

# FUJI ELECTRIC REVIEW

Automation Technology  
Cultivates the Future



2010 VOL.56





3 keys

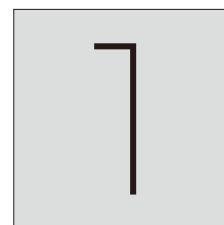
- Smarter
- Safer
- Greener





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Cover photo:

Automation technology is expected to contribute to overcoming societal challenges such as global warming and an aging population, and business management challenges such as globalization and how to increase competitiveness. With the goal of realizing a safe, secure and sustainable society, Fuji Electric is moving ahead with technical development focused on energy, the environment and safety. Smarter, safer and greener automation are the three keys to success, and Fuji Electric is pursuing business development in the energy, industry and "socio" fields.

The cover photo depicts the concept of automation, with a wind power generation output stabilization system, a turbine protection system and a laser gas analyzer symbolizing the trends toward smarter, safer and greener automation.

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# Current Status and Prospects of Automation Technology

Motofumi Matsumura<sup>†</sup> Kenichi Kurotani<sup>†</sup>

## ABSTRACT

Fuji Electric has expanded its automation business in various fields, such as for power and industrial applications, and has compiled a record of many successes. Based on our technical strategy for the Japanese market and on global market and technology trends, Fuji Electric is advancing technical development focused on energy, the environment and safety with the goal of realizing a sustainable society that is a safe and secure. With smarter functions, improved safety and greening seen as the critical factors for success, Fuji Electric has subdivided its automation business activities into energy, industry and socio-automation sectors, and is advancing efforts to realize safety engineering, platform development that includes embedded systems, and “3R” (reduce, reuse, recycle) engineering.

## 1. Introduction

Fuji Electric has been engaged in creating the latest measurement control technology and information technology in the power, water treatment and transit sectors of the social infrastructure field, the iron/steel and petrochemical sectors of the basic materials industry, the electric and electronic sectors of electromotive power applications, the assembly and processing industries, and as applications to commercial buildings and stores., Fuji Electric has developed an automation business for realizing power savings, automation, higher efficiency and higher reliability, with a record of many pioneering accomplishments. Aiming to realize next-generation automation that will contribute to resolving such social issues as global warming, low birth-rate and aging society, the realization of safety and security, and economic issues such as globalization and how to improve competitiveness, Fuji Electric is presently advancing technical development with a focus on the energy, environment and safety fields.

## 2. Current Status and Trends of Automation Technology

### 2.1 Technology strategy in Japan

The strategic technology roadmap formulated and published by the Japanese Ministry of Economy, Trade and Industry, focuses on critical technology, and shows installation scenarios, technical maps, and a technology roadmap. The fields of energy and measurement systems, which are closely related to automation technology in the 2009 version<sup>(1)</sup> of this strategic technology roadmap, are described below. Information technology

(IT) is described below based on the “i-Japan Strategy 2015<sup>(2)</sup>” proposed by the Japanese government’s IT Strategic Headquarters.

#### (1) Technology strategy for energy

In the energy field, the following five policy objectives were established based on Japan’s “New National Energy Strategy” formulated in 2006 and the “Cool Earth 50” plan of 2007, and major technologies that can contribute to these policy objectives were identified.

- (a) Improvement of total energy efficiency
- (b) Diversification of fuel for transport sector
- (c) Promotion of the development and introduction of new energy
- (d) Utilization of nuclear power
- (e) Guarantee of a stable supply of fossil fuel, and effective and clean utilization

Category (a) can include energy-saving industrial processes (iron manufacturing, petrochemical production, etc.), and process control technology will contribute to attaining the objective of this category. Next-generation energy-saving devices made of SiC (silicon carbide) and GaN (gallium nitride), and high-efficiency inverters are also included in this category. Efficient energy management systems for homes, buildings and regional areas are common to both categories (a) and (c). Category (c) can include solar power, wind power, and biomass power, and the importance of grid interconnection technology for these distributed power sources is also indicated. Category (e) includes fuel cells, CO<sub>2</sub> collection and storage technology, and so on.

#### (2) Technology strategy for measurement systems

Aiming to ensure safety and security and to advance technical competitiveness, Fuji Electric aims to accelerate the development of new measurement devices and to popularize the technology for utilizing the measurement devices.

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The following items are common to both the specific challenges and representative projects involved in the research and development of hardware and software for measurement devices.

- (a) Development of leading-edge measurement devices based on new sensors and new principles, and expansion to the global market
- (b) Technical development for ensuring software embedding and traceability requirements according to the field user's preference
- (c) Provision of measurement solutions, such as failure inspections, to manufacturing sites
- (d) Measurement standards improvement, standardization activities and certification method

The most crucial technical challenges for improving gas flow measurement performance include how to achieve higher precision, reliability and speed, widen the range of gas types, ensure traceability, and so on.

### (3) IT strategy

The “i-Japan Strategy 2015” was formulated as a new strategy that sets targets for information technology in Japan by the year 2015. This strategy aims to realize digital inclusion, in which digital technology, like air or water, is universally accepted without resistance and encompasses the entire economy and society, and digital innovation, in which digital technology and information generate new vitality by reforming the entire economy and society, in Japan by 2015. With “industrial and regional invigoration and the cultivation of new industries” as one of the three pillars of support for this strategy, measures to increase the functionality and reliability of embedded software and to reduce carbon emissions through clean IT are cited as examples of the implementation of this strategy.

## 2.2 Market and technical trends

Recent trends of global markets and technology relating to automation technology are described below.

### (1) International standardization

Compliance with international standards is becoming increasingly important. Standardization in the measurement and control fields for energy and industrial processes is being advanced mainly by the TC8, TC59, TC65 and TC95 IEC Technical Committees. The trends toward digitization, networking, industrial wireless networks, and international standardization from a systems perspective are intensifying, and there is interest in technology for supporting system vertical integration, the Smart Grid, and the like. Standardization of industrial wireless technology is being advanced with the Wireless-HART standard of the HART Communication Foundation, and the SP100 standard of the ISA (International Society of Automation). With ISO 12100 (safety of machinery) and IEC 61508 (functional safety of electrical systems) as upper level standards for machinery and equipment safety, standardization is also being advanced for various industries and equipment. In Japan, JIS stan-

dards are being adopted, and as part of this trend, the introduction of safety instrumented systems is gradually becoming accepted as a common sense measure.

### (2) Production and environmental technology

For energy management, the ISO 50001 standard is being advanced and aims to be released by the end 2010. ISO 50001 for energy management will provide similar standardization as ISO 9001 for quality management and ISO 14001 for environmental management. Meanwhile, environmental regulations for products, such as RoHS\*<sup>1</sup> and lead-free regulations, are also being advanced.

### (3) Sensor networks

Under the guidance of the Japanese Ministry of Internal Affairs and Communications, research and development of ubiquitous sensor network technology is being carried out to realize a network in which sensors can recognize people and objects and their peripheral environments, and information can be distributed autonomously among the sensors, enabling real-time responses to situations. To realize such a network, various efforts are conducted to overcome challenges involving wireless communications, networking, MEMS (micro electro mechanical systems) sensors, sensor interfaces, and batteries (or self-generation technology), and a method to achieve long-term operation without degrading the reliability of these elements.

### (4) Control technology

Since the 1990s, robust control and neural networks have been applied to the industrial and consumer fields, in household appliances, cars and the like, and coupled with advances in information technology, have had a dramatic effect. As prospective applications, the theories and methods of hybrid control for seamlessly handling continuous and discrete systems, and dependable control for realizing higher reliability, availability and safety, have recently attracted attention.

### (5) Smart Grid technology

As a centerpiece of U.S. President Obama's “Green New Deal” legislation, Smart Grid technology is attracting attention. The Smart Grid is a next-generation transmission and distribution power systems, having a control system that uses IT to automatically adjust the power flow from both the supply side and the demand side. With dedicated devices and software embedded into a portion of the transmission and distribution network, the Smart Grid continuously monitors electricity and is able to achieve a good balance between power demand and supply, and is attracting attention from Europe, China, Japan and elsewhere throughout the world. Since the underlying assumptions about power infrastructure differ according to the country, there are various opinions concerning the

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\*1: RoHS: EU directive that restricts the use of certain hazardous substances in electrical and electronic equipment

challenges and net effect of the Smart Grid. Japan is said to be a superpower for Smart Grid element technology. With the anticipated spread of photovoltaic power generation to ordinary households and the expanded use of distributed generators, development efforts are focused on measurement sensors for the precise control of distribution systems, control technology for control terminals and next-generation distribution systems.

### 2.3 Demand trends

In the energy and environment related markets, demand in China and Asia is expected to increase. In Japan, the environmental and energy conservation related markets are forecast to grow by an average annual rate of about 8% and to reach 15 trillion yen by the year 2020. The Smart Grid related market is also growing rapidly, and reportedly is expected to reach US\$20 billion in size by the year 2014. Demand for safety and security is expected to increase in the Middle East and in Asian regions such as China and India, and a high growth rate of approximately 10% is forecast. The markets related to environment, energy conservation, safety and security are expected to continue to grow both in Japan and overseas, and automation will play a significant role in that market growth.

## 3. Fuji Electric's Vision for its Automation Business

### 3.1 Customer issues and needs

Especially due to changes in the business environment of manufacturers, customer issues and needs have changed as follows.

#### (1) Support of a global manufacturing environment

The manufacturing industry must be able to supply products in a timely manner to the required markets. Manufacturers are therefore establishing manufacturing sites near to their desired markets, and are consolidating their manufacturing sites at countries and regions where labor and other costs are low. Meanwhile, technology for the integrated management of distributed sites, global supply chain management, security, intellectual property protection and the like has become critical.

Moreover, since the employees at these distributed sites will have different cultural backgrounds, work standardization, work history management, and a higher level of safety design for field equipment are being requested more than ever.

#### (2) Optimization of asset utilization

A manufacturing system capable of responding flexible to fluctuations in demand, business climates and exchange rates, changing needs and other market risks, and the ability to construct, modify and relocate manufacturing sites and production lines quickly and with low cost is essential. As a result, equipment is trending to become modularized, generalized and por-

table.

In response, global simulations that include simulations of the distribution among multiple sites, precise simulations of manufacturing processes, wire-saving and wireless field devices, and devices having plug-and-play functionality that enables operation just by connecting the equipment are requested.

#### (3) Investment risk reduction (high utilization rate, improved safety) and product safety

Field equipment is requested to provide increasingly higher utilization rates, and in the case of an accident or equipment breakdown, the operation shut down time and opportunity loss must be minimized. Accordingly, high reliability and safety are requested and the capability for early detection and future prediction of abnormal symptoms is anticipated so that countermeasures can be implemented prior to a breakdown. In addition to the conventional level of reliability, dependable design technology is also sought to improve system availability, enhance resistance to breakdown, and so on.

The ensuring of product safety is a principal risk that, without mentioning specific cases, may affect the continuing existence of a company. Particularly in the case of food, drugs and the like, the removal of defective products, more sophisticated inspections to detect contamination with foreign matter, microorganisms and the like, and guaranteed traceability from raw materials to manufacture and distribution are requested.

#### (4) Mobility of human resources and retention of the skills

The generation of baby boomers is approaching retirement age, and the workforce is becoming more mobile. The ratio of temporary employees to regular employees is increasing, in order to be able to respond flexibly to changes in material resources due to the fluctuations in the business climate and so on. Further, there is a shortage of younger workers, not only in Europe and the US, but also in Japan. Foreign employees in these countries are being hired in increasing numbers as a result of globalization.

Consequently, there is a need for work tasks to be simplified so that an employee may engage in the work after only a short-term training course and for safe equipment and devices that can be easily operated even by non-experts. Providing the equipment with intelligence such as self-diagnosis and functional safety capabilities gives support to the workers. Additionally, the capability to monitor the health and conscious state of workers in order to ensure safety is also requested.

#### (5) Support of eco-friendly society

As one solution for mitigating the impact of global warming and achieving zero emissions, support for an electric vehicle (EV)-oriented society is requested. For this purpose, devices must be made to consume less power and to be smaller in size, and their operating efficiencies must be monitored and improved regularly.

Moreover, in support of the regulation of harmful substances (Air Pollution Control Act, Water Quality Pollution Control Act, RoHS, REACH\*2, etc.), the low concentrations and small quantities of harmful substance components in flue gas and waste water emissions from business establishments must be measured. Challenges to the realization of an EV-oriented society include the development of safe and highly efficient drive control technology and the provision of an infrastructure that includes rapid charging stations.

### 3.2 Three key concepts

Figure 1 illustrates the progress of devices used to configure automation systems, with the horizontal axis showing the I/O processing speed and the vertical axis showing the memory capacity installed in the devices. Electronic technology and software technology have exhibited rapid progress, and the changes in system configuration have been remarkable.

\*2: REACH: EU regulation concerning the registration, evaluation, authorization and restriction of chemical substances

Figure 2 shows Fuji Electric's automation business activities. As shown in the top of this figure, accompanying the distribution of risk and the increasing sophistication of functions, the constituent devices

Fig.1 Automation system constituent devices and technical progress

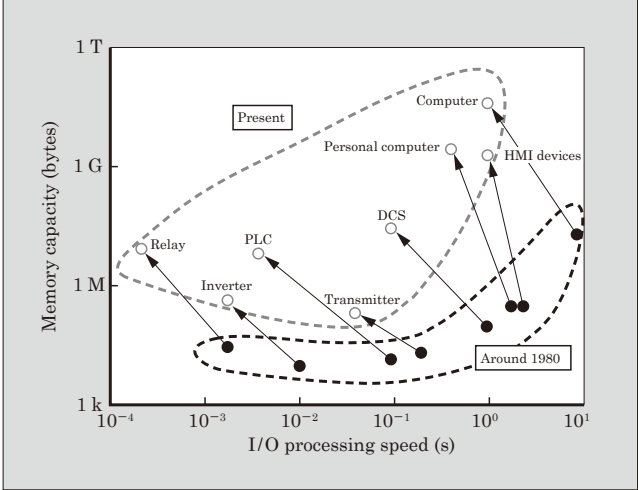
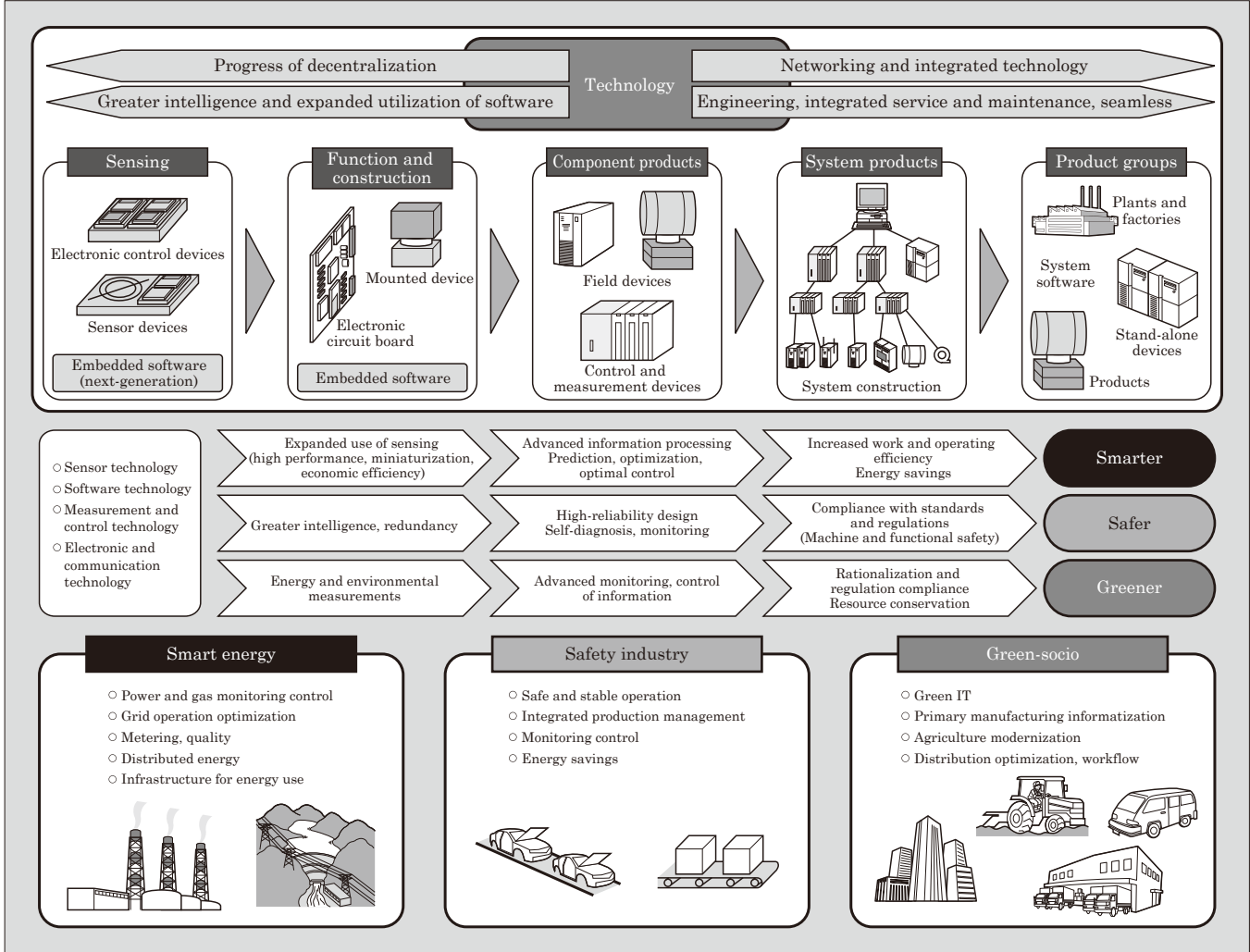


Fig.2 Fuji Electric's automation business activities





have become more physically dispersed and autonomous. Meanwhile, from the perspectives of operation and engineering services, a seamlessly integrated environment is requested. The future of automation is in solutions that contribute to improved economic competitiveness by “increasing the visibility” of processes and manufacturing and by “increasing the comfort and safety” of operation. With this aim, from sensors to system construction, Fuji Electric is advancing technical development and the commercialization of products based on the key concepts of (i) smarter, (ii) safer and (iii) greener technology.

Smarter technology means higher performance sensing, advanced information processing such as optimization, higher efficiency for work and operations, and energy savings. Safer technology ensures safety and security by providing high-reliability redundant systems, high-reliability designs and safe designs, functional safety systems that conform to international standards, and the like. Greener technology supports the environment with environmental load measurement, sophisticated monitoring, support of environmental regulations, resource conservation, and so on.

Business fields are categorized into the energy field, which includes electric power, gas, oil, etc., the industry field, which includes food, chemicals, iron/steel, electrical machinery, machinery, etc., and the “socio” field, which includes agriculture, distribution, services, commerce, public utilities, etc. The above-mentioned three key concepts are important to each of these three fields, and technical development is being advanced with particular emphasis on smarter technology in the energy field, safer technology in the industry field, and greener technology in the “socio” field.

### **3.3 Fuji Electric’s activities for automation technology**

#### **(1) Safety technology**

Fuji Electric has long been engaged in efforts to increase the reliability of plant safety control systems for power utilities, public utilities, factories and the like, and has also been involved in many efforts including plant and device fault diagnosis based on sensor technology. Fuji Electric has also achieved many successful results with security management for information control systems and the like. Additionally, Fuji Electric is stepping up efforts to train engineers and provide products so as to comply with standards and regulations for safety of machinery and functional safety. In all its products, Fuji Electric endeavors to incorporate safety system design principles based on risk assessment and on development using safety techniques that conform to international standards.

#### **(2) Platform development**

Previously, development was performed uniquely according to the industry sector, organizational structure and type of equipment, and as a result, the development period would be prolonged, and technology would stagnate and efficiency would decrease due to

the individual development. Therefore, Fuji Electric is moving ahead with efforts to establish a common platform (cross-sectional development and establishment of infrastructure technology) that would provide a technical foundation. The establishment of a platform enables development processes and technology to be shared and standardized, software and hardware components to be standardized, and efforts to develop leading edge technology to be shared and the technology accumulated. Consequently, the development period can be shortened, technical sophistication enhanced, and quality improved.

#### **(3) Embedded system technology**

Software is embedded in all sorts of electronic devices. Moreover, as the scale of development work continues to increase, it is important that the development work be more efficient and result in higher quality products. For this purpose, hardware and software platforms have also been established for embedded systems, and the standardization and modularization of development techniques and development processes are being advanced.

#### **(4) 3R engineering**

Fuji Electric is advancing the use of common platforms for software development and for engineering work involving the controller, computer and HMI (human machine interface) devices that configure a control system, and the use of an integrated engineering environment to improve work efficiency. The result promotes the reducing of design and development work, the reusing of design assets, and the recycling of components. Fuji Electric calls this 3R (Reduce, Reuse, Recycle) engineering.

#### **(5) Control technology**

Control technology is the core technology for realizing optimization and prediction and diagnosis capabilities in order to improve the energy savings and safety of devices and plants, and Fuji Electric has long been involved in this core technology. By engaging in efforts to establish platforms for single-input-single-output PID control and multivariable model predictive control, and to train control engineers, Fuji Electric aims to raise the level of applied technology. Fuji Electric is also heavily involved in non-linear optimization technology and multi-variable statistical process control technology.

#### **(6) MEMS and sensor technology**

It is important that the sensors and actuators used to configure a control system are themselves power-saving and resource-saving type, and the use of MEMS (micro electrical mechanical systems) devices that integrate electrical circuits and mechanical systems are an effective means for realizing the desired power and resource savings. Fuji Electric has been involved with MEMS technology for more than 20 years, and the application of MEMS technology to measurement devices, radiation sensors, gas analysis sensors and the like has contributed greatly to their miniaturization and



the realization of power savings. Fuji Electric has recently been developing a methane gas sensor housed in a gas alarm device for detecting gas leaks, and a vibration sensor for detecting abnormalities and abnormal symptoms and for diagnosing the soundness of equipment, buildings and the like.

#### (7) Network technology, wireless technology

For control system networks, Fuji Electric is advancing development to realize a mechanism for transmitting information at the network level, targeting vertical integration of the engineering environment that extends from the field devices to the controller and up to the computer. Specifically, Fuji Electric is advancing the application of Ethernet/IP at the controller level and FDT/DTM (field device tool/device type manager) technology for integrated engineering.

For wireless technology, Fuji Electric is promoting the establishment of a wireless platform for specified low-power radio waves for short distances and a mesh network for wide areas. At the same time, Fuji Electric is attempting to reduce communication trouble by standardizing the engineering technology for wireless networks and using interference avoidance technology.

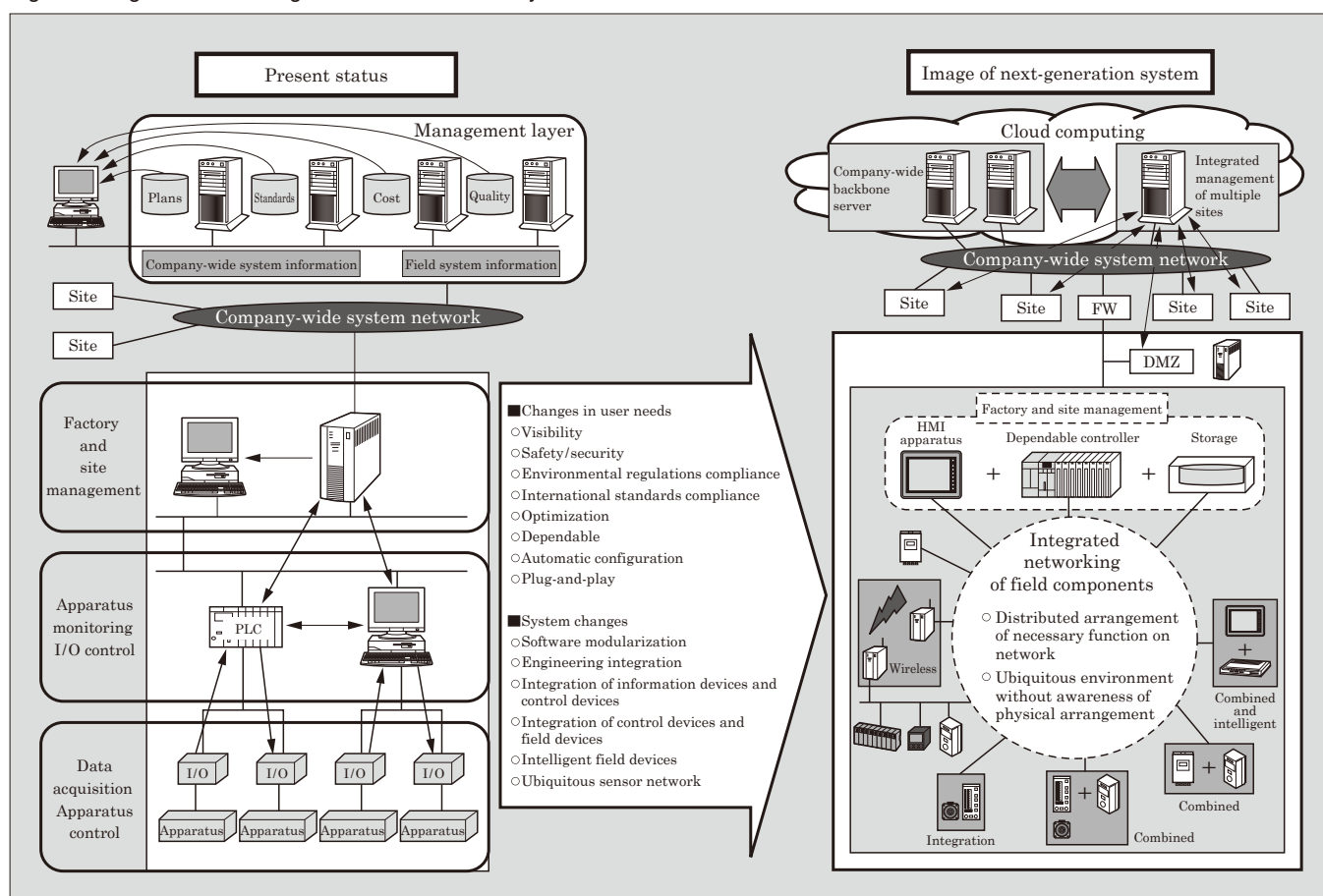
## 4. Future Outlook

Entrusted by the Japanese Ministry of Economy, Trade and Industry, the relevant associations met in 2008 to discuss future visions for cross-sectional scholarship, and for four topics, prepared an academic road map<sup>(3)</sup> targeting the years 2010 to 2040. In this work, WG1 (control and management engineering field) listed the construction of a safe and secure society and an approach to environmental problems as the most important needs, and the technology of “increasingly complicated objects and increasingly complicated systems” as seeds for future development. To understand, analyze and control these seeds for development, it is said that the status of objects and systems must be monitored at various levels and made “visible.”

However, visualization is not simply the same as “measuring,” and also includes data “consolidation” and “presentation.” These three elements are important, and visualization technology must evolve while maintaining the close relationship between these elements.

In reference to the above and based on current needs and the progress of information control technology, an example implementation of the imminent next-generation automation system conceived by Fuji

Fig.3 Configuration of next-generation automation system



Electric is shown in Fig. 3.

## 5. Postscript

Based on Japan's technology strategy and trends of the global market and technology, Fuji Electric's activities and outlook for its automation business and technology have been described. To mitigate global warming, the total greenhouse gas emissions worldwide, converted into the corresponding CO<sub>2</sub> emissions, must be cut by at least 50% of year 1990 levels by year 2050. To realize this goal while maintaining our lifestyle will require various measures and policies, and the potential for automation technology to contribute to the attainment of this goal is extremely large. Automation technology also holds many promises for ensuring the safety and security of society.

Positioning its business around "Energy and Environment," Fuji Electric intends to provide automa-

tion technology as a cornerstone for the realization of a safe, secure and sustainable society.

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# Automation for Realizing “Smart Energy”

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## 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

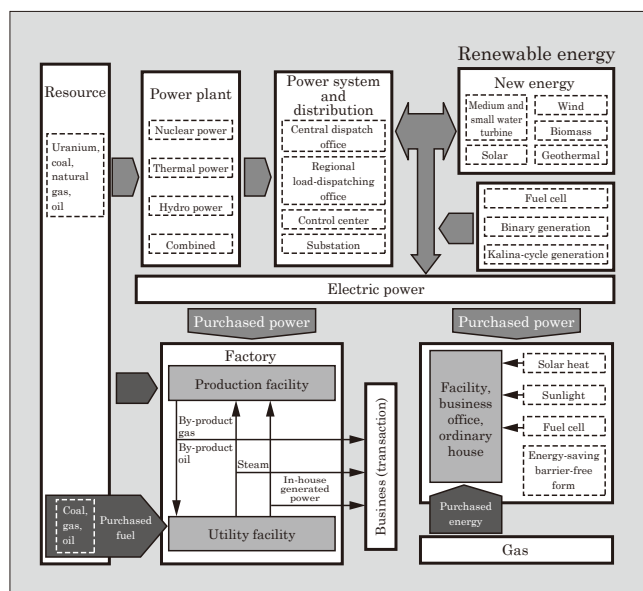
Global warming, believed to be caused by mankind’s increased use of greenhouse gases, has serious implications for natural ecosystems and for humans. The amount of greenhouse gases emitted globally is already larger than the amount that can be absorbed naturally by more than a factor of two, and in consideration 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)<sup>(1)</sup>. 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

Fig.1 Energy flow overview



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.”

## 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.

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Table 1 Requirements for smart energy and technical challenges

Requirements	Technical challenge	
	Equipment/component	System
Higher reliability Higher quality Improved stability	<ul style="list-style-type: none"> <li>○ More measuring points with sensors and measuring instruments</li> <li>○ Remaining life assessment, preventative maintenance</li> <li>○ Semiconductor integration using power electronics, MEMS, etc.</li> </ul>	<ul style="list-style-type: none"> <li>○ Widely distributed backup</li> <li>○ IP network security</li> <li>○ Interconnection of distributed generators, power stabilization</li> <li>○ Rapid response to disturbances</li> <li>○ Stable supply of various types of energy (i.e., electric, thermal, steam, etc.) in a business</li> </ul>
Higher efficiency Higher performance	<ul style="list-style-type: none"> <li>○ Super critical power generation, combined cycle power, coal gasification at a power plant</li> <li>○ Improved conversion efficiency with low loss magnetic material</li> <li>○ Electronic device, optical, superconducting</li> <li>○ More compact, lighter weight (gas insulation technology)</li> <li>○ Treatment of aged facilities</li> </ul>	<ul style="list-style-type: none"> <li>○ Reduced transmission/distribution loss: loss minimizing control, higher voltage</li> <li>○ Optimal operation of various types of energy (i.e., electric, thermal, steam, etc.) in a business</li> <li>○ Energy savings and energy recovery in the production process</li> <li>○ Historical management</li> <li>○ Energy-savings when mining fossil fuel, and maximization of amount mined</li> <li>○ ISO 50001</li> </ul>
Eco-friendliness, safety, security	<ul style="list-style-type: none"> <li>○ Safety standard compliance</li> <li>○ CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>x</sub> countermeasures</li> </ul>	<ul style="list-style-type: none"> <li>○ Safety instrumentation</li> <li>○ Visualization</li> <li>○ ISO 14001</li> <li>○ Installation of distributed generators</li> </ul>



More advanced operation and utilization	<ul style="list-style-type: none"> <li>○ Energy management</li> <li>○ Smart grid</li> <li>○ Micro grid</li> <li>○ Smart factory</li> <li>○ Smart mining</li> <li>○ ICT (high-speed and large capacity information communication system, cloud computing)</li> </ul>
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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<sub>2</sub>, NO<sub>x</sub> and SO<sub>x</sub> 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

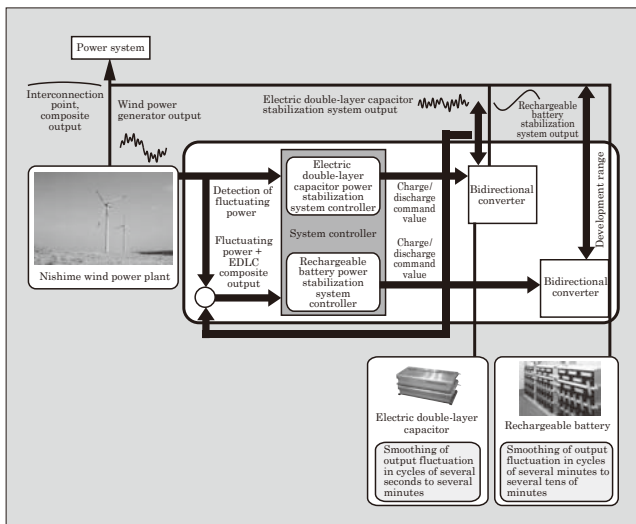
generation facilities at power companies to individual customers (companies, factories, households) to establish a “smart grid concept” that aims to realize advanced operation.

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

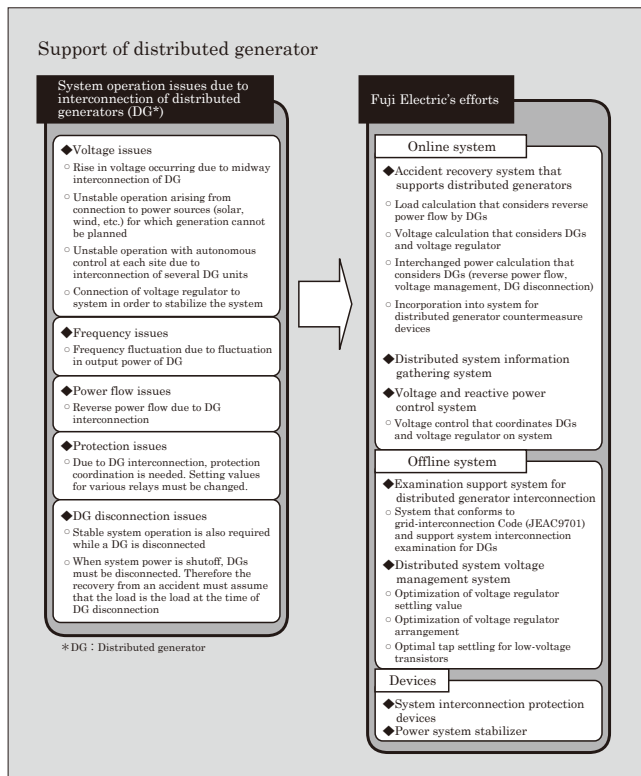
Over many years, Fuji Electric has addressed this challenge of energy utilization, and has made positive contributions through technical and product development. Fuji Electric's automation technology for smart energy, which leverages Fuji's accumulated engineering expertise, is described below.

#### 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<sup>(2)</sup>. 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<sup>(3)</sup>. 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<sup>(4)(5)</sup> 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<sup>(6)</sup> 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\*<sup>1</sup>, 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.

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\*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 op-

timization function, and control is implemented so that an actual plant will realize a 10% energy savings compared to the past<sup>(7)(8)</sup>.

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.

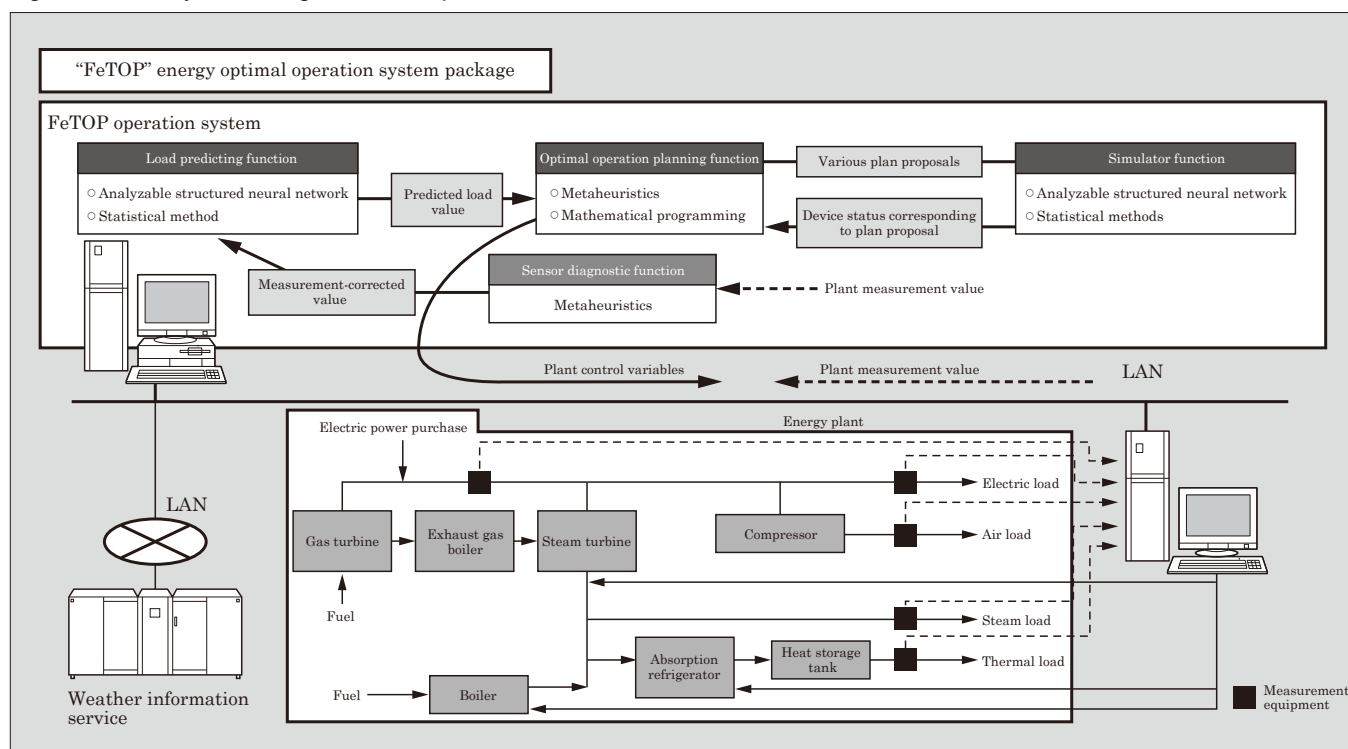
### 3.3 Efforts to address safety

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.

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# Safety Industry Automation for Realizing Safe and Secure Manufacturing

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## ABSTRACT

Fuji Electric aims to supply proprietary safety solutions not only that provides the traditionally requested safety technology such as higher reliability and higher quality but also that meet international safety standards. The safety solutions encompass the three fields of energy automation, industry automation and socio-automation, and customer manufacturing facilities and systems are constructed and maintained by them so as to operate safely throughout their lifecycle. The safety solutions consist of consulting, safety control solutions, safety components, after-sales service and the like, and support the realization of a safety industry for “safe and secure manufacturing.”

## 1. Introduction

Recently, there has been an increase in serious accidents involving equipment and machinery at plants, and public concern regarding safety and security has heightened throughout the world.

Also, “corporate social responsibility” is being emphasized in corporate activities, requests for safety and security have intensified, and demand for safety industry automation technology has increased for plants, equipment and machinery. This paper describes the new safety industry and Fuji Electric’s efforts therein.

## 2. Present Status of the Safety Industry

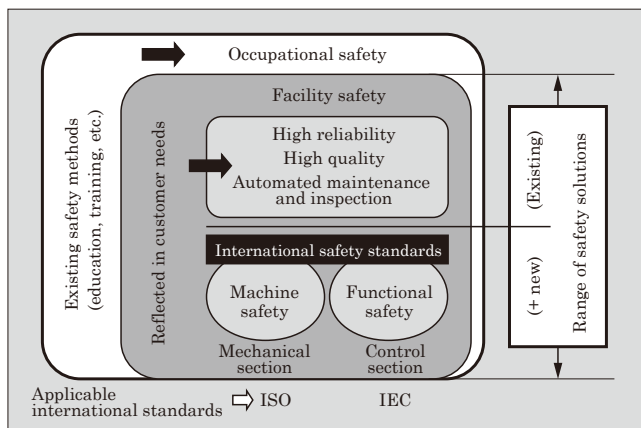
Safety technology is established internationally with ISO and IEC standards. In Europe, an EU directive obligating compliance with ISO and IEC standards for all products has been issued, and the markets for safety-related goods and services are growing rapidly. In accordance with international standards, JIS standards (JIS C 0508, issued in 2000, and JIS C 0511, issued in 2008) have been established in Japan, and GB standards have been implemented in China. The safety-related market is expanding even in Asia. In 2008, the size of the machine safety and functional safety-related market was approximately 800 billion yen in Europe and US, and approximately 50 billion yen in China and Asia (excluding Japan), and globally, the portion of the market for safety instrumented systems, relating to functional safety, exceeded 150 billion yen<sup>(1)</sup>. Moreover, Fuji Electric estimates the machine safety and functional safety market in Japan to be approximately 180 billion yen, and in the future, expects

all safety-related markets to grow rapidly. Future growth will be driven by the following 3 factors.

- As automation advances, compliance will be difficult to achieve unless methods to ensure safety are changed (accidents will be on a large scale, and predicting their occurrence will be difficult).
- Technology to ensure safety has continued to be developed.
- As a consequence of (a) and (b), global safety standards have been established.

At a manufacturing site, previously, safety (occupational safety) had been ensured by instructing the operators with accident prevention measures. Recently, however, a new technique known as safety technology that halts the operation of machinery and minimizes harm to people and damage to equipment has been developed. This safety technology is categorized as “machine safety,” which applies to the mechanical parts of a drive system, and “functional safety,” which applies to the control section that governs the central part of the drive and control systems.

Fig.1 Range of Fuji Electric’s safety solutions



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Fig.2 Applicable fields for safety solutions

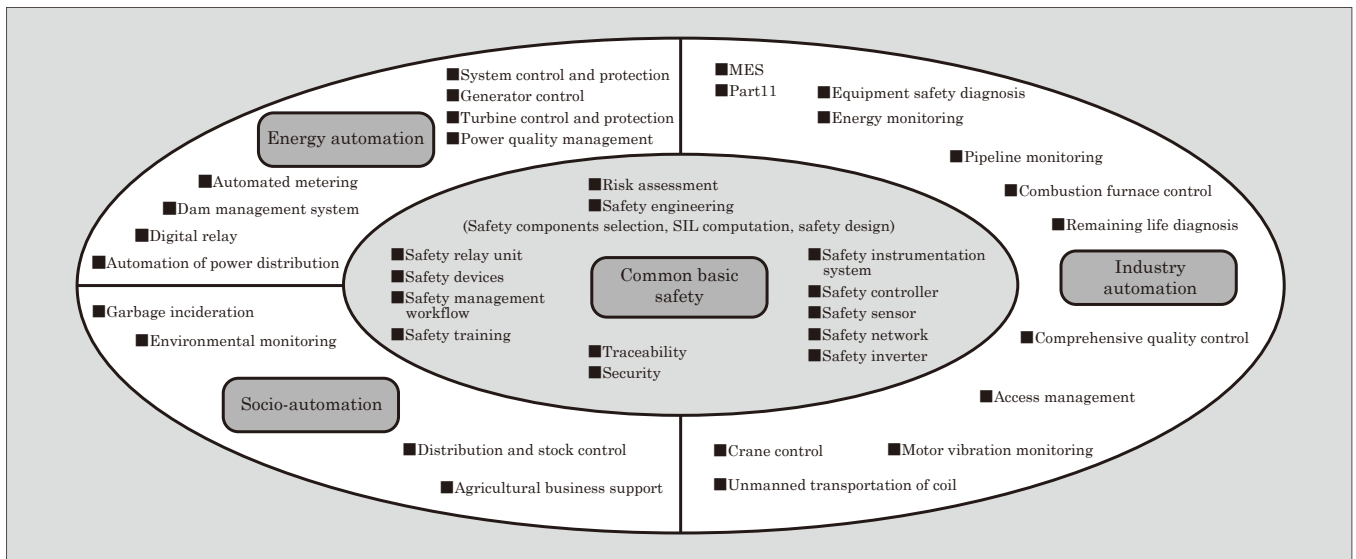


Fig.3 Concept of safety industry realized by combining IT, control, and equipment technology

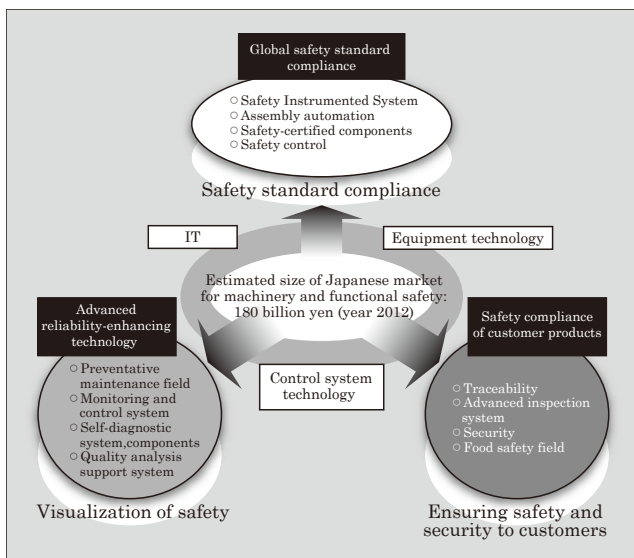


Figure 1 shows the range of safety solutions that Fuji Electric provides.

Japan is about to enter a critical period as most plant facilities are approaching their time for renewal, while at the same time, onsite maintenance workers who possess a high level of maintenance technology expertise are retiring. For the maintenance task of regularly repairing old facilities, there is a growing need for safety industry automation. In other words, safety is being addressed by quantitatively estimating the opportunity loss involved in a sudden plant shut-down, and making a corresponding capital investment in safety, and because the facilities are old, countermeasures for preventing human accidents and product defects are obtained from a comprehensive risk analysis of the entire facility.

On the other hand, safety for this type of manufac-

turing site is often under the control of the occupational health and safety management department, and the application and advancement of new safety standards remain as challenges for the future.

### 3. Fuji Electric's Efforts to Advance Safety Industry Automation

#### 3.1 Efforts in regard to the safety industry

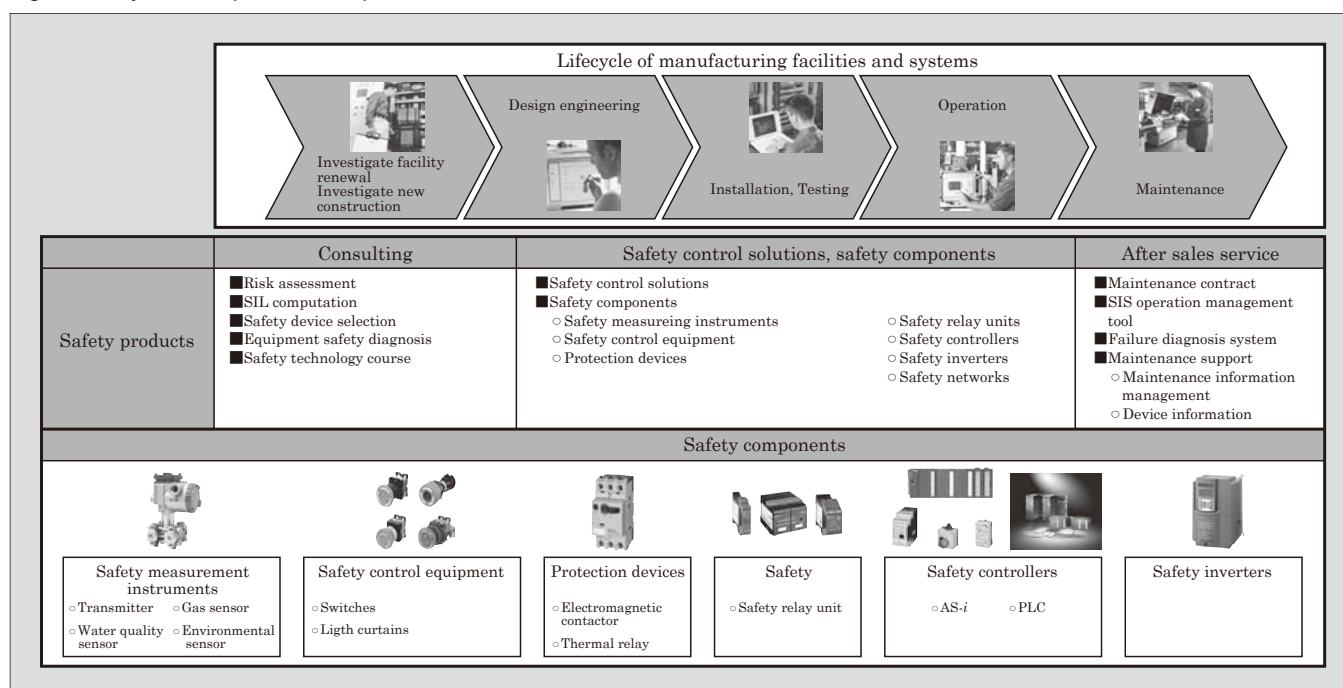
The fields of application of Fuji Electric's safety solutions are shown in Fig. 2. Fuji Electric is working in the industrial automation sector to develop next generation processes, components for machinery and equipment, and automation systems. Figure 3 illustrates the concept of the "safety industry," which is an important theme. In order to provide compliance with global safety standards for Safety Instrumented System and factory automation, to advance the performance of reliability-enhancing technology, such as preventative maintenance and self-diagnostic systems, and to ensure the safety compliance of customer products, safety industry automation combines IT, control platforms and plant engineering.

By offering comprehensive consulting services concerning machine safety and functional safety, and by supporting "safe and secure manufacturing," Fuji Electric aims to become a comprehensive safety solution supplier.

#### 3.2 Safety solution product lineup

Figure 4 shows Fuji Electric's lineup of safety solution products. A lineup of various safety components is provided for realizing safety industry automation. Specifically, this lineup comprises safety instruments (push-button switches, door switches, light curtains), protection devices (electromagnetic contactors, thermal relays), safety relay units, safety controllers (PLC (SIL3), MICREX-NX Safety (SIL3)), safety pressure

Fig.4 Safety solution product lineup



transmitters (FCX-A III (SIL2)), safety inverters, safety networks and so on, conforming to a diverse range of safety standards.

Moreover, in addition to providing safety components, throughout the lifecycle of customer manufacturing facilities and systems, Fuji Electric also provides safety consulting (risk assessment, maintenance support, operations support, replacement support, safety technology lecture hosting), safety engineering (safety machine selection, SIL computation, safety system design) and safety control solutions. A safety control solution aims to combine safety technology acquired in the energy sector with international safety standards based on new concepts.

For further details, refer to the paper titled “Safety Control Solution that Protects Onsite Safety” in this edition.

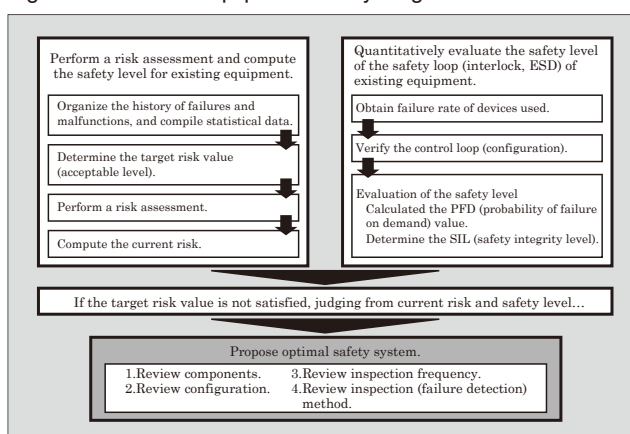
#### 4. Safety Consulting

In the industrial sector, the construction of a “safe and secure system” requires a wide range of technologies for risk assessment, machine safety, functional safety, security, electronic recording of data, preventative maintenance of equipment, and so on. Fuji Electric provides safety consulting and safety control solutions as a comprehensive engineering-oriented approach to these technologies. A portion of Fuji Electric’s safety consulting service is described below.

##### 4.1 Equipment safety diagnosis

Fuji Electric provides an “equipment safety diagnosis” service to support the replacement of existing equipment. Figure 5 shows an overview of this service. In cases where it would be difficult to renew or make

Fig.5 Overview of equipment safety diagnosis



major repairs on plant equipment, the safety of the existing equipment must be enhanced. As one such method, it is effective to diagnose the safety level of existing equipment from the perspective of maintenance. The current risk is computed from a risk assessment based on compiled statistical data and the history of past failures and malfunctions. Next, the safety level is quantitatively computed from the system configuration, failure rate, proof test period and the like for the devices used. If the risk, as determined from the above two results, does not meet the targeted level, the machinery, configuration, proof test period, inspection method (failure detection method) and the like will be reevaluated so that an optimal safety system can be proposed.

##### 4.2 Risk assessment

Fuji Electric provides risk assessment as a part of

its safety consulting service. The international standard IEC 61508 prescribes that safety be managed over the safety lifecycle. Within the lifecycle, the “hazard and risk analysis” phase is positioned as the most important phase. To clarify hazards and hazardous events that occur in plants and control systems, Fuji Electric uses a risk analysis method such as HAZOP (Hazard and Operability Study) and a risk graph to evaluate methods for eliminating hazards, assess the frequency of occurrence of hazardous events, clarify the severity of occurrence relating to a hazardous event, and to estimate and assess plant risk (perform a risk assessment).

#### 4.3 Safety engineering

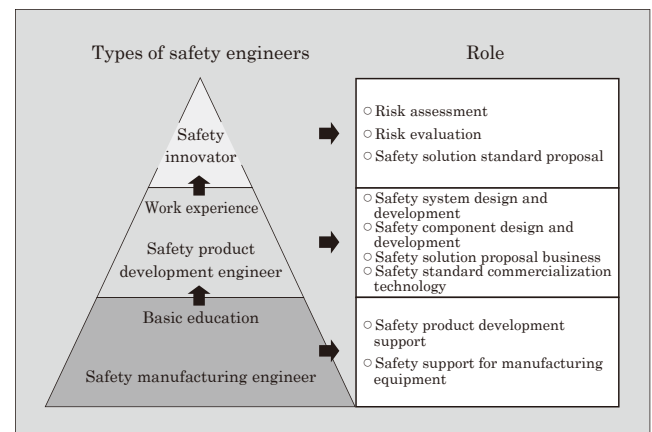
IEC 61508 was established as an international standard for control system safety (functional safety). The establishment of guidelines and standards for each industrial field, such as international standard IEC 61511 for the process industry, is progressing. The concept of functional safety is to maintain a certain level of safety by adding safety devices and systems, rather than by removing hazards. This is a reasonable method for situations in which intrinsic safety cannot be realized due to costs or other reasons. Fuji Electric provides safety engineering based on such international standards. For example, in the design of a SIS (Safety Instrumented System), after the SIS satisfies the requested safety specifications (i.e., provides the requested SIFs (Safety Instrumented Functions)), engineering services (safety device selection, safety system design, and SIL computation) can be provided to satisfy the requested safety integrity level (SIL) of each SIS function loop. The SIL (Safety Integrity Level) is a scale for measuring the failure of a safety function, having been assigned to an electronic safety device and/or system, with respect to its targeted function. SIL is defined as four levels (1 to 4) of safety. With this definition, the PFDavg (average probability of failure on demand) for safety devices and systems is once per 10, 100, 1,000 or 10,000 years, respectively.

#### 4.4 Support of equipment maintenance

Fuji Electric also supports equipment maintenance work. The following four items relating to maintenance management are prescribed as functional safety standards.

- (a) Creation of plans for operation and maintenance with the goal of ensuring that functional safety will be maintained
- (b) Maintenance and repair so as to maintain the functional safety implied by the design
- (c) Ensuring that the functional safety is sufficient while improvements and modifications are being implemented
- (d) Training of safety personnel in order to maintain functional safety level

Fig.6 Safety engineers that support safety solutions



Thus, for safety devices or systems with which the safety level is evaluated quantitatively, proper installation, proper usage, and proper maintenance management are vital in order to maintain and ensure the assumed safety level. Consequently, constant assessment of the failure status of the devices being used, and the storage and management of this data are important for maintaining and ensuring the safety level.

#### 4.5 Cultivation of safety engineers

Fuji Electric is also focusing on educating safety engineers to become capable of proposing the various safety solutions introduced in paragraph 3.2 in a timely manner with specific content. Figure 6 shows the types and roles of safety engineers. This education is being advanced with the goal of establishing “all engineers as safety engineers,” with “safety innovators” capable of safety consulting about risk analysis, risk evaluation and the like, “safety product development engineers” capable of designing safety systems, and “safety manufacturing engineers” for providing safety product development support and safety support of manufacturing equipment.

### 5. Postscript

An overview of Fuji Electric’s entire safety industry automation technology, as well as Fuji’s product lineup and product technology for safety solutions and safety components, has been presented. These safety technologies incorporate both machine safety and functional safety, since the safety of plants and equipment must be maintained comprehensively. Fuji Electric intends to continue to provide solutions that lend support to the realization of “safe and secure manufacturing” environments for our customers.

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# Green Socio-Automation to Realize a Comfortable Society

Kouichi Kawajiri <sup>†</sup> Hiroyuki Hirayama <sup>†</sup> Yutaka Fueki <sup>†</sup>

## ABSTRACT

Aiming to realize a “green society”, which can be defined as “a society that leads a comfortable lifestyle in harmony with the environment”, Fuji Electric uses sensors, wireless networks, wide area distributed systems and the like as core technology to provide environmental and energy-savings solutions as well as safety and security solutions. For the environment and energy-savings, Fuji Electric’s solutions enable the amounts of energy usage and waste to be visualized, and provide energy-saving solutions such as merchandise of “GreenUSE”. For safety and security, Fuji Electric’s solutions provide food safety proposals such as cultivation history management for agricultural products, production history management for food products, location management for emergency medical treatment, and so on, aiming to realize a green society.

## 1. Introduction

Governments are advancing “environmental and energy-savings” initiatives that aim to introduce new types of energy and prevent global warming, and to provide their citizens with a “safe and secure” lifestyle, and are actively advancing economic measures that will lead to the creation of new industries. The infrastructure for broadband communications, cell phones, wireless communications and terrestrial digital broadcasts has been established, and all industries are able to utilize this communication infrastructure<sup>(1)</sup>. New business models to overcome the challenges involved in realizing “environmental conservation and energy savings” and “safety and security” with this communications infrastructure are being investigated. As a result of the “Kyoto Protocol” enacted in December 1997, global warming prevention measures with an awareness of the “global environment” have been watched closely<sup>(2)</sup>. In Japan, where approximately 90% of greenhouse gas emissions (a total of 1,370 million tons in 2007) is energy-derived CO<sub>2</sub> emissions, laws to limit the generation of energy have been enacted and the revised “Law Concerning the Rational Use of Energy” (i.e., the Revised Energy Law)<sup>(3)</sup> will be enforced as of April 2010. As a governmental policy, the year 2020 goal of reducing CO<sub>2</sub> emissions by 15% based on 2005 levels is expected to have a significant effect on energy-saving measures and the introduction of new energy.

Defining green society (“green socio”) as “a society that provides a comfortable lifestyle in harmony with environment,” Fuji Electric aims to contribute to the construction of a comfortable and affluent society.

## 2. Fuji Electric’s Efforts

Previously, Fuji Electric has provided products, such as eco-friendly automated vending machines and energy-saving open showcases, for improving the comfort of daily life as well as other products, such as ETC-use vehicle sensors, for ensuring that the traffic flow at a highway entrance is safe, smooth and with minimal congestion. Now, Fuji is working to develop green socio-automation technology to provide solutions that are in harmony with the environment, comfortable and closely related to everyday life.

### 2.1 “Green socio” concept

The desired state of the societal and environmental sectors in 2020, as cited in the Third Phase of the Basic Program for Science and Technology<sup>(4)</sup>, matches Fuji Electric’s aim for a “green socio” policy.

- (a) To establish a route for overcoming global warming and energy problems
- (b) To realize a recycling-oriented society that is in harmony with its environment
- (c) To realize a ubiquitous network-connected society that will fascinate the rest of the world
- (d) To ensure the safety of the nation and society
- (e) To ensure the safety of daily life

To provide the market with solutions for realizing the “green socio” concept shown in Fig. 1, sensing, traceability, security, optimization technology and other previously acquired technology must be combined with technical know-how. “Green socio” aims to provide solutions that seamlessly combine technologies for “measuring objects with sensors,” “reducing work and labor,” “transmitting, distributing and preserving energy, objects and data,” “maintaining and managing equipment and systems,” and the like to solve environmental, energy-savings, safety and security-related

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problems as required by society. The target area is society at large, i.e., the fisheries industry, agroforestry industry, commerce, food industry, construction industry, transportation industry, distribution industry, warehousing industry, service industry, and public works.

## 2.2 Green socio-products

Fuji Electric has proposed many solutions for realizing a living environment that is human-friendly, comfortable and safe. To realize a comfortable and safe living environment, it is necessary to assess changes in the environment, people or objects with an intelligent system incorporating a network of sensors or ubiquitous computing, and to configure a structure that can be controlled with total optimization so as to always be in a favorable state. Fuji Electric is focused on technical development that will generate innovation for this purpose. Specifically, the relevant technologies and solutions involved in Fuji's work have the following three characteristics.

- Miniaturization and energy-savings achieved through application of MEMS (Micro Electrical Mechanical Systems) to measurement devices, radiation sensors, gas analysis sensors and the like
- Provision of intelligence to field equipment by providing wireless network functionality<sup>(6)</sup> to sensors, and field visualization enabled by seamlessly linking the field equipment to the system
- Measurement by sensors, data collection via a wireless network, and construction of an efficient business system through application of a wide area distributed system platform

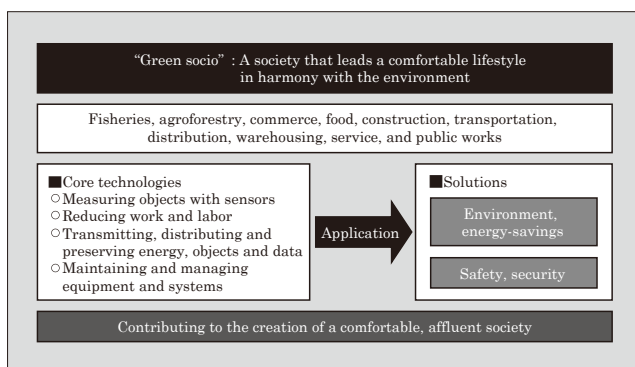
Figure 2 shows green socio-solution products that utilize these related technologies.

## 2.3 Supporting technology for green socio-products

In support of green socio-products, development efforts are focused on sensor technology, wireless network technology and a platform for wide area distributed systems, and an overview of each of these technologies is presented below.

### (1) Sensor technology

Fig.1 The "green socio" concept



Typical sensors include pressure sensors for transmitters, thin-film gas sensors for gas alarms, vibration sensors, analysis chips for environmental chemicals, RI sensors for personal dosimeters, flow sensors for detecting the airflow in a clean room and for infrared gas analyzers, etc. These sensor elements incorporate MEMS technology to achieve small size, light weight and low power consumption. A circuit board attached to the sensor element is composed so as to reduce the size and weight of the entire sensor assembly using high density mounting technology. The sensors are equipped with wireless network functionality powered by coin cells to realize wire savings, and to support the frequent rearrangement of devices on the line, status monitoring of mobile devices, etc.

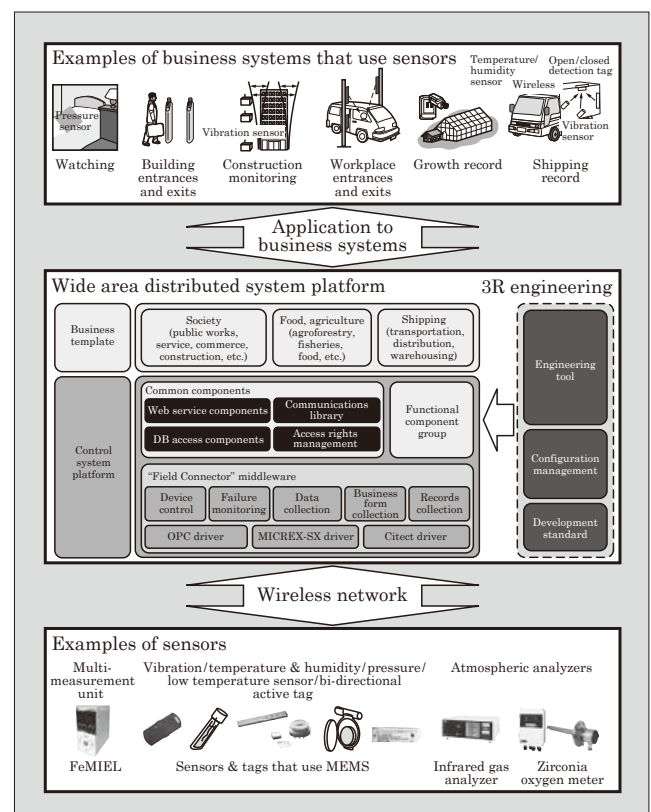
### (2) Wireless network technology

Fuji Electric was early to commercialize RFID tags and use them for controlling distribution and the like. As wireless technology, low-power mesh network technology has been used for the automatic reading of electric power, gas and water meters, and for continuous energy measurements. Additionally, wireless technology for low-power acceleration sensors for motor vibration diagnosis and wireless technology for tire pressure sensors in a tire pressure monitoring system (TPMS) that continuously monitors and measures the tire air pressure of trucks and other vehicles in a metallic structure environment have been realized.

### (3) Wide area distributed system platform

Fuji Electric has completed development of "Field

Fig.2 Green socio-solution products



Connector” middleware for collecting field data measured by sensors distributed over a wide area, and has successfully devised a structure for collecting and controlling in real-time the measurement values from sensors distributed over a wide area. The Field Connector middleware is configured from the following four components, as shown in Fig. 3, so as to facilitate field visualization.

- (a) I/O servers that collect field data from sensors and component devices
- (b) Broadcast servers for sharing field data among distributed sites
- (c) Agents for accessing field data from the business system
- (d) An intelligent viewer for the screen display and setting

The use of Field Connector middleware enables the real-time monitoring and control of up to 100,000 points, 64 locations, and 4,096 stations for the entire system.

A business system for processing, editing, displaying, setting and controlling field data can be developed with a common procedure shown in the wide area distributed network platform of Fig. 2. The platform is configured from shared components such as the Field

Connector middleware, a Web service, and a communications library; functional components groups classified according to screen, control, data collecting and monitoring functions; engineering tools, including tools for automatically generating source programs and test automation tools; and business templates for tasks

Fig.3 Configuration of wide area distributed system that uses Field Connector

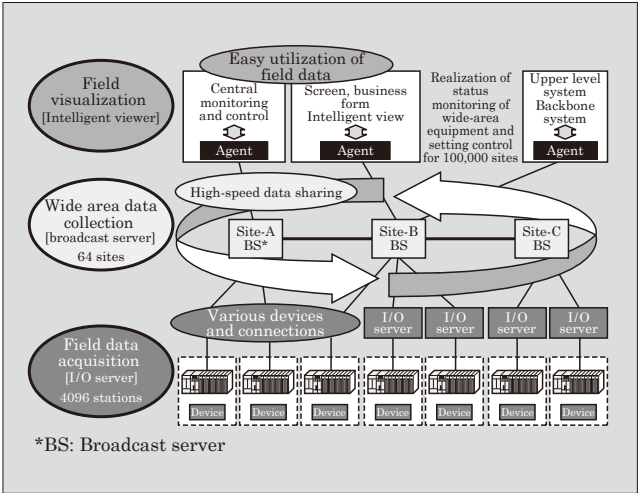


Table 1 Examples of green socio-product solutions

Green socio (environmental harmony, comfortable lifestyle)	Society (public works, service, commerce, construction, etc.)	Food & agriculture (agroforestry, fisheries, food, etc.)	Shipping (transportation, distribu- tion, warehousing)
Environment, energy-savings	Environmental monitoring Energy measurement New energy Energy-saving diagnosis and counter- measures Store energy management GreenUSE Green Cabinet Environmental reports	Energy conservation Diagnosis and countermeasures New energy Water purification processing Local production for local consumption	Modal shift Cooperative distribution
Safety, security	Remote monitoring of buildings Remote monitoring of gas equipment Motor vibration diagnosis Tire air pressure diagnosis ETC-related Watching over infants and the elderly Location management, contamination detection Building & workplace entrances and exits Control to prevent removal of important items Customs clearance inspection, facility monitoring Safety reports	Pest control guidance Production records, disclosure Traceability Growth monitoring	Traceability Measurement of shipping status Container distribution

Fig.4 Comprehensive view of solutions for environment conservation and energy savings

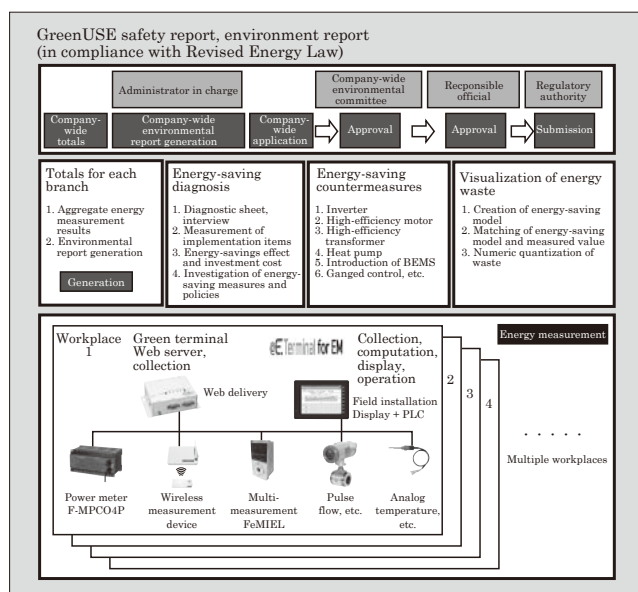
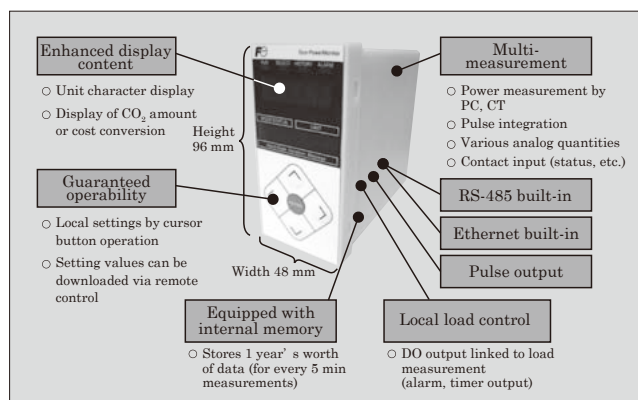


Fig.5 FeMIEL compact, multi-measurement unit



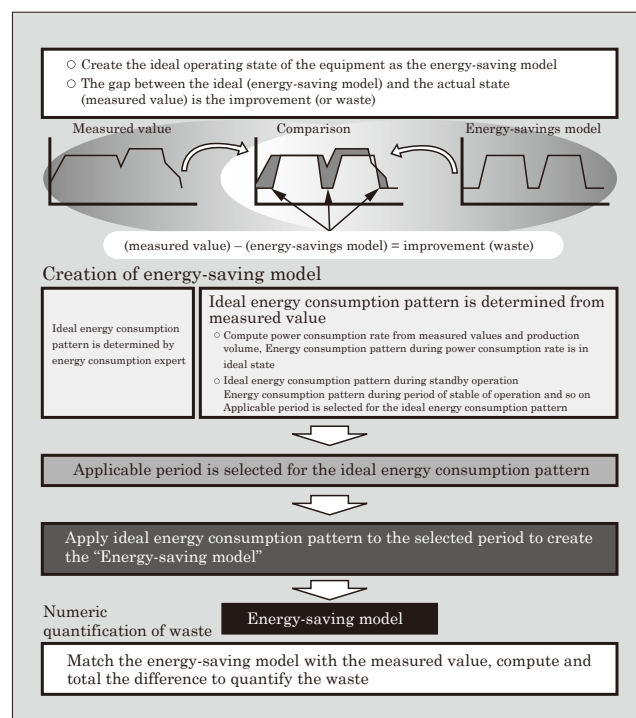
previously encountered. When creating the screen program, the required screen specifications are defined with XML (Extensible Markup Language) according to screen definition rules. The definition and program components for each screen component are extracted and combined by an automated generation engine to generate a screen program automatically with the required specifications. In this manner, reusability is enhanced, new program generation is minimized, and a high quality business system can be provided in response to a customer's requirements.

Green socio-products for realizing “environmental conservation and energy-savings” and “safety and security” are being provided to the societal sector, food agriculture sector and shipping sector, and examples of these product solutions are listed in Table 1.

### 3. Examples of Green Socio-Solutions

Examples of green socio-solutions for “environmental conservation and energy savings” and “safety and

Fig.6 Waste visualization based on energy-saving model and measured value



security” are presented below.

#### 3.1 Solution for environmental conservation and energy savings

Figure 4 shows a comprehensive view of a solution for environment conservation and energy savings. This solution consists of visualizing the amount of energy usage based on energy measurement, performing an energy-savings diagnosis and proposing energy-saving measures, visualizing wasted energy based on an energy-saving model, and using a GreenUSE function that supports energy-saving activities and the generation of reports.

##### (1) Visualization of amount of energy usage

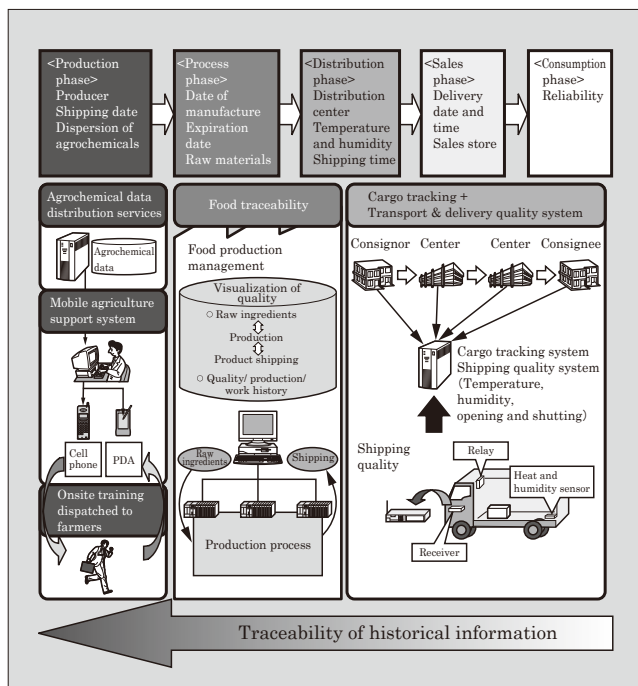
The amount of energy usage can be visualized by using the compact FeMIEL multi-measurement unit shown in Fig. 5. FeMIEL has the following characteristics.

- In addition to power circuit measurements, various energy measurements can also be taken
- Measured amount of power can be converted into the corresponding CO<sub>2</sub> emissions or cost
- Main unit is capable of storing one year's worth of data recorded in 5 minute intervals
- Equipped with network function (Ethernet, RS-485 selectable)

##### (2) Visualization of energy waste

For customers who already have the capability to visualize their amount of energy usage or who have already implemented energy-saving measures using inverter driving, Fuji Electric also provides energy-saving diagnostic consulting known as “waste

Fig.7 Food safety solution

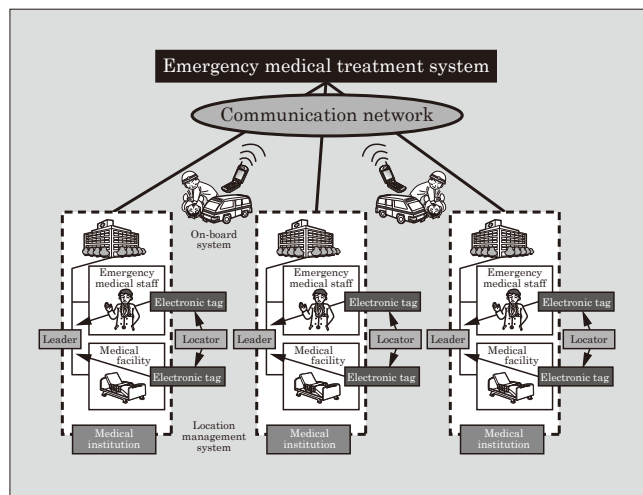


visualization” as a simple energy-saving measure. The amount of energy used by equipment in an ideal operating state (the energy-saving model) is compared with the measured amount of energy usage, and the difference is presented as wasted energy. This procedure is shown in Fig. 6. For example, an energy savings of 5 to 10% was achieved at a parts factory by referencing the visualized waste to correct the operating status of equipment. This method is applicable not only to the industrial sector, but also to the consumer sector for use in rental buildings and the like, and is an effective measure for realizing energy savings in manufacturing equipment and business facilities.

### (3) GreenUSE for supporting energy-saving activities and report generation

With the Revised Energy Law which will take effect in 2010, a company whose energy usage exceeds the oil-equivalent of 1,500 kl is obligated to perform energy management. GreenUSE is provided to support the energy-saving activities and reporting work for these types of companies. GreenUSE utilizes a workflow function for obtaining department totals or for processing inter-department applications or approvals, and enables visualization of the corporate environment and safety. Specifically, the energy usage and safety inspection results for individual stores are to be reported from the store manager to the regional manager, and environmental and safety reports for the entire business are to be submitted to the regulatory authority and stored. With GreenUSE, energy measurement, totals within a branch office, company-wide totals, approval and reporting to the regulatory authority are integrated seamlessly, increasing the efficiency of reporting work and supporting environmental

Fig.8 Location management solution for emergency medical treatment



business practices.

## 3.2 Solutions for safety and security

As solutions for safety and security, a food safety solution provided to the agriculture, fisheries, food, distribution and commerce sectors, and a location management solution for emergency medical treatment provided to the service sector are introduced below.

### (1) Food safety solution

The food safety solution, as shown in Fig. 7, supports the provision of safe agricultural products and processed food to consumers by centrally managing historical information ranging from the growth record of agricultural products to food production and shipping quality.

#### (a) Management of growth record of agricultural products

A system that uses a mobile terminal in the field to display and collect production information of the agricultural product growth process has been developed. The production information consists of pest control guidance and the growth status record. A database of necessary agrochemicals for growing the products is transmitted to the producer's mobile terminal, and guidance regarding the type, concentration and dispersion period of agrochemicals appropriate for the product being grown and pest control is provided to the producer. The name of the grower, the record of agrochemical dispersion, and the record of fertilization are collected from the mobile terminal. As a result, the use of ineffective agrochemicals and violations of agrochemical usage standards will be prevented, and safe production processes are supported.

#### (b) Management of food production history

History management for food production processes has been realized by installing a food production management system, and assigning material procurement numbers, serial numbers, ship-



ping numbers and the like corresponding to each subsystem, i.e., material procurement, production planning, production history and distribution. From the serial number stamped on a product, the production history information (the production factory, production line and distribution warehouse) and the distribution history information (when and where shipped), and from the material procurement number, raw material history information (the shipping destination of products that use the procured material), can be referenced instantaneously.

In the case of a defect such as contamination with a foreign substance, this mechanism for historical management can be utilized in collecting the product from consumers or to issue a sales cessation order quickly.

#### (2) Location management solution for emergency medical treatment

Figure 8 shows a location management solution for emergency medical treatment. In a medical institution distributed over a wide area, electronic tags are attached to the medical staff and medical devices, and when used in combination with a locator (an apparatus for transmitting location numbers, such as room numbers, to an electronic tag) inside the medical institution, the location of medical staff and the working condition of medical devices can be assessed accurately (as a specific location) in real-time. The notification to an emergency vehicle of the working condition of a medical device enables the determination of the appropriate type of medical conveyance in an emergency. Electronic tags were developed based on NTT Network Innovation Laboratories' specifications and are non-contact bi-directional active tags that permit both reading and writing. The electronic tags have the following three features.

- (a) The tags place the equivalent of 32 bytes of data on the same HF radio wave band utilized by the IC cards used at a railway ticket gate, and the tags can be written to or read from at a distance of 10 m.

- (b) Using UHF band radio waves, written data and the identifying code of a tag can be read at a distance of 100 m.
- (c) According to the application, the tags may also capture sensor measurement values.

## 4. Postscript

The challenges to “environmental conservation and energy savings” and “safety and security” are not limited to manufacturers or certain businesses, and in many instances are closely related to our everyday life. Having previously provided many solutions for overcoming these challenges, Fuji Electric intends to continue to develop green socio-solutions and to contribute to the construction of a society in which the lifestyle is comfortable and in harmony with the environment

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# Safety Control Solutions Protecting Onsite Safety

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## ABSTRACT

Efforts to establish safety standards and address safety in Japan have become more active as a result of the international standardization trends toward functional safety and machinery safety. Fuji Electric is developing a safety control solution that combines global standards with basic technologies, acquired from our experience with system controls, to realize high reliability and a high availability rate. With risk-reducing measures based on risk assessment, Fuji Electric can provide a safety related system having a safety integrity level of 3 (SIL 3). For steel coil transportation systems, a wide range of choices are available for the circuits and components according to the required safety level. For power systems, highly reliable numerical protection relays help to maintain a stable supply of electric power.

## 1. Introduction

New concepts of safety integrity quantification, safety design, safety certification and safety management originating in Europe and based on functional safety and machinery safety standards have led to a recent surge in efforts to ensure total safety for components and systems. In Japan, these international standards have already been adopted as JIS (Japanese Industrial Standards) and efforts are underway to incorporate these standards into the chemical, oil, steel, automotive and power generation industries.

Meanwhile, Fuji Electric's safety systems for the public infrastructure have evolved systematically, based on the advanced concepts of the times, with a

focus on reliability-enhancing technology, availability rate-boosting technology, sensing technology and diagnostic technology. These systems proactively prevent a situation (such as a power failure) in which the breakdown or incorrect operation of a system in the energy field or the like would threaten the foundation of our lifestyle.

The scope of Fuji Electric's safety control is shown in Fig. 1. Fuji Electric's safety control solutions have evolved based on the safety technology that Fuji Electric has cultivated over the years, combined with technology that incorporates new international safety standards.

Fuji Electric aims to construct solutions that maintain the safety of an entire site with Total Safety, a concept that employs IT to integrally manage safety components such as onsite sensors and a system that improves the safety of control.

This paper describes the configuration of basic safety technologies, summarizes safety technologies for which standardization is being advanced, presents a full picture of Fuji Electric's safety-related efforts by showing specific examples, and discusses the efficacy of Fuji's safety control solutions<sup>(1)</sup>.

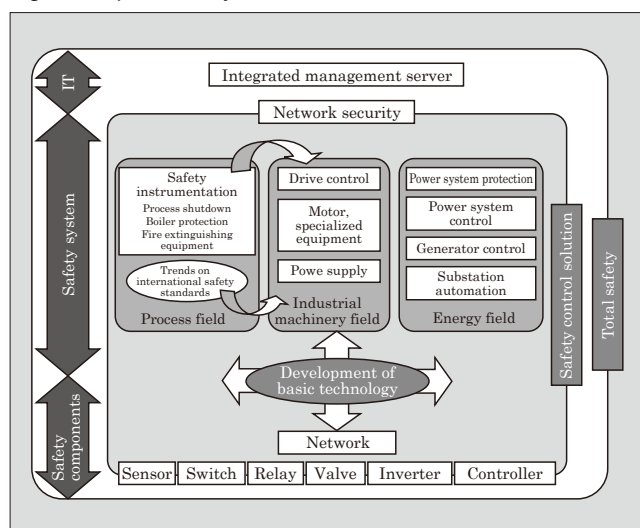
## 2. Fuji Electric's Efforts Involving Safety Control

### 2.1 Efforts for safety control in the energy field

Fuji Electric is applying basic safety technologies to protection and control systems for electric power facilities in the energy field and elsewhere.

Fuji Electric's basic safety technologies for sensing, diagnosing and analyzing technology and reliability-enhancing technology and the like have been developed through independent efforts that include theoretical research. For example, as shown in Fig. 2, in order to protect electric power facilities quickly from electrical

Fig.1 Scope of safety control

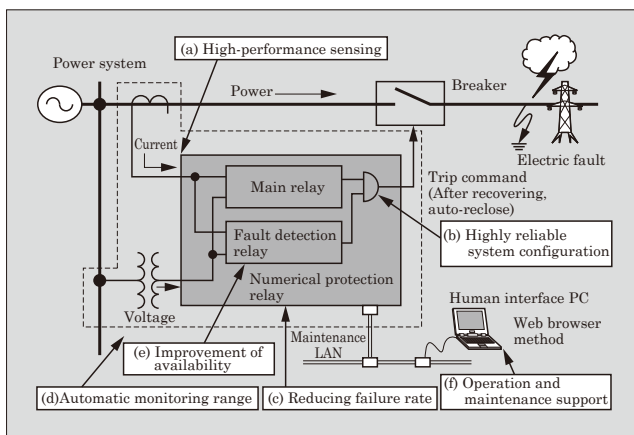


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faults due to accidents and the like, high-performance numerical protection relays are used. The safety-related advantages of these basic technologies are as follows.

- (a) High-performance sensing capable of analyzing and selecting detectable components at high speed
- (b) Highly reliable system configuration that does not malfunction due to a single failure
- (c) Technology for reducing the failure rate and prolonging the service life of hardware
- (d) Automatic monitoring of a wide area for diagnosing device failures even outside of the system

Fig.2 Basic technologies relating to the safety of numerical protection relays



- (e) Technology to improve availability rate by preventing excessive detection of transient failures
- (f) Maintenance support technology that provides operational guidance, fault analysis, etc.

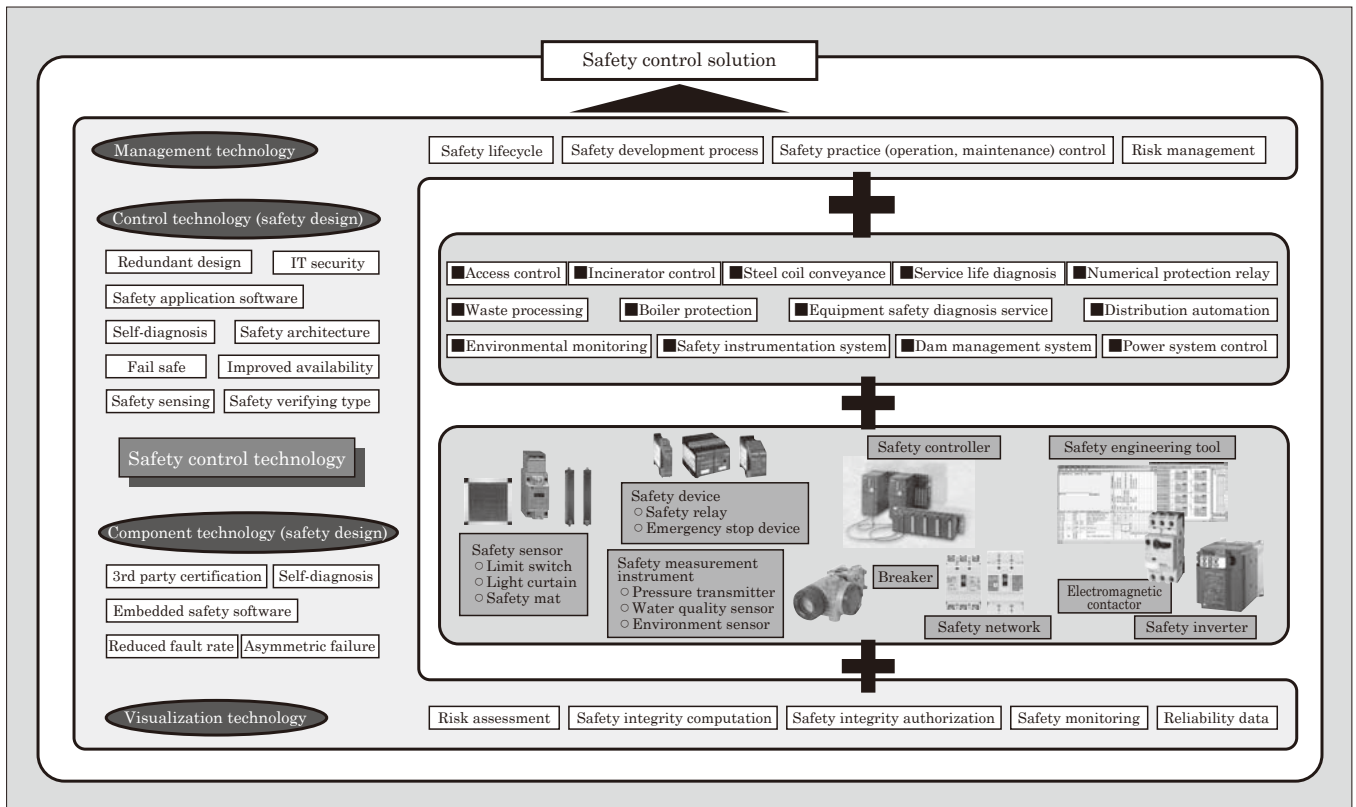
In this way, the safety technologies for electric power facilities realize high reliability. Efforts are underway to apply similar technologies to other fields.

## 2.2 Fuji Electric's vision for safety control solutions

By combining basic safety technologies based on reliability-enhancing technology and the like with risk assessment and onsite safety concepts that conform to international safety standards, the transition from individual optimization to total optimization can be advanced while evaluating the safety and economic efficiency of components and systems. Data collected from operations and maintenance activities can also be utilized effectively.

Fuji Electric has the technology for realizing this vision, and Fig. 3 shows the configuration of a safety control solution based on unified safety control. This safety control solution is realized as the result of many safety control technologies. Management technology features systemic safety management that realizes and maintains onsite safety. Control technology and component technology are technologies unique to safety design and are used to realize safety control. Additionally, visualization technology also includes indices for quantitatively expressing and computing

Fig.3 Configuration of safety control solution



methods for product (system and component) safety.

### 3. Safety Control Technologies for Realizing Safety Control Solutions

#### 3.1 Example of safety management technology

The safety lifecycle prescribed by the functional safety standard IEC 61508 is an example of safety management that facilitates the management, verification and preparation of necessary documents when planning, installing and operating safety control on-site. The safety lifecycle classifies the required items (tasks) for realizing functional safety, and comprises 16 phases, ranging from a conceptual phase for drafting and planning the system, risk analysis phase, realization phase for designing and manufacturing the system, operating phase, and maintenance and repair phase, to a phase for decommissioning and the like. Adopting the safety lifecycle enables the prevention of omissions and mistakes for each task, construction of a safety control system having the targeted safety level, and long-term operation and maintenance. In safety management consulting, Fuji Electric proposes visualization of the safety integrity by utilizing IT.

#### 3.2 Example of safety system technology

##### (1) Safety design

Safety design is based on reliability-enhancing technology for ensuring the safety of components and control, and is realized<sup>(2)</sup> by reducing the probability of dangerous failure, applying safety design technologies for safety verification, failsafe design, asymmetric failure, etc. and by applying safety design theory<sup>(2)</sup>.

##### (2) Redundant design

Redundancy is an important design technique for preventing the loss of safety control system functionality when a component or system failure occurs. Functional safety standards require a redundant design that conforms to the SIL (safety integrity level). This concept is also applied to the design of safety circuits inside components. Moreover, redundancy is useful in fields where the shutdown of a system such as a lifeline must be avoided.

##### (3) High performance sensing

To realize safety control, an implementation of sensing must consider the properties of the measurement object, allowable error, required responsiveness, selection and removal of causes of false positives, and the like. Detection value allowing inherent noise may lead to mistaken operation.

#### 3.3 Example of safety component technology

##### (1) Self-diagnosis technology

The ability of a component itself to reliably detect failures in its own internal circuitry leads to increased reliability and ensures safety. The self-diagnosis capacity is expressed with the SFF (safety failure fraction) and DC (diagnostics coverage) indices. Fuji

Electric has engaged in the development of advanced diagnostic technology in order to reduce undetectable failures (failures that lead to danger) as much as possible. Self-diagnosis technology is also applied to the failure monitoring of components in a control system and to the failure monitoring of communications lines.

##### (2) Safety components

###### (a) Pressure transmitters

For the previous product (FCX-AIII), FMEDA (failure modes effects and diagnostic analysis) was implemented, and failure modes, failure rates, and effects of failure were analyzed for internal constituent components. From the analysis results, the probability of dangerous failure  $\lambda_{DU}$ , which cannot be detected by self-diagnosis, was calculated, and the PFDavg (probability of failure on demand) was computed. The validity of the PFDavg was evaluated by TÜV SÜD, a German 3rd party certification authority, and a SIL 2 technical report was issued. Presently, a next-generation pressure transmitter having SIL 3 certification is underdevelopment.

###### (b) Safety inverter

The safety inverter is a core component for safety control in the drive field. Fuji Electric is already supplying products that are certified according to the EN 954-1 Cat.3 European safety standard<sup>(3)</sup>. Additionally, safety inverter products conforming to advanced ISO 13849-1 PLd and IEC 61508 that finely segment the drive system shutdown categories are being developed, and Fuji Electric plans to support all international safety requests for drive systems.

###### (c) Electromagnetic contactor

Electromagnetic contactors are regarded as being highly reliable final-stage switches for safe shutdown, and they provide failure rate data to the user. A mirror contact (auxiliary N/C contact) is mounted in a safety application feedback circuit. The mirror contact prevents the auxiliary N/C contact from closing while the coil is in a non-excited state during welding of the main contact. This function enables detection of the welding of the main contact of an electromagnetic contactor, which had not been possible previously, and conforms to the safety requirements of IEC 60204-1 (JIS B 9960-1).

#### 3.4 Example of safety visualization technology

##### (1) Risk assessment and safety management

Risk assessment is an important technique for learning the required safety integrity. An understanding of the existence and size of risk enables an optimal balance between cost and safety to be achieved in the safety control system to be installed. Fuji Electric is intensifying its efforts involving risk assessment at the time of installation of a safety control system.

##### (2) Quantification of safety

A scale for quantitatively evaluating the safety of components and systems relating to safety control has



Table 1 Quantifying indices that incorporate various standards

SIL IEC 61508 (SIL1 to 4) IEC 61511 (SIL1 to 3) IEC 62061 (SIL1 to 3)	PFDavg* IEC 61508 IEC 61511	PFH(/h)* IEC 61508 IEC 61511 IEC 62061	PL* ISO 13849-1 2006	Goal of risk reduction (RR)
4	$10^{-5}$ to $10^{-5}$	$10^{-9}$ to $10^{-8}$	—	10,000 < RR ≤ 100,000
3	$10^{-4}$ to $10^{-3}$	$10^{-8}$ to $10^{-7}$	e	1,000 < RR ≤ 10,000
2	$10^{-3}$ to $10^{-2}$	$10^{-7}$ to $10^{-6}$	d	100 < RR ≤ 1,000
1	$10^{-2}$ to $10^{-1}$	$10^{-6}$ to $10^{-5}$	c b	10 < RR ≤ 100
—	—	—	a	

been standardized, and products certified with safety levels according to international safety standards have begun to appear in recent years. The safety levels of systems and components are expressed mainly with two indices, SIL and PL (performance level) (see Comment 1 on page XX), and their correspondence is shown in Table 1. Fuji Electric is developing and selling components having safety levels (SIL, PL) that conform to the various standards. Fuji Electric also is experienced in constructing systems up to SIL 3.

#### 4. Example of Specific Safety Control Solutions

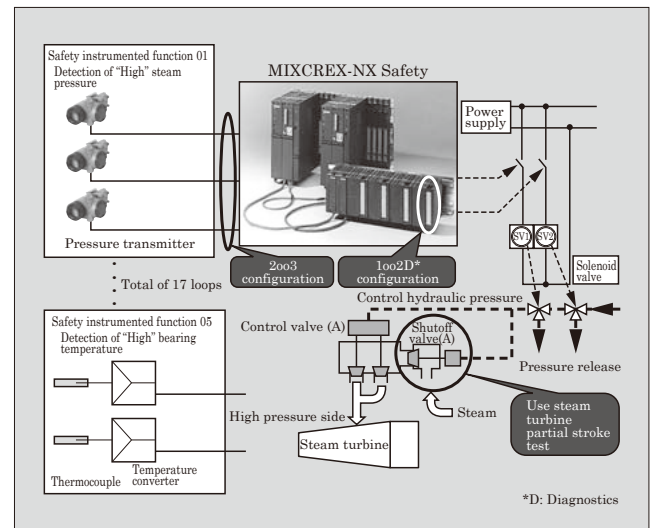
##### 4.1 Example instrumentation solution for realizing safety control

Safety instrumented systems are the representative safety control systems used in the process control field. These systems quantify risk and safety in accordance with international standards, realize a high level of safety through safety design, and protect people, the environment and equipment from unpredicted plant accidents and trouble. These systems are applied mainly to emergency shutdown systems, interlock systems, burner management systems and turbine protection systems. Fuji Electric is intensifying its efforts to develop interlock systems and emergency shutdown systems for chemical plants, oil plants and steel plants, and is also focused on developing boiler protection systems mainly for facility protection. This paper presents an example application of a safety instrumented system to a steam turbine protection system that Fuji Electric received order in 2008, and describes Fuji Electric's technology and its advantages.

##### (1) Configuration and technology of safety control for protecting a steam turbine

A turbine protection system is a safety control system that uses multiple field sensors to detect the operation of a running turbine, and when the condi-

Fig.4 Overall configuration of turbine protection system



tions are dangerous, prevents turbine damage and accidents. Figure 4 shows the overall configuration of a turbine protection system, which incorporates a safety design. In brief, the safety control uses sensors to detect turbine abnormalities, and processes that data with a dedicated safety controller. If a dangerous condition is found, the valve for cutting off the steam used to drive the turbine is closed by an independent safety control system. There are 17 safety control loops in total. The following safety control technologies were applied to the design of this system.

##### (a) Risk assessment

The following process risks were identified for the risk assessment of the turbine process.

- (i) High steam pressure
- (ii) Abnormal shaft vibration
- (iii) Excessive turbine speed
- (iv) High condenser water level
- (v) High bearing temperature
- (vi) Low steam temperature
- (vii) Abnormal shaft position
- (viii) Abnormal power generation frequency

##### (b) Risk reduction measures

Fuji Electric has previously realized reduced risk with the control of MICREX-SX general-purpose PLC. In the future, the assignment of a SIL to a turbine protection system is expected to become standard. In the risk reduction measure used here, a SIL, which is an international standard, was also specified. To realize a system that has a SIL, the safety control unit must be configured independently, and risk reduction measures that are based on risk assessment must be employed. The required risk reduction was implemented with the example configuration shown in Fig. 4.

##### (c) Self-diagnosis technology

Self-diagnosis is a core safety control system for the early detection of faults in systems and components. Fuji Electric's "MICREX-NX Safety" control

shown in Fig. 5 has received SIL 3 certification from the third party certification authority TÜV SÜD, and is equipped with various self-diagnosis functions in its CPU and I/O units.

(d) Safety system design

Safety performance (to shutdown operation) and availability (to prevent mistaken trips) are both important in safety instrumented systems for turbine protection systems. The system architecture is designed in proportion to the safety and availability. In this system, the detector unit has a 2oo3 configuration and realizes both high safety performance and availability, and the output unit has a 1oo2 configuration for reliably shutting down in response to a shutdown instruction. The different configurations result in different probabilities of failure as shown in Fig. 6.

(e) Safety level quantification

Quantification of the safety level is important for selecting appropriate measures for reducing risk of the entire system. The safety level is determined by the computed value of PFDavg for the entire system, from the detector unit to the output unit. If the computed result is not within the targeted SIL, additional countermeasures are implemented. In this example, in the initial computation, the PFDavg value did not fit within the targeted SIL value, and therefore engineering work (i.e., changing the product, configuration, and test method) was carried out to attain the targeted level, and ultimately a 3rd party certification authority verified that the generated calculation sheet satisfied the targeted SIL.

(2) Safety control problems and solutions

Problems encountered when attempting to construct a safety instrumented system are listed below.

(a) Component selection based on actual use

The design of a safety instrumented system requires SIL-certified components and a specified failure rate, but the inability to construct the entire system with SIL certified products is a problem. The sensors, solenoid valve and shutoff valve used in this example are products that Fuji Electric has successfully used in the past, but they are not SIL-

certified products and have no public failure rate data. To resolve the problem of safety level quantification in this type of case, the following methods are available.

(i) Compute with failure mode analysis

(ii) Refer to failure rate handbook such as the MIL standards (military standard: established by US Dept. of Defense)

(iii) Calculate from the product's MTBF value

In this example, method (iii) was adopted, and statistical processing ( $\chi$  squared method) was also used to increase the reliability of the MTBF value. In this case, technical documents that clearly indicate the basis for the computation of the failure rate must be retained.

(b) Partial stroke test (PST)

Since valves generally have a low safety level, increasing the valve safety level will improve the safety level of the entire system. The valve (shutoff valve) used in this system is a hydraulic-driven mechanical type made by Fuji Electric. The following methods can be used to increase the safety level of these sorts of products.

(i) Change the device

(ii) Redundant design

(iii) Shorten the proof test interval

(iv) PST

In consideration of issues involving the turbine mechanism, method (iii) was adopted, but with a limitation of one generator shutdown per year, method (iv) was also introduced for further improvement, and the PFDavg value was increased.

(i) In the case of one proof test per year:  
 $2.13 \times 10^{-3}$

(ii) In the case of (i) and PST once per week:  
 $8.76 \times 10^{-4}$

PST is a partial-operation inspection for verifying the functional safety of a valve without halting the process. With benefits that include preventing the sticking of drive parts, the application of this technology is expected to increase in the future.

As described above, safety control engineering requires specialized knowledge and experience, and

Fig.5 Self-diagnosis of "MICREX-NX Safety"

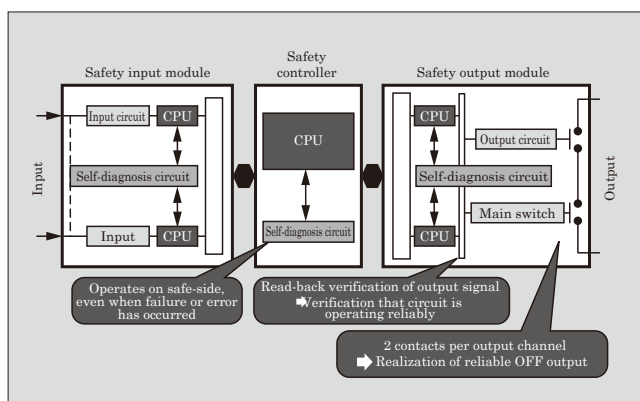
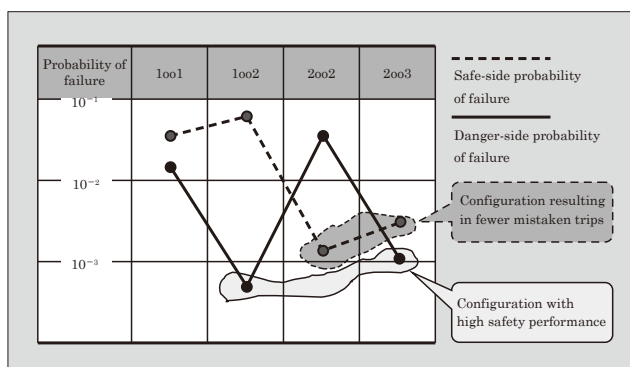


Fig.6 Change in probability of failure according to differences in system configuration



this is the type of safety engineering that Fuji Electric performs.

(3) Increased effectiveness and expanded application range

Fuji Electric possesses a wide range of technologies, including safety component technology, safety system construction technology, self-diagnosis technology, safety level calculation technology, engineering, etc., and is able to provide safety operation management such as maintenance service and equipment diagnostic service. The above-mentioned Fuji Electric safety control solution has the advantage of being able to provide, as “Total Safety,” a wide range of safety control for the user’s entire or partial onsite equipment and for new or existing equipment systems. Applications are not only to oil and petrochemical plants, but are also expanding to steel, food/beverage production, semiconductor manufacturing, and the social system field. Additionally, Fuji Electric is also expanding application of industrial-use combustion furnace control to the field of combustion safety equipment and the application of safety controllers to interlock circuits.

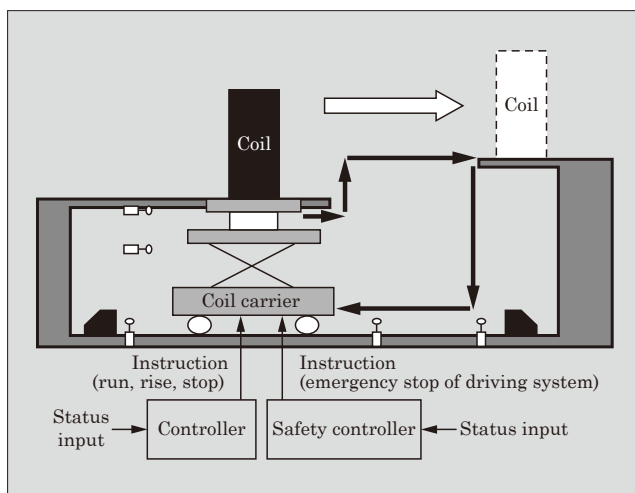
#### 4.2 Example drive control solution for realizing safety control

Also in the industrial machinery field, with the revision of safety standards, enactment of the “Revised Occupational Health and Safety Law” and so on, the support of international safety standard concepts is becoming necessary. IEC 62061 was derived from IEC 61508 and is a functional safety standard for specialized equipment for machinery safety control. A verified example that applies this standard is described below.

(1) Configuration and technology of safety control for steel coil conveyance system

Figure 7 shows the overall configuration of a conveyance system. In this system, travel motor control is implemented with an inverter, and lifting and low-

Fig.7 Configuration of safety control for steel coil conveyance



ering control is implemented with a hydraulic pump and solenoid valve. Previously, this system was provided with an emergency shutdown function which was configured as a safety circuit that uses a hardwired relay. From the results of a verification inspection of this safety-related electric control system (SRECS), we found that a safety level could not be applied to a safety circuit that uses a hardwired relay, and that no measures were being implemented for reducing the risk found from a risk assessment. In contrast, the following safety control technology can be applied to a system that has a 1001 configuration and attains the required safety level of SIL 1.

(a) Quantification of safety

Hazards such as dropping the coil or collision with a mechanical stopper were identified in the risk assessment. As a safety measure, the reliability of an emergency shutdown function and position detection function was clarified to be increased.

(b) Risk reduction measure

Reliability is improved by clearly separating the functions of the safety control circuit and the ordinary control unit, and by applying a safety controller to the safety control circuit. A failsafe design ensures to operate on the safe-side (emergency-stop-side) even when a danger signal is disconnected or when there is a loss of input circuit power.

(2) Increased effectiveness and expanded application range

From the verification inspection results, components that satisfy the required safety level and cost, and the selection of the self-diagnosis range and redundancy can be defined quantitatively. Additionally, by using the latest safety inverter technology, the number of output-side contactors can be reduced, and positioning control, damping control in response to rocking, and the like can be installed, thus expanding the available options for Fuji Electric’s safety control system.

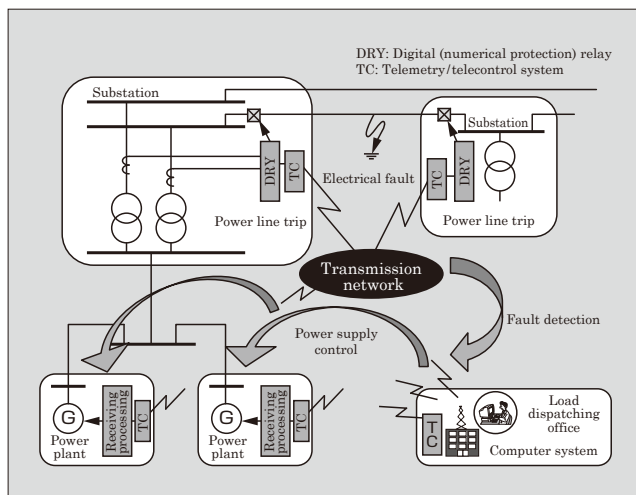
#### 4.3 Example of power system protection that realizes advanced safety control

The electric power field has long been engaged in the development of safety control for the supply of power. An electric power system is a wide area network and has the risk of a major blackout if its supply and demand become unbalanced<sup>(4)</sup>. If an electrical fault occurs, advanced safety control that rapidly determines a minimal appropriate section of the network and isolates it from the rest of system is needed. Optimal control is performed so that even if the attempted isolation of a section fails, by backing up with an upper level section, the safety of the entire system can be maintained within a short time.

(1) Configuration and technology of safety control for protecting an electric power system

Figure 8 shows the configuration of Fuji Electric’s safety control for protecting an electric power system. The main constituent equipment are numerical pro-

Fig.8 Configuration of safety control for protecting power system



tection relays, telemetry/telecontrol systems and a computer system. A numerical protection relay is an intelligent terminal equipped with multiple functions, and has a function for power equipment protection and system isolation, and a field sensor function for reporting faults to the computer system in order to maintain the safety of the entire system. The transmission network links the power plant and substations with dedicated lines via telemetry/telecontrol systems so as to avoid the risk of network traffic at the time of a major disaster. The computer system is provided with a system operator support function that informs the system operator of an operation sequence for minimizing the amount of the power supply disruption at the time of an electric power fault, and a function for optimizing the overall system. Safety control technology is applied as follows.

(a) High performance sensing

Field sensors realize high-speed performance for sampling the electric strength of a fault in approximately 0.2 ms, and incorporate digital filter technology equipped with an algorithm for removing unwanted high-frequency noise and selecting a specific frequency.

(b) Failsafe

To improve the reliability of failure identification, each CPU has software with diversity, equipped with an algorithm for handling combinations of different input quantities, and is configured with AND-control outputs.

(c) Optimal redundant design

The configuration of each piece of equipment is evaluated for redundancy based on the amount of risk, to realize a balance between reliability and cost. In the case where cost is prioritized, the protection and control functions are combined.

(d) Traceability

Detailed data records retained before and after a fault or equipment breakdown enable the cause

to be identified through analysis and enable safety management to improve operation technology and the like.

(2) Reliability-enhancing technology

A numerical protection relay independently accumulates and evaluates reliability data such as the probability of failure and the probability of incorrect no-operation in order to perform operations management safely at a site where voltage and large currents are sensed directly.

According to data from the Electric Technology Research Association<sup>(5)</sup>, in the operation of 6,940 units throughout Japan, the probability of failure is  $3.51 \times 10^{-6}$  per hour and the probability of incorrect no-operation  $4.75 \times 10^{-5}$  per hour. In the performance record of the more than 600 units that Fuji Electric has delivered to date, the probability of failure is  $1.47 \times 10^{-6}$  per hour and the probability of incorrect operation  $1.98 \times 10^{-5}$  per hour. Upon arranging and converting the various conditions and then verifying the data with functional safety standards, the failure rate became  $1.47 \times 10^{-6}$  per hour, the average probability of failure on demand became  $7.55 \times 10^{-4}$  per hour, and with a 1001 loop configuration and an automatic monitoring function detection rate that exceeds 90%, the hardware fault tolerance (HFT) corresponds to a SIL 3 PFDavg value (low demand mode of operation) in Table 1.

The following safety technologies are factors that contribute to the realization of SIL 3.

(a) Reduction of part failure rate

As measures to extend the wearout life and to eliminate initial-stage failures, part counts are being reduced, and high temperature aging and designs that inhibit rising temperatures are being implemented.

(b) EMC measures to prevent common cause failure

Based on an analysis of noise generating sources, a capacitor terminal block is used to prevent the infiltration of external noise, and filters are employed to reduce external and internal noise.

(c) Measures to improve availability

Based on failure mode analysis, operation is allowed to continue by restarting the CPU in such a case as transient memory defect of which the failure mechanism is identified.

(3) Increased effectiveness and expanded application range

By reducing the failure rate, and enhancing the self-diagnosis functions and improving maintenance support, we satisfied user needs for extending regular periodic inspections to every 6 years, and achieved labor savings in maintenance work. Fuji Electric possesses a full-range of safety control technology, from power system sensor functions to transmission equipment and computer-based large-scale protection control technology. The application of this technology extends to all aspects of energy solutions such as



energy-saving measurements, monitoring and analysis of power quality, natural energy stabilization control, etc. Electric energy from complex distributed sources such as the smart grid, if not correctly adjusted and controlled, may affect safety not only within the grid but of the power system, and for this reason, the application of safety technology will continue to expand in the future.

## 5. Postscript

Fuji Electric's efforts and specific examples of safety control solutions that establish onsite safety have been discussed.

Presently, safety is often established through on-site safety management activities. In the future, in addition to such activities, with the efforts described in this paper involving technology that creates safety, we will aim to increase the reliability of safety and productivity. Moreover, at present, the safe operation of equipment put into service in the 1980s is being ensured by experienced safety engineers. By replacing this equipment, even partially, and introducing safety

control, even a maintenance engineer with relatively little experience will be able to ensure safe operation.

Fuji Electric intends to continue to provide added safety solutions that can be applied to various fields.

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# Modeling and Control Technologies for Improving Product on Efficiency and Quality

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## ABSTRACT

Requests for quality and safety in automation systems have recently intensified more than ever. Using advanced modeling and control technologies, these are actively worked to overcome the challenges in Fuji Electric. A multivariate statistical process control and quality simulation package which is able to diagnose anomalies in a manufacturing process and estimate product quality, and a proprietary disturbance observer are being developed and installed in general-purpose PLCs used for model-based predictive control. These modeling technologies and products will contribute to the realization of more advanced manufacturing and process automation.

## 1. Introduction

The control technology for more advanced automation is not limited to the field of industrial applications, and is increasingly being used in consumer applications such as automobiles and household appliances. There are many various types of advanced control technology, including two-degree-of-freedom PID control, non-interference PID control,  $H$  infinity control, fuzzy control, neural network control (neuro control), chaos technology, etc. Fuji Electric has previously utilized advanced control technology and modeling technology for load forecasting and river flow rate forecasting using neuro control, water purification chemical dose control using fuzzy control, fuzzy crane control and so on, in many products. Particularly in recent years, requests for product quality and safety have intensified. In response to such needs, multivariate statistical process control (MSPC) technology, which enables quality management that takes into account the correlation among multiple input variables, and model predictive control (MPC), which enables multivariable control that takes into account the constraints with a decoupling control system and provides excellent control stability, have been used in actual plants. Fuji Electric is actively engaged in MSPC technology and MPC technology on which modeling is based. To improve the efficiency of thin-film solar cells, MSPC has been applied to quality simulation technology and the results show an improved in efficiency. Also, to advance the application of MPC to the process control sector, which includes water treatments, iron and steel treatments and chemical processes, a disturbance observer function has been developed and incorporated into MPC.

MPC has also been implemented with programmable logic controllers (PLCs) so that it can be used in control applications for medium and small-scale plants and equipment.

This paper describes Fuji Electric's efforts involving MSPC and MPC, as modeling control technology for advanced automation.

## 2. Efforts With Multivariate Statistical Process Control (MSPC)

### 2.1 Quality management that applies MSPC

In the manufacturing industry, as a higher level of quality control is sought, manufactured components and products are inspected to detect products that do not satisfy the required level of quality. However, by only judging whether the results of manufacturing are good or bad, the particular manufacturing process that causes the defect cannot be identified and consequently, product yield cannot be improved.

Therefore, in the manufacturing process, efforts to remove the cause of failure by detecting abnormalities early in the manufacturing process and then feeding back such information to the manufacturing site, and efforts to improve quality by the early detection of changes in product quality are being implemented. There are two main approaches.

- (a) Fault diagnosis of the manufacturing process
- (b) Product quality estimation using manufacturing process information

### 2.2 Fault diagnosis of the manufacturing process

The statistical process control (SPC) method is used for performing fault diagnoses of the manufacturing process. When performing a diagnosis, upper and lower limits that prescribe the range of normal operation for each process variable measured by the sensor

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are set, and if a process value exceeds these limits, an alarm is issued to notify the user of the fault.

With prior implementations of SPC, univariate SPC (USPC) was used to perform fault diagnoses based on whether the process value being monitored was within the upper and lower limits for each variable. However, if two variables are uncorrelated, for example, then even if each value is within the upper and lower limits, a fault would still be possible, such as when the two variables deviate from a correlation relationship. In such cases, faults cannot be detected with USPC, and as shown in Fig. 1, a method for performing fault diagnosis that takes into account the multivariate correlation is needed. For this purpose, multivariate statistical process control (MSPC) is used.

Principal component analysis (PCA), one type of MSPC, summarizes information into an orthogonal principal component based on the correlation among multiple variables, and can be represented with a small number of variables. When PCA is applied to fault analysis, the two indices of  $Q$  and  $T^2$  statistics are used.

$Q$  statistics are computed as follows.

$$Q = \|x - \hat{x}\|^2 = \sum_{n=1}^N (x_n - \hat{x}_n)^2 \quad (1)$$

Where,  $\hat{x}$  is the estimated vector based on the PCA model of input variable  $x$ .

The  $Q$  statistic is an index for evaluating violations based on the correlation among variables for which model creation data existed, and faults can be detected by monitoring this index.

Also, each element of the  $Q$  statistics expresses the contribution of each input variable to the  $Q$  statistics,

and the function that caused the detected fault can be identified from a contribution plot.

Next,  $T^2$  statistics are computed below using principal component scores  $t_m$ .

$$T^2 = \sum_{m=1}^M \frac{t_m^2}{\sigma_{t_m}^2} \quad (2)$$

Here,  $\sigma_m$  represents the standard deviation of the  $m^{\text{th}}$  principal component score.

In the principal component space obtained by compressing the original variables, the  $T^2$  statistics correspond to the distance from the mean to each sample and express the degree of divergence from the mean within the range of the model (correlation). As a result, the correlation among variables is maintained. Since the divergence from the mean (amplitude) is large, "faults" can be detected.

### 2.3 Product quality estimation using manufacturing process information

In product quality estimation using manufacturing process information, a technique known as multivariate analysis, typified by multiple linear regression analysis, is used and based on the operating status of a manufacturing process, the manufacturing condition set points and the like, the correlation between the process status and the product quality is modeled, and the final product quality is estimated from the process status.

(1) Quality estimation based on a multilinear regression model

A multilinear regression model approximates an output variable (target variable) with the linear sum of input variables (explanatory variables), and is applicable not only for product quality estimation, but also for various types of predictions and diagnoses in many industrial fields, and has the advantage that the model formula is easy to understand intuitively.

With a multilinear regression model, if the data has multi-collinearity and the explanatory variables are correlated, the model will become numerically unstable and a stable model will be difficult to obtain. In order to create an appropriate model in such a case, correlated variables must be removed from the input variables. Previously, the typical procedure was to perform a preliminary analysis such as a correlation analysis and then choose the variables to be used in the multilinear regression model. Especially when there are many input variables, there is a strong tendency for the input variables to be correlated among themselves. But the increase of combinations of mutually correlated input variables which could be removed, are significant. This process is an extremely labor-intensive when performed manually.

(2) Quality estimation based on partial least squares

PLS (Partial Least Squares) is a modeling method developed in 1983 by Herman Wold and Svante Wold in the field of economics. In the case where correlation exists among the input variables, because these input

Fig.1 Comparison of USPC and MSPC

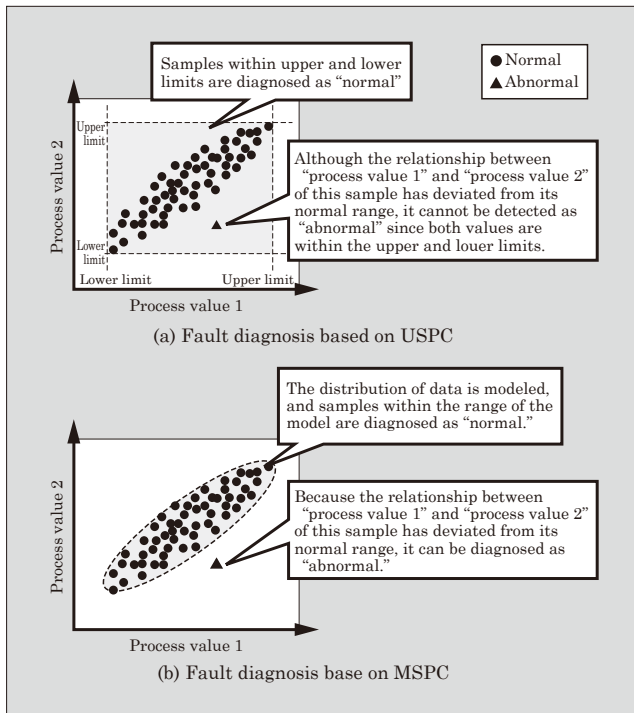
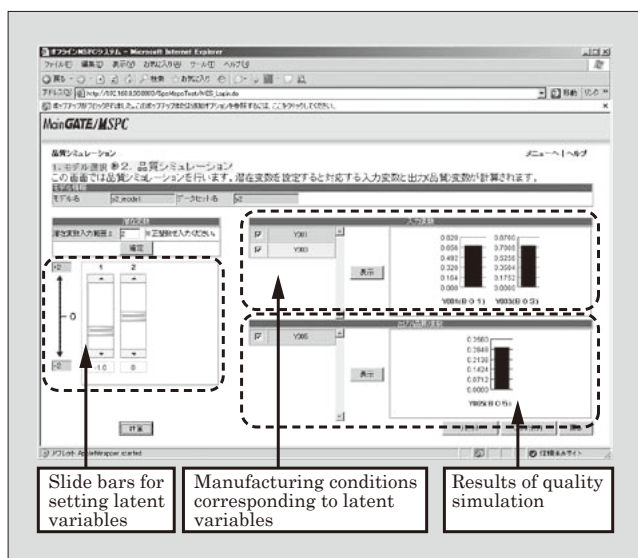


Fig.2 Example screenshot of quality simulation



variables are summarized into intermediate variables known as latent variables and are then used to express the output variables, this method has an advantage in that a stable model can be obtained even if there is multi-collinearity.

Moreover, with a PLS model, even in the case of many input variables, there is no need to choose input variables with a preliminary analysis as in the case of the multilinear regression model, and a model can be created simply using all variables directly. Consequently, the necessary effort to create a model can be reduced dramatically.

As shown below, the PLS model can express, as a regression equation, an output variable from an input variable via a latent variable.

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

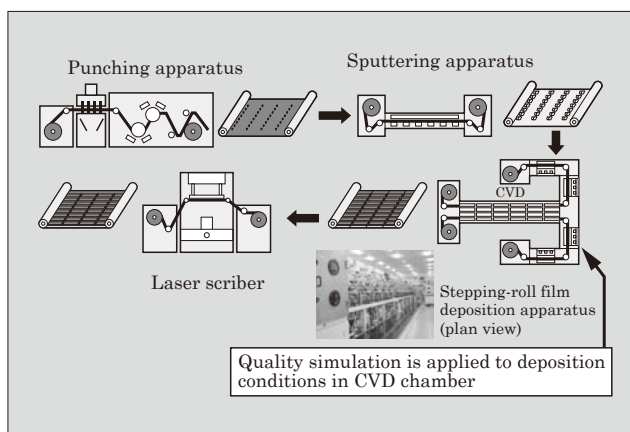
$$\hat{y} = Q_C t = Q_C (W^T P_C)^{-1} W^T x \quad (4)$$

Where,  $x$  is an input variable,  $t$  is a latent variable and  $\hat{y}$  is the estimated value of the output variable, all of which are column vectors for one sample, and  $W$  is a weight matrix.  $P_C$  and  $Q_C$  are coefficient matrices relating to input variables and output variables. The dimension of vector  $t$  corresponds to the number of latent variables. Equation (4) directly expresses the output variable from the input variable  $x$ , and is equivalent to the multilinear regression model. By converting the PLS model into the form of a multilinear regression model, regression coefficients can be obtained. Accordingly, even in cases where there are many input variables and the construction of a direct multilinear regression model would be difficult, once the PLS model has been constructed, multiple regression coefficients can be obtained as described above.

### (3) Quality simulation using the PLS model

A function has been developed for simulating with the PLS model how the output (quality) variable  $y$  changes in response to changes in the input (process) variable  $x$ . With a conventional multilinear regres-

Fig.3 Manufacturing processes of thin-film solar cells



sion model, in the case where mutual correlation exists among the input variables, the implementation of settings without consideration of the correlation among input variables would result in unrealistic combinations of input variables.

Therefore, the user sets the latent variable  $t$ , which is a variable that has summarized correlated input variables, and the estimated value of the input variable  $\hat{x}$  and the estimated value of the output variable  $\hat{y}$  are computed from the corresponding PLS model so that simulations can be carried out with the correlation among input variables maintained. Figure 2 shows an example screenshot of a quality simulation which has been developed as a package that runs on Windows<sup>\*1</sup>. The user is able to freely and easily run simulations to determine how quality will change when manufacturing conditions are changed while comparing the results with their physical knowledge of manufacturing processes.

## 2.4 Quality simulation example of solar cell deposition process

An example quality simulation of the deposition process for Fuji Electric's thin-film solar cells shown in Fig. 3 is described below, wherein the relationship between manufacturing condition parameters and product quality is modeled with the PLS method and the manufacturing conditions are changed in order to improve product quality.

As manufacturing conditions in the deposition process, there are approximately 10 types of parameters, such as temperature, pressure, deposition time, deposition rate, thickness and doping rate, and the entire process has about 100 parameters. These parameters are mutually correlated, and changes in the manufacturing conditions must be carried out while maintaining the correlations. Product quality is evaluated according to the conversion efficiency of the cell.

A manufacturing experiment was conducted by

<sup>\*1</sup>: Windows is a registered trademark of Microsoft Corporation in the United States and/or other countries.



changing the condition values gradually in consideration of the correlation for 30 parameters that have a strong effect on quality, among the approximately 100 parameters. Using data of 115 samples, a PLS model was created with the 30 condition parameters as input parameters and the efficiency value as the output parameter.

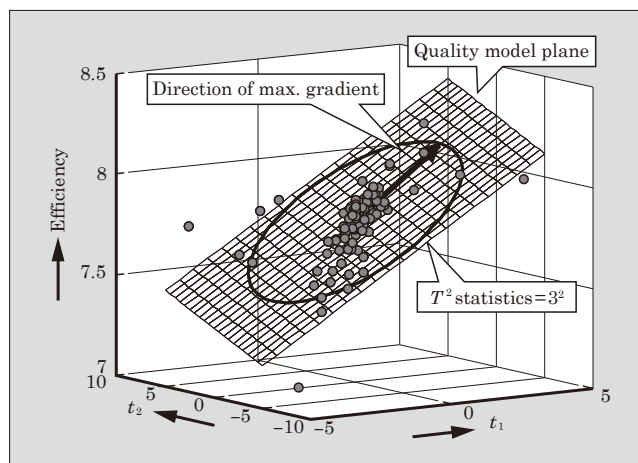
Figure 4 shows the distribution of efficiency values for two main latent variables. In the figure, the flat plane (quality model plane) represents the PLS model, and the distribution of actual data shown by points is approximated with this model.

Here, it is desirable for the efficiency to be as high as possible, and the efficiency can be increased by changing the parameters in the direction in which the slope of the plane is steepest (highest gradient direction). This is the “recommended direction” for change in the latent variable space.

In this case, the recommended direction is expressed as the direction of change of two latent variables ( $t_1$ ,  $t_2$ ), and as the range determined to be “normal” in the latent variable space (the  $t_1$ - $t_2$  plane), the  $T^2$  statistic is constrained inside a  $3^2$  (corresponding to 3 times the standard deviation) circle so that conditions can be determined realistically within an appropriate range. Also, this can be converted to the direction of change of the original condition parameters. At this time, because the change maintains the correlation among the original parameters, the direction of change will be realistic and reasonable.

To obtain the best manufacturing conditions, in cases where a PLS model is not used, the changing of even 30 parameters by 3 levels each, for example, would require  $3^{30}$  experiments which is impractical. Experimental points are determined by trial and error or empirically. In cases where a PLS model is used, optimal conditions are obtained by conducting searches on the quality model plane. Therefore experimental points can be determined efficiently.

Fig.4 The example of quality simulation using PLS model



### 3. Efforts with Model Predictive Control (MPC)

MPC is a control algorithm that is effective for multivariable systems having interference, for which sufficient control performance would be difficult to realize with PID control, and for control that involves long dead times. MPC has been utilized frequently in applications for the process control field, such as petrochemical plants, iron and steel processes, air conditioning and so on. Fuji Electric has used MPC in such applications as flocculation process control, rubber polymerization plants, energy plants and the like. So that MPC may be used in even more fields in the future, a disturbance observer is used to enhance the disturbance suppression performance and enable better control performance. Also, to improve the system performance, Fuji Electric has pioneered a real-time MPC computing unit (MPC execution engine) with a general-purpose PLC.

#### 3.1 New method of MPC with disturbance observer

MPC enables much greater control precision than PID or the like since constraints and the convergence to a target trajectory can be taken into account when making long-term predictions. However, in cases of modeling error, occurring due to an unknown disturbance or nonlinearity not contained in a measured value, the actual performance will deviate from the prediction and the control performance will deteriorate as a result. Especially with MPC based on a step response model, a significant deterioration in performance is noted when a ramp-like disturbance occurs<sup>(1)</sup>. The particular weakness to ramp-like disturbances is attributable to the MPC method of correcting prediction errors and is a fundamental problem.

To address this problem, three main approaches have been adopted in the past, namely, a method for modifying the model itself into a nonlinear model or state-space model (Method A)<sup>(1)(2)</sup>, a method for including disturbance response characteristics in the model (Method B)<sup>(2)</sup>, and a method for incorporating principles of robust control (Method C)<sup>(2)</sup>. The advantages and disadvantages of these approaches are listed in Table 1. In all these methods, the difficulty in simultaneously addressing a modeling error and an unknown disturbance, and the increase in computational cost

Table 1 Comparison of methods to improve the disturbance characteristic

	Method A	Method B	Method C	How to evaluate
Modeling error	Fair	Poor	Good	Robustness with respect to modeling error
Unknown disturbance	Poor	Fair	Fair	Stability when unknown disturbance occurs
Computational time	Fair	Good	Poor	Computational time for implementation

are disadvantages.

In order to improve disturbance rejection performance, Fuji Electric developed a method that incorporates the concept of a disturbance observer, which has been used successfully in motor control applications and the like. Figure 5 shows a block diagram of the MPC with disturbance observer and an explanation of its operation.

Based on the computations of the block diagram, the reduction in prediction error due to an unknown disturbance  $d$ , when compared before and after introduction of the disturbance observer is as follows<sup>(3)</sup>.

$$\|(I + P_n(j\omega)L)^{-1}P_n(j\omega)\| \leq \gamma \|P_n(j\omega)\| \quad \dots\dots\dots (5)$$

- $I$  : identity matrix
- $P_n(s)$  : nominal plant model
- $L$  : observer gain
- $\gamma$  : performance index of disturbance rejection

The transfer function of a ramp-like disturbance ( $1/s^2$ ) has infinite gain at zero frequency and converges to zero at high frequencies. To suppress this type of disturbance, conditions can be devised and established in the vicinity of zero frequency.

$$\|(I + P_n(0)L)^{-1}P_n(0)\| \leq \gamma \|P_n(0)\| \quad \dots\dots\dots (6)$$

The solution  $L$  of inequality (6) can be obtained via a singular value decomposition of  $P_n(0)$  as an explicit function of  $\gamma$ <sup>(3)</sup>.

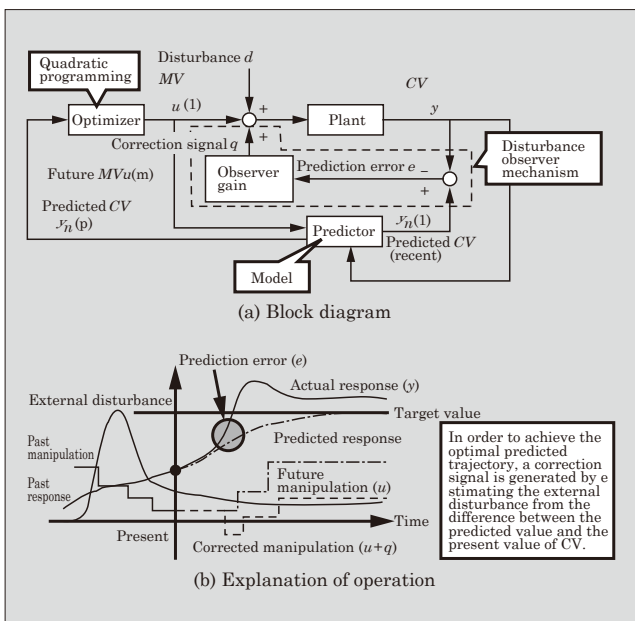
Meanwhile, according to the final value theorem,

$$\begin{aligned} \lim_{t \rightarrow \infty} (P_n^* U_i)(t) &= \lim_{s \rightarrow 0} (P_n(s) U_i(s)) \\ &= \lim_{s \rightarrow 0} \left( P_n(s) \frac{1}{s} e_i \right) = P_n(0) e_i \quad \dots\dots\dots (7) \end{aligned}$$

holds.

- $e_i$  :  $i^{\text{th}}$  unit vector
- $U_i(s)$  : unit step function comprised of only the  $i^{\text{th}}$  element

Fig.5 MPC with disturbance observer



$P_n(0)$  : matrix of collected convergence values of each element from step responses in a plant

Thus, based on the step response model, this method can be applied to MPC.

Figure 6 shows simulation results comparing the ability to maintain steady-state levels with MPC when a ramp-like disturbance is imposed on a Wood-Berry model<sup>(4)</sup>, which is a benchmark problem in the process control field. The application of a disturbance observer enables a 75% reduction in the fluctuation of the value of internal variable CV.

The fluctuation of gain at manipulation inputs is considered to be equivalent to an input disturbance. For example, imposing a disturbance that is the same as that of the manipulated variable has the same result as doubling the gain. In order to reduce the sensitivity of prediction error to an input disturbance, model error for this type of manipulation input gain can be absorbed with this method. Moreover, this method can be realized with the observer computation only, and therefore the computational load is small. Accordingly, in the comparison of the three methods shown in Table 1, this method is superior in three aspects: modeling error, unknown disturbance and computational time.

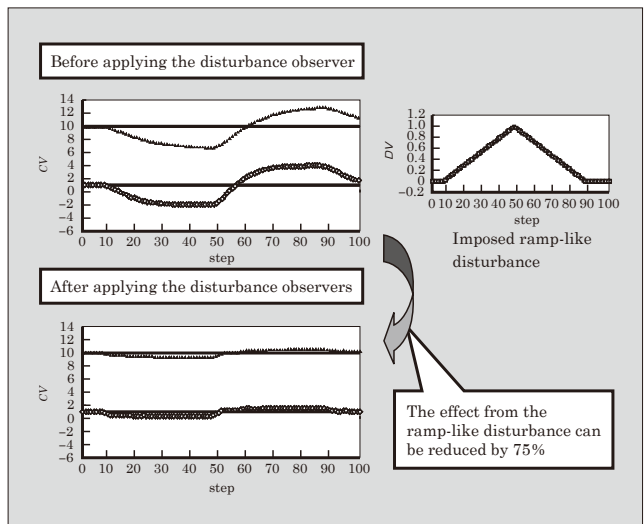
Also, methods for adjusting gain to ensure MV constraints of model predictive control have been investigated<sup>(3)</sup>.

By applying this technology, an MPC function strongly resistant to disturbances can be provided to plants where high-level reliability is required for long-term continuous operation.

### 3.2 MPC system implementation using a general-purpose PLCs

MPC has been successfully utilized for many relatively large-scale processes involving more than 100 control variables, such as petrochemical plants and iron/steel processes. On the other hand, in small-scale

Fig.6 Simulation of the effect of the disturbance observer



processes and equipment having fewer control variables, controlling the variables simultaneously with MPC is also expected to achieve successful results such as stable operation and improved control performance. However, due to such constraints as reliability, installation cost and the like, MPC has only been utilized in certain processes. Consequently, Fuji Electric has realized an MPC system that uses a general-purpose PLC so that users can easily implement MPC for control objects having a modest number of inputs and outputs.

The system configuration is shown in Fig. 7. This system is configured with the MPC execution engine located in a PLC, and support tools such as for MPC tuning and internal modeling located in a PC. Features of the developed system are described below.

#### (1) Realization of high reliability with PLC

An MPC module contains the MPC execution engine and is constructed as an embedded application on Fuji Electric's PLC, the MICREX-SX. Consequently, the reliability of a device having PLC can be enjoyed. For control applications requiring high reliability, MPC modules can be mounted on a duplex system and an environmentally-resistant CPU may be used.

Usually, the MPC module and another module that executes a different control program are both mounted (in a multi-CPU configuration) on the same baseboard. However, the system may be configured with only the MPC module by itself, and for example, a MPC module may be installed as an add-on system to existing equip-

ment.

#### (2) Realization of high-speed with MPC with constraints

MPC control rules implement the same functions as those implemented with PC software, and for example, constraints for controlled variables and manipulated variables are embedded directly. Also, as described above, the MPC execution engine operates with a single CPU, and therefore does not affect the execution of other applications. With an MPC having 4 inputs (manipulated variables) and 6 outputs (controlled variables), execution can be implemented with a minimum control period of 5 seconds.

#### (3) Improved convenience and ease of maintenance

When embedding MPC into a system, the MPC operating conditions, transfer conditions, stabilization processing when transferring, I/O processing such as filtering of controlled variables, and MPC peripheral functions such as fault processing must also be embedded. Previously, this engineering work had to be performed separately for the MPC tools running on a PC and for the control system on PLC or others. With this system, the MPC execution engine is provided as a function block (FB) of the "D300Win" design support tool for the MICREX-SX. The user can centrally configure and manage an MPC application, including the abovementioned peripheral processes, as the same software program and with the same tools as a PLC plant control program. A user familiar with MPC is able to utilize MPC as if it were PID control. Since

Fig.7 MPC system configuration using MICREX-SX

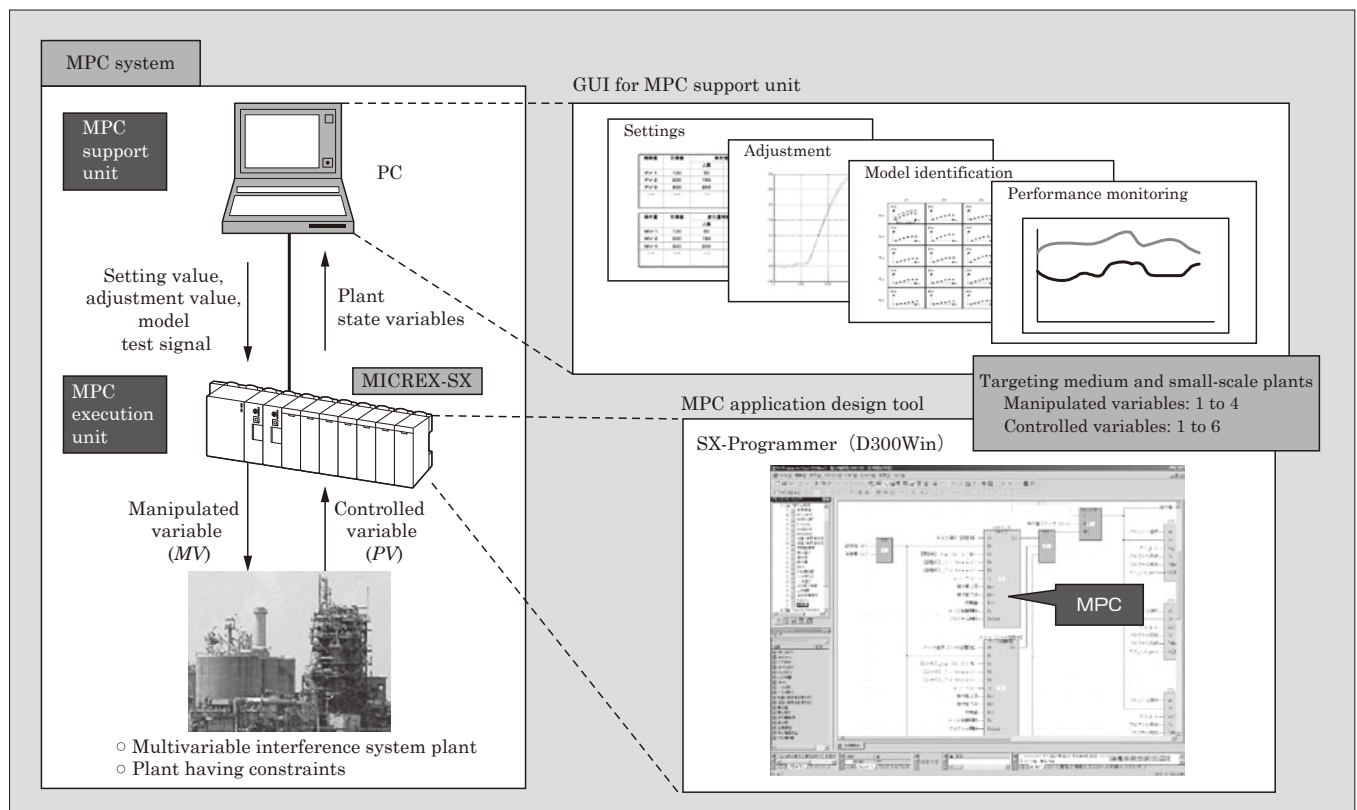
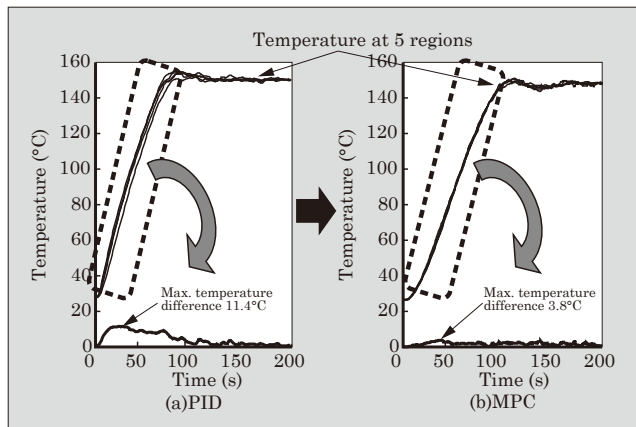


Fig.8 Results of application of MPC to glass substrate synchronous heating



the MPC module is embedded in the control panel that houses the PLC, the user will not be inconvenienced with respect to installation efficiency.

### 3.3 Application example of MPC to manufacturing process

MPC was applied to the heat treatment of glass substrates which are a basic unit in the manufacture of flat panel displays (FPDs). In the manufacturing process, the glass substrates must be heat-treated with an annealing process or the like. To prevent cracks and display unevenness, while being heated, the entire surface to be processed must be controlled to a uniform temperature (synchronous heating). Previously, for this process, a glass substrate was subdivided into multiple regions, and for each region, PID control having the controlled variables for the temperature and the heater as its inputs and outputs was used to implement multi-point synchronous heating. Using MPC to perform synchronous heating, we investigated whether the temperature difference between the region having the highest temperature and the region having the lowest temperature, i.e. the maximum temperature difference, would decrease. Figure 8 shows the results

of a comparison of the maximum temperature difference when using PID and MPC. By using MPC, the maximum temperature difference in the heating process was found to be 3.8°C which is significantly lower than the value of 11.4°C when PID control was used.

## 4. Postscript

This paper has discussed MSPC and MPC as control technology for the advancement of automation. The application of MSPC to quality simulation technology for making thin-film solar cells more efficient has been described. For MPC, Fuji Electric's proprietary disturbance observer function, the implementation of MPC functions with a PLC, and application examples have been introduced.

Fuji Electric's future plans regarding MSPC are to embed the newly developed engine into various packages and to expand the range of applications mainly in the industrial field. Fuji Electric will actively pursue applications of MPC to medium and small control systems in addition to applications to control systems for large-scale energy plants such as petrochemical and iron and steel plants.

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# Environmental Automated Measuring Systems for Flue Gas

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## ABSTRACT

Flue gas regulations have been enacted into law in order to prevent air pollution in countries such as Japan, Europe and China. With a conventional-type continuous flue gas measuring system consisting of a sampling-type gas analyzer that samples flue gas and performs pre-processing, the realization of long-term stable measurements has encountered such problems as requiring the removal of blockage or contamination in the sampling pipe, periodic calibration of the analyzer, increased power consumption of heating tube, and so on. Fuji Electric's simultaneous seven-component measuring gas analyzer uses cross stack laser method for HCl measurement and is capable of overcoming the above problems. Fuji Electric is also advancing research and development so that the cross stack laser method can be used for measuring other components.

## 1. Introduction

The flue gas emitted from thermal power generation and boiler equipment, and from industrial furnaces used for steel production, cement production and the like is known as a stationary source, and is a major cause of air pollution. Countries such as China, India and Russia, have rapidly raised their GDP with vigorous production activities. However, global environmental pollution due to flue gas and waste water has become a serious problem, and environmental protection initiatives, especially the Kyoto Protocol, are essential for all countries. In Japan and Europe, restrictions on flue gas emission have already been deployed in each industry, and the results have been evaluated. Meanwhile, in China, legislation and implementation based on emissions standards in advanced countries are being advanced as a national project. However, so far such activities have only focused on large corporations. In India and Russia, environmental legislation is being advanced, and future full-scale implementation is anticipated.

For measurement of the regulated substances in flue gas, in addition to the official method of manual analysis (the specified analytic method used in international organizations, and national or official testing institutions and research laboratories that conform to national standards), the installation of an environmental measurement system containing a built-in continuous automatic analyzer is mandated in order to measure the total amount of emitted matter. The environmental measurement system used for flue gas

is known as a continuous emission monitoring system (CEMS) and is equipped with an analyzer that has been approved by each country and is provided with functions for measuring the concentration, temperature, pressure and flow rate of regulated substances, and also with functions for forms control, for sending data to regulatory authorities, and so on. As a result of activities to protect the global environment, the CEMS market is expanding. Especially in China, the CEMS market is expected to grow by more than 10% annually, and Japanese, European and domestic Chinese manufacturers of analyzers are entering this market.

Fuji Electric's automation business is centered on "energy, environment and safety" technology, and aims to make a positive contribution to society. The development of an environmental measurement system for monitoring flue gas is based on sensing, data processing and transmission and other important automation technology. Below, Fuji Electric's environmental measurement system for monitoring flue gas and an implementation example are described. The future outlook is also discussed.

## 2. Each Country's Laws and Regulations Concerning Flue Gas

Table 1 lists each country's laws and regulations relating to air pollution control. In Japan, with the industrial development that began in the 1960s, adverse health effects have resulted from the photochemical smog caused by sulfur dioxide and nitrogen oxides contained in the flue gas emitted from factory stacks. As a result, the government enacted an "Air Pollution Control Law" (1968) and enacted regulations on smoke and soot emissions. Thereafter, flue gas washing technology that uses pollution control equipment such as

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Table 1 Laws and regulations of each country to prevent air pollution

Item	Japan			Europe (EU)			China		
Laws & regulations	Air pollution control Law (1968) Electricity Enterprises Law (1964) The Basic environment Law (1993)			Directive on Ambient Air Quality Assessment and Management (1996) Directive on the Incineration of Waste (2000) Directive on the Limitation of Emission of Certain Pollutants into the Air from Large Combustion Plants (2001)			Integrated Emission Standard of Air Pollutants (1997) Enactment of Emission Standards by Industry (1997)		
Measurement device certification	Measurement Law (revised 1996) JIS			European Norm EN1418 (2004) EN 14956 (2002)			China Environmental Protection Related Standard (2002) (HJ/T 76-2001) “Specifications and Test Procedures for Continuous Emission Monitoring Systems of Flue Gas Emitted from Stationary Sources”		
Certifying authority	JQA (Japan Quality Assurance Organization)			TÜV (Germany) MCERTS (England), etc.			Ministry of Environmental Protection of the People's Republic of China		
Environmental standards	Components	Range	Method	Components	Range	Method	Components	Range	Method
	SO <sub>2</sub>	0~50 ppm~	IR UV	SO <sub>2</sub>	0~50 ppm~	IR UV	SO <sub>2</sub>	0~50 ppm~	IR UV
	NO <sub>x</sub>	0~50 ppm~	IR Chemiluminescence	NO <sub>x</sub>	0~50 ppm~	IR Chemiluminescence	NO <sub>x</sub>	0~50 ppm~	IR Chemiluminescence
	CO	0~50 ppm~	IR	CO	0~50 ppm~	IR	O <sub>2</sub>	0~25%	Paramagnetic
	CO <sub>2</sub>	0~20%~	IR	CO <sub>2</sub>	0~20%~	IR			Zirconia
	O <sub>2</sub>	0~25%	Paramagnetic Zirconia	O <sub>2</sub>	0~25%	Paramagnetic Zirconia			Galvanic
	Dust	0~100 mg/Nm <sup>3</sup> ~	Light transmission Electrostatic quantity	Dust	0~100 mg/Nm <sup>3</sup> ~	Light transmission Electrostatic quantity	Dust	0~1,000 mg/Nm <sup>3</sup> ~	Light transmission Electrostatic quantity
	HCl	0~50 mg/Nm <sup>3</sup> ~	Ion-selective electrode IR	HCl	0~50 mg/Nm <sup>3</sup> ~	IR	HCl	0~1,000 mg/Nm <sup>3</sup> ~	IR
	Measurement components and concentration may vary depending on the type of industry			Measurement components and concentration may vary depending on the type of industry			Measurement components and concentration may vary depending on the type of industry		
Sampling method	Direct sampling type, cross stack type			Direct sampling type, cross stack type			Direct sampling type, dilution type, cross stack type		

desulfurization and denitrification equipment, dust collectors and the like, and technology for the continuous automatic measurement of regulated substances has been developed<sup>(1)</sup>.

In Europe, laws and regulations concerning air pollution control are well underway from 1950s and emission monitoring systems are being installed sequentially, beginning with business entities that emit large quantities of flue gas, and the installation of such equipment is nearly complete in Japan and Europe. In the future, in response to stronger local regulations, the addition and installation of automatic continuous measurement devices is anticipated for monitoring

low concentrations and for newly regulated substances such as mercury.

In China, the Integrated Emission Standard of Air Pollutants (1997) and the Specifications for Continuous Flue Gas Analysis (2002) were enacted based on Euro-American standards, and emission regulations were initiated for large-scale coal power plants near large cities. Emission regulation in China is less strict than in Europe, the US and Japan, but in the future, the expansion of emission regulation to more than 20,000 medium and smaller-size boilers and heat treatment furnaces is estimated to result in the addition of regulated substances and to accelerate the regulation of

emissions.

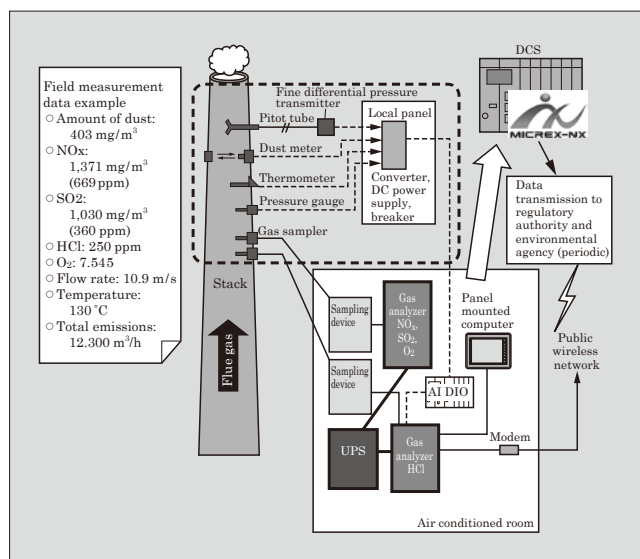
### 3. Current Status of Continuous Emission Monitoring Systems

Figure 1 shows an example of a continuous emission measurement system for measuring nitrogen oxides ( $\text{NO}_x$ ), sulfur dioxide ( $\text{SO}_2$ ), oxygen ( $\text{O}_2$ ) and hydrogen chloride ( $\text{HCl}$ ). A gas extractor, a dust meter, a pressure meter, a thermometer and flow meters (Pitot tube and differential pressure gauge) for measuring flue gas are installed in a smoke stack. In this system, after the primary filter of the gas extractor removes dust, a sampling device removes dust and moisture, and then the result is fed to an analyzer to continuously measure each measurement component of the flue gas. Hydrogen chloride content is measured with a separate dedicated analyzer since the measuring method is different. The system transmits measured values to a computer or distributed control system (DCS), performs temperature and pressure compensation, stores data, generates the appropriate written forms, and periodically transmits the measured values and equipment status to the regulatory authorities. An uninterrupted power supply is used frequently as the power supply. Continuous emission monitoring systems are housed in an air-conditioned analysis room or analysis chamber. The challenges for long-term stable operation of a continuous emission measurement system are described below.

#### (1) Stability of the sampling device

With a sampling-type analyzer, pre-processing of a sample gas that is suitable for the plant is essential, and the stability of the sampling device is important. In particular, in China where the main fuel is coal, care must be taken to remove sulfuric acid mist and dust, which cause pipe blockages and contamination, from the flue gas.

Fig.1 Example of continuous gas emission monitoring system



#### (2) Handling of analyzer

Because specialized knowledge is needed to resolve problems involving abnormal measurement values, the manufacturers of continuous emission monitoring systems must train and guarantee the availability of service personnel skilled in trouble resolution. The different measurement principles (Table 1) for the components being measured with an analyzer leads to complicated handling.

#### (3) Periodic calibration of analyzer

In order to maintain its precision, the analyzer must be calibrated periodically with a traceable standard gas for each measurable component. The calibration cycle ranges from once per week to once per month. Automatic calibration is possible with a sequence that uses the traceable standard gas in combination with a solenoid valve, but the results are uncertain in cases involving piping anomalies or an empty gas cylinder, and a final check by a human is essential. Also, the periodic preparation of standard gas is very expensive.

#### (4) Power consumption

The gas sampling device and piping that feed the sample gas to the analyzer apparatus are heated to more than 100 °C in order to reduce dissolution loss of the measurable components due to condensation and to prevent corrosion of the metallic areas. The sampling tube extends from 30 m to 50 m, and accounts for more than 50 % of the total power consumption. In a continuous emission monitoring system for  $\text{NO}_x$ ,  $\text{SO}_2$  and  $\text{O}_2$ , and including a hydrogen chloride ( $\text{HCl}$ ) analyzer based on the ion-selective electrode method, because each analyzer requires a heating pipe, the total power consumption exceeds 4,000 VA. Moreover, if a system is to be installed in an environment where the ambient temperature exceeds the installed temperature conditions, an air-conditioned analysis chamber or room is often used to house the system. However, this will lead to increased power consumption when the system is used for continuous emission monitoring.

To summarize the above challenges, it is desirable that a measurement system is capable of simultaneous and continuous measurement and is strongly resistant to sulfuric acid mist and dust, and that the analyzer is easy to handle, maintenance cost is low, and the operation is stable.

### 4. Environmental Measurement System Proposed By Fuji Electric

Shown in Fig. 2, the “ZSU-7” seven-component simultaneous gas analysis system that forms the core of an environment measurement system for monitoring flue gas is described below.

#### 4.1 Environment measurement system

In order to overcome the abovementioned challenges, the ZSU-7 measures the four components of

NO<sub>x</sub>, SO<sub>2</sub>, CO and CO<sub>2</sub> with an infrared method, and measures O<sub>2</sub> with a zirconia method, using sampling system. Moreover, the ZSU-7 is an integrated analysis apparatus<sup>(2)</sup> that also measures HCl with a cross stack laser gas analyzer for which a sampling device is unnecessary, and measures dust with an electrostatic induction method. The necessity of sampling devices has not completely been eliminated for all measurable components, but a cross stack laser analyzer which does not require a sampling device is used to measure hydrogen chloride. The cross stack laser method provides significant benefits for overcoming the above abovementioned challenges.

## 4.2 Measurement method

### (1) Laser type

The measurement principles of the laser-type gas analyzer are shown in Fig. 3, and a schematic drawing of its installation is shown in Fig. 4. The relationship between infrared absorption intensity and concentration of the measurement gas can be expressed with the same “Lambert-Beer Law” (see Eq. (1)) as with the conventional infrared gas analyzer, but the method of detecting the concentration is different. The emission wavelength of an infrared semiconductor laser light source is modulated at a fixed cycle, and the vicinity

Fig.2 Appearance of the “ZSU-7” Seven-component simultaneous measurement gas analyzer apparatus

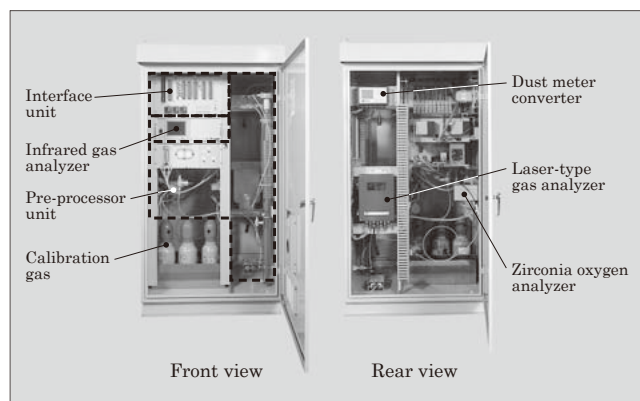
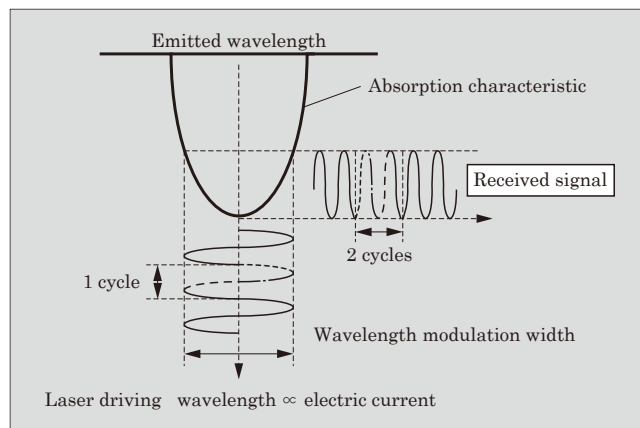


Fig.3 Measurement principle of laser-type gas analyzer



of the absorption spectrum of the measurement gas components is scanned. At this time, according to the gas concentration, sample gas that passes through the laser light is absorbed and the volume of transmitted light reaching the receiver unit decreases. This volume of transmitted light is detected at the photodiode of the receiver unit, and the gas concentration is measured with synchronous detection by detecting twice the frequency of the modulated signal<sup>(3)(4)</sup>.

The relationship between infrared absorption intensity and concentration adheres to the Lambert-Beer Law and is expressed by Eq. (1).

$$I = I_0 e^{-kCL} \quad (1)$$

$I$  : intensity of transmitted infrared light

$I_0$  : intensity of emitted infrared light

$k$  : coefficient of absorption

$C$  : concentration of measurable component

$L$  : length of measurement cell

### (2) Infrared type

Figure 5 shows the configuration of an infrared gas analyzer.

The infrared-type gas analyzer uses a double-beam non-dispersive infrared method. The light emitted from the infrared-red light source is split into two halves by a distribution cell, and irradiated on sealed reference cell containing inert gas having no infrared absorption and a sample cell through which sample gas flows. The incident infrared rays are absorbed in the sample cell according to the gas concentration.

The detector contains two detection spaces for re-

Fig.4 Schematic drawing of laser-type gas analyzer installation

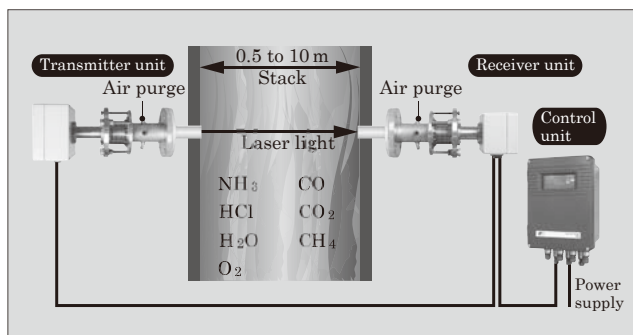


Fig.5 Configuration of infrared-type gas analyzer

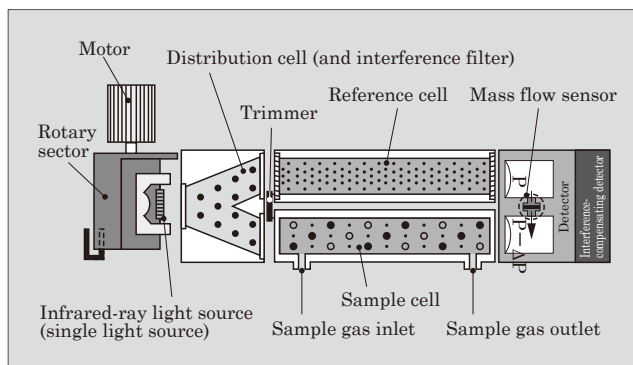




Table 2 Advantages of the cross stack laser gas analyzer

Item	Ion-selective electrode-type infrared gas analyzer	Cross stack laser gas analyzer	Advantage of cross stack laser gas analyzer
Sample gas sampling method	Sampling type	Cross stack type	Simple measurement system
Pre-processing Sampling device	Necessary	Unnecessary except for gas purging	Low lifecycle cost Low power consumption
Measurement gas	NO, NO <sub>2</sub> , SO <sub>2</sub> , HCl, NH <sub>3</sub> , CO, CO <sub>2</sub> , CH <sub>4</sub> ...	HCl, NH <sub>3</sub> , CO, CO <sub>2</sub> , O <sub>2</sub> , CH <sub>4</sub> , H <sub>2</sub> O (NO, NO <sub>2</sub> , SO <sub>2</sub> ) <sup>*1</sup>	Water-soluble, adsorptive gases such as NH <sub>3</sub> and HCl can be measured without loss
Response time	2 to 4 minutes (not including tube)	1 to 5 seconds	Applicable to plant control No deviation in responses to different measurement components
Dust resistance	0.5 g/Nm <sup>3</sup> (max.)	30 g/Nm <sup>3</sup> (max.)	Can be applied to combustion control and denitrification control without pre-processing
Maintenance	12 to 24 times/year	1 to 2 times/year	Low lifecycle cost Few parts requiring maintenance
Calibration	53 times/year (weekly)	1 to 2 times/year	Low lifecycle cost
Interference from other gases	Countermeasures may be implemented depending on measurement components and concentration	Rare	Almost none
Stability	±2 % FS <sup>*2</sup> /week	±2 % FS <sup>*2</sup> /6 months	Good stability adjacent zero point Low lifecycle cost

\*1: Gas targeted in the next development

\*2: Full-scale (FS): Measurement range

ceiving the infrared rays that have passed through the reference cell or the sample cell. The detection tanks are filled with the same gas as the measurable components, and according to the difference in absorption, a pressure difference proportional to the amount of light is generated in the two spaces. From the pressure difference ( $\Delta P$ ) of the detection tanks and the correlated change in resistance ( $\Delta R$ ) of the mass flow sensor, the concentration of measurement gas can be expressed with Eq. (2).

$$\Delta R \propto \Delta P \propto I_0 - I = I_0(1 - e^{-kCL}) \div kCL \dots \dots \dots (2)$$

#### 4.3 Implementation example

A half-year field test of a continuous automatic measurement system that combines a laser-type analyzer and an infrared gas analyzer performed with the general waste incinerator of a certain Tokyo-based facility is described below as an example implementation.

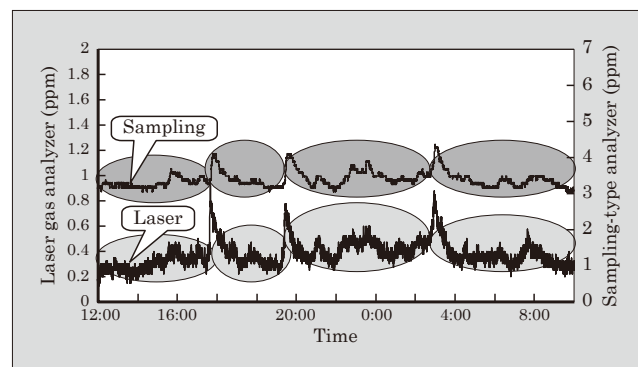
Figure 6 shows the correlation between the measured values of a sampling-type hydrogen chloride analyzer and a laser-type gas analyzer.

The sampling-type hydrogen chloride analyzer was installed at approximately the same site as the laser-type analyzer.

From the output trend, a correlation relationship can clearly be seen. In a manual analysis value for this period, the correlation with the laser-type analyzer was obtained at an average HCl concentration of 0.5 ppm. Zero drift performance was stable with no more than 0.5 % full-scale fluctuation over a half-month.

The power consumption could be reduced by at least 2,000 VA compared to a flue gas continuous monitoring system combined with a sampling-type hydro-

Fig.6 Correlation between measured values of sampling-type hydrogen chloride analyzer and laser-type gas analyzer



gen chloride analyzer

#### 4.4 Advantages of the cross stack laser gas analyzer

Advantages of the cross stack laser gas analyzer are listed in Table 2.

The cross stack laser gas analyzer does not have a sampling device and only needs gas purging control. With long-term stability that fluctuates by only ±2% full-scale over 6 months, the analyzer requires little maintenance and infrequent calibration. Since there is no need for a heated sampling tube, a greater than 40% reduction in power consumption compared to a hydrogen chloride analyzer was achieved. Compared to a sampling-type ion-selective electrode-type hydrogen chloride analyzer, the lifecycle cost for maintenance was reduced to less than half.

## 5. Future Efforts

If the cross stack laser gas analyzer becomes capable of measuring all regulated substances, the abovementioned series of problems could certainly be resolved all at once. Currently, cross stack laser gas analyzers can only be manufactured with semiconductor laser light sources that are in the near-infrared wavelength band (700 to 2,000 nm range). Therefore the detectable components and measurement sensitivity, and the number of components that can be detected simultaneously are limited. When monitoring air quality with a cross stack laser gas analyzer, because the absorption wavelengths for NO, NO<sub>2</sub> and SO<sub>2</sub> are in the mid-infrared wavelength band (4,000 to 8,000 nm), the difficulty of measurement and the inability to measure an arbitrary number of components simultaneously are problems.

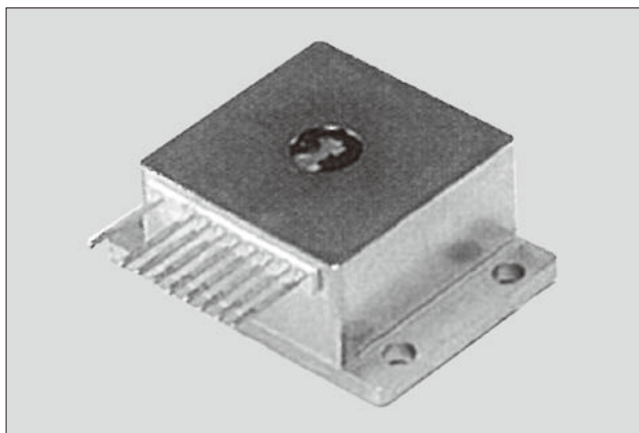
Through joint research with Hamamatsu Photonics K.K., Fuji Electric is engaged in development work that will enable detection of NO, NO<sub>2</sub> and SO<sub>2</sub> using a quantum cascade laser capable of emitting light in

the mid-infrared wavelength band (4,000 to 8,000 nm wavelength). Figure 7 shows the appearance of the newly developed quantum cascade laser light source that emits light at a wavelength of 7,300 nm and is capable of detecting SO<sub>2</sub>. The SO<sub>2</sub> detection has been verified as having the same level of sensitivity as that of the previous sampling-type gas analyzer, and is ready for practical application.

## 6. Postscript

As described herein, in addition to being energy-efficient, the cross stack laser gas analyzer also provides higher response, has fewer parts requiring considerable maintenance and is easier to maintain than the conventional sampling-type gas analyzer, and its range of applications is expected to expand. As awareness of environmental preservation heightens throughout the world, the addition of new components to measure and the ability to handle multiple components will become necessary. Fuji Electric will continue to develop technology to meet these needs and intends to make positive contributions to society with environmental technology that incorporates automation.

Fig.7 Appearance of quantum cascade laser source



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