra-low oxygen
(b) Power reception/generation optimization control for determining the price of a power demand contract, the in-house power generation amount, and for realizing a steady supply of steam to a production facility
(c) Automated preferential fuel control for a boiler to realize the effective utilization of by-product energy
(d) Optimal load distribution control that considers the efficiency of each thermal power plant
(e) Optimal route control for steam at production facilities to realize the minimum cost

These energy reducing controls are highly effective when implemented comprehensively. These controls are realized with prediction, optimization and simulation technology that utilize analyzable structured neural networks (ASNN) and a metaheuristic optimization method.

Fuji Electric is also developing the "FeTOP" system which, based on the load forecasting, optimal operation plan and simulator function, will enable the optimal control of utility facilities. The FeTOP system configuration is shown in Fig. 4.

In the past, a utility facility was operated by an operator based upon their experience and in consideration of certain tolerances. But with FeTOP, predictions concerning various types of energy (electrical, steam, and thermal) are made based on process data. The optimal operating method for a utility facility is automatically computed using a simulator and an optimization function, and control is implemented so that an actual plant will realize a 10% energy savings compared to the past[7][8].

Additionally, to improve energy visualization in the industrial sector, various measurement devices, sensors and monitoring systems are combined to provide the "Main Gate" energy management system for realizing centralized control of energy information. Main Gate is equipped with a wide variety of functions, such as energy operational analysis, facility operational analysis and quality trend analysis, which are necessary for energy-savings management.

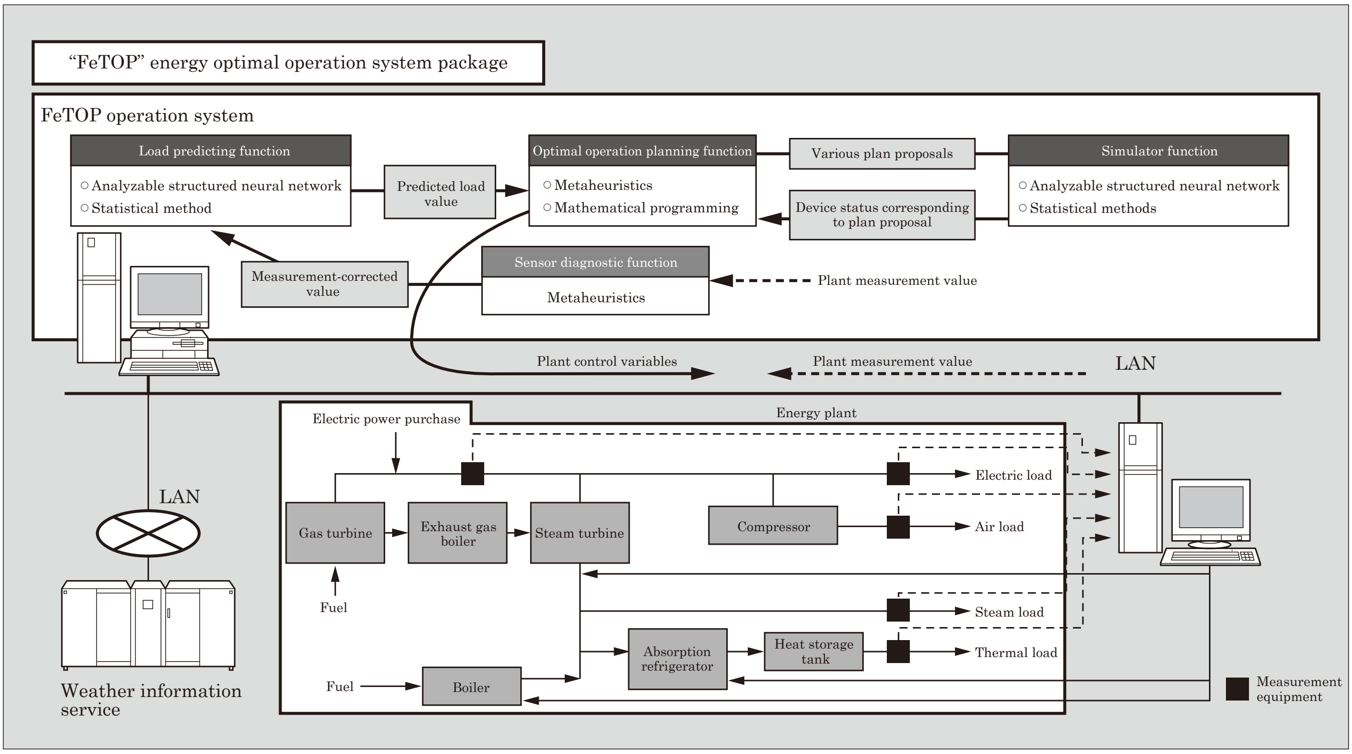
3.3 Efforts to address safety

In recent years, based on the amount of risk associated with a plant or equipment, a mechanism that uses the quantitative scale known as the safety integrity level (SIL), specifying the required level of risk-reduction for a safety device, is requested for quantitatively determining risk and investment amounts. Fuji Electric is actively promoting the application of this type of safety instrumentation system.

4. Postscript

The energy problem is a global challenge, and while advancing solutions to stem the growing demand for energy by effectively utilizing resources and dealing with environmental issues, the goals of a stabilized supply of energy and reduced consumption are targeted through international cooperation. Noteworthy trends include the goal of establishing the EMS inter-

Fig.4 "FeTOP" system configuration example



national standard (ISO 50001) by the end of 2010, and the various standard specifications for a transition to smart electric power. Focusing the collective technical strength of the Fuji group, according to the globally-expanding market environment and the evolution of new technology, Fuji Electric intends to continue to advance its research and development efforts, and to strive to provide even higher levels of automation.

References

(1) OECD/IEA World Energy Outlook 2008

(2) E. Ibaragi, et al. "Technology for Distributed Energy Systems", Fuji Electric Journal, 2005, vol.78, no.6, p.423-430.

(3) T. Jintsuugawa. "Application to Wind Power Generator Output Fluctuation Suppression", 2009 Institute of Electrical Engineers of Japan Conference, Symposium on Use in Distributed Generator Energy Storage Systems (Use with Solar Power Generation, Wind Power Generation, Micro Grid), 6-S7-4, 2009-3.

(4) Y. Fukuyama, Hsaio-Dong Chiang, "Fast Distribution Power Flow Using Multi-Processors", Journal of Electrical Power & Energy Systems, 1996, vol.18, no.5, p.331-337.

(5) S. Naka et al. "Practical Equipment Models for Fast Distribution Power Flow Considering Interconnection of Distributed Generators", Panel on Challenges on Distribution Systems, IEEE PES Summer Meeting 2001.

(6) S. Naka et al., "A Hybrid Particle Swarm Optimization for Distribution State Estimation". IEEE Trans. On Power Systems, 2003, vol.18, no.1, p.60-68.

(7) T. Kou, et al. "Optimal Operation of Engine Equipment Plant and Application Example". Fuji Electric Journal, 2004, vol.77, no.2, p.166-170. (in Japanese)

(8) Y. Fukuyama, Y. Totaka. "Energy Savings through Optimal Operation of Utility Facility". Journal of the Society of Instrument and Control Engineers, 2006-10, vol.45, no.10. (in Japanese)