Whole Number 254, ISSN 0429-8284

FUJI ELECTRIC REVIEW

2016 Vol.62 No. 3

Instrumentation and Control Solutions in the New Age of the IoT

Fuji Electric

Innovating Energy Technology

FUJI ELECTRIC
REVIEW

2016
Vol.62 No. 3

Instrumentation and Control Solutions in the New Age of the IoT

The Internet of Things (IoT) has been attracting much attention in recent years as a mechanism for exchanging information by connecting all types of things to the Internet. It is in a position to transform traditional industries and social structures through creation of new customer value based on developments in big data technology and artificial intelligence.

Fuji Electric has been actively pursuing energy and environmental technology innovation, and as such, it is offering solutions for every stage of the equipment and facility life cycle to meet the needs of its customers' production activities based on the pillars of "stable supply of energy," "realization of energy conservation" and "provision of safety and security." We are confident that the IoT will play a big role in the solutions being offered by Fuji Electric.

In this special issue, we will introduce Fuji Electric's latest instrumentation and control solutions that provide a glimpse into the new generation of the IoT.

Cover Photo

A quote from the catalog "IoT solutions"

FUJI ELECTRIC REVIEW vol.62 no.3 2016

date of issue: September 30, 2016

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

editorial office Fuji Electric Journal Editorial Office
c/o Fuji Office & Life Service Co., Ltd.
1, Fujimachi, Hino-shi, Tokyo 191-8502,
Japan

Contents

Preface

IoT and Open Innovation

SHIN, Seiichi*

The word Internet of Things (IoT) is becoming very popular. It refers to the concept of connecting every single object with the Internet. This is exactly the same as the concept of ubiquitous computing that was popular around the year 2000.

However, things have changed in the decade and a half since then, in terms of our technological environment and social environment. For example, the Internet protocol (IP) has been upgraded from version 4 to 6. This means that the IP addresses for distinguishing objects have changed from 32 bits to 128 bits. Specifically, whereas only 4 billion objects in the whole world could be distinguished in the past, it is now possible to distinguish 39-digit number of objects in the decimal system. This is an outrageous number, since a trillion is 13-digit number, and a quintillion is 19-digit number. Come to think of it, roughly assuming the current population of the world is 10 billion people, if each of these people has 100 objects connected to the Internet, then we were lacking IP addresses with version 4 while it is more likely to make the IoT a reality with version 6.

Another change in the environment is that analog TV broadcasting came to an end in July 2011 in Japan. The Image quality has been dramatically improved as the signals have become digitized. In fact, the efficiency of radio wave usage has been improved more than the size of improvement in the image quality. As a result, there is some vacancy in the frequency that is the so-called platinum band that it is easier to connect to and that makes large-capacity transmission available. This is called white space, and this vacant 700 MHz zone has been allocated to intelligent transport systems (ITS). This has led to a possibility of realizing practical application of vehicle-to-vehicle and vehicle-to-road communication. This is one of the reasons why self-driving vehicles have become a popular topic in recent years.

As you may already know, Japan is rich in innovation. Karaoke and instant noodles were invented by Japanese people, and they are changing the lives of people around the world. The basic technology related to the IoT is also in Japan. However, it is highly questionable whether we have the capability to expand it to the entire world.

The significant difference with “ubiquitous” that was often referred to at the beginning of 2000 is attitude toward open innovation. Ubiquitous technology was an enclosure type of technology. Ubiquitous computing enabled connection with products provided by some specific companies only, and this led to consumers not understanding such technology very well. On the other hand, the IoT is based on the concept of open innovation in which absolutely anyone can participate. Openness is ensured not only in the vertical direction between the data provider, analyzer and service provider, but also in the horizontal direction between anyone who wishes to participate, at all stages.

Other participants may be friend or foe. We will need a different mindset and a different system from when openness was ensured only among our allies, but it seems that people have yet to develop an awareness of this.

For the engineers in the 20th century, drawings were their lifeline. They were never to be disclosed to those in other companies. However, for open innovation, sharing these drawings is the starting point. In other words, the drawings are made open to all. Some may be upset, considering this situation to be like being naked in front of a large audience. However it is not. What we need to pay attention to is TPO (Time, Place and Occasion). Of course, in some cases, we may appear naked, but in other cases, we may be wearing a jacket, or may be wearing a small piece of underwear only. In those cases, we need to wear nice underwear. In other cases, we may need armor or a coat. Whether such provisions are registered as intellectual property will become the touchstone as to whether we can survive in this open age of the IoT.

The story still continues. In this open age, the age of the IoT, it seems that there will be no border between professionals and amateurs. Prosumers (where producers and consumers are combined) as predicted by Alvin Toffler in “The Third Wave” have emerged.

The professionals of nowadays design and produce products with the help of computer-aided design (CAD) systems and manuals. Professionals of the 20th century are deeply concerned that the skills of the professionals in the 21st century have deteriorated. Come to

* Professor, Graduate School of Informatics and Engineering, The University of Electro-Communications

think of it, products of the 21st century are composed of a vast amount of software in addition to numerous electrical and mechanical components. They are also sold while meeting various requirements regarding not only their performances, but also their cost, mass-production suitability, safety and environment friendliness. No designing, production, procurement or purchasing can be made without the aid of computers. That is the nature of the age we are living in.

On the other hand, amateurs can also design, produce, procure and purchase products as long as they have the aid of computers. The combination of CAD systems, 3D printers and the Internet will let us realize a dream where factories merge into households. We are living in 2016, and a long time has passed since the turn of the 21st century. We are in a totally different time from the 20th century.

Amateurs create equipment, amateurs gather data, and amateurs provide services; that is open innovation. Preparing an environment that enables this situation is what the professionals need to do.

Instrumentation and Control Solutions in the New Age of the IoT: Current Status and Future Outlook

KONDO, Shiro* FUKUZUMI, Mitsunori*

1. Introduction

Fuji Electric has been providing the state-of-the-art instrumentation and control technologies for use in various areas, including social infrastructure such as electric power and transportation, equipment for industrial use such as iron and steel, chemicals, automobiles and electric and electronic devices and consumer products such as buildings, retail stores, vending machines and in-vehicle devices. These technologies are characterized by their diverse range of pioneering achievements, which include labor saving, automation and improved efficiency and productivity. We are currently working to contribute to the creation of safe, secure and sustainable societies through research and development for energy and environmental technologies(1).

Recently, the Internet of Things (IoT)*1 has been attracting a great deal of attention and the instrumentation and control technologies in the industrial world are entering a phase of major change. This paper describes Fuji Electric's approach to the IoT and the current status of and future outlook for instrumentation and control solutions.

2. Global Trends in the Age of the IoT

The IoT related activities become very active on a global scale. Overlooking the various activities, we can see that they are essentially the same in that they are intended to create new values by using information and communications technology (ICT), which has become available at low costs, while there are some differences such as the scope.

As the scope of the technology in the IoT is vast, it is very difficult for one company to build and provide all of it. Formation of enterprise partnerships (ecosystems*2) thus becomes active and many companies around the world are looking for partners so that they can take advantage of their mutual strengths.

This section summarizes such trends with the focus on activities in Germany, the U.S. and Japan.

2.1 Trends in Germany

Since the German government announced the "High-Tech Strategy 2020 Action Plan(2)" in November 2011, efforts to realize "Industrie 4.0," or the fourth industrial revolution, have gained momentum. Its content can be roughly classified into promotion of standardization, creation of a reference architecture model, and demonstration projects of the customer value.

The IEC standardization activities of Industrie 4.0 started with a proposal from Germany in October 2013. However, since the scope of study is very wide, it is said that the standardization including coordination with existing standards will be done around 2020, and it will take another 10 years to penetrate the market. Meanwhile, with the subsidies of German governmental agencies, demonstration projects for mutually connecting equipment between multiple companies, such as It's OWL and Smart Factory KL have started, and evaluation of

* Corporate R&D Headquarters, Fuji Electric Co., Ltd.

***1: IoT**

Abbreviation for Internet of Things. In a narrow sense, it means a system in which various things are connected to the Internet to exchange information among them. Currently, the term is used to refer to entire services that create new values, which are realized by this kind of system. This concept has been devised as a result of the innovation in information and communications technologies, including inexpensive realization of Internet connection and data distribution and management.

***2: Enterprise partnership (ecosystem)**

An enterprise partnership means an entire relationship built by cooperation of multiple companies that provide different products, technologies and services, aiming for achieving a common objective and is sometimes referred to as an ecosystem. It sometimes takes a key role in quick and low-cost realization of a complicated system based on various technology components such as the IoT. The term "ecosystem" originally means an ecological system in which living things in the natural world and the environment surrounding them exist while interacting with each other, and it is used figuratively in the fields of economy and IT.

Table 1 IoT related activities in Japan

Establishment	Name of organization	Secretariat	Function		
			Standard	Modeling	Demon-stration
April 2015	Cyber Physical System (CPS) Task Force	Japan Electronics and Information Technology Industries Association	○		○
May 2015	IEC-APC_SG8 Subcommittee (domestic committee): Smart Manufacturing IEC/TC65 (domestic committee): Strategic Group (SG) 8	International Electrotechnical Commission Activities Promotion Committee (IEC-APC) Japan Electric Measuring Instruments Manufacturers' Association	○		
	Robot Revolution Initiative	The Japan Machinery Federation	○		○
	Industrie 4.0 Working Group	Nippon Electric Control Equipment Industries Association		○	
June 2015	Industrial Value Chain Initiative (IVI)	The Japan Society of Mechanical Engineers		○	○
August 2015	Special Committee on Smart Manufacturing	The Japan Electrical Manufacturers' Association		○	
October 2015	IoT Acceleration Consortium	Mitsubishi Research Institute		○	○

the effect is proceeding.

2.2 Trends in the U.S.

In the U.S., 5 companies including GE launched the Industrial Internet Consortium (IIC)[3] in March 2014. More than 240 companies including Fuji Electric and other Japanese companies are participating in the IIC. The IIC mainly carries out 2 activities:

(a) Study of technology and security architecture
(b) Field verification

Field verification is called testbed in which the IIC invites ecosystem proposals and offers opportunities for their demonstration. As of April 2016, 20 testbeds have been proposed, and a total of 40 companies have participated in them. In addition, companies several times as many as that are closely watching the progress.

2.3 Trends in Japan

In Japan, full-scale examination of the use of the IoT has begun since December 2014. Innovative change via the IoT was mentioned as a key policy measure in the Revolution in Productivity by Investment in the Future of the "Japan Revitalization Strategy — Revised in 2015," which was decided upon by the Cabinet on June 30, 2015[4]. It aims at a society in which interrelation between the real world and cyberspace is applied in every field to create big value as a "data-driven society." With this as a turning point, many organizations in Japan have also started activities such as IEC standardization, modeling of architecture and demonstration of customer value (see Table 1).

3. Fuji Electric's Approaches to Instrumentation and Control Making Use of the IoT

Based on the global trends described in Section 2, this section presents Fuji Electric's approaches that make use of its technical features.

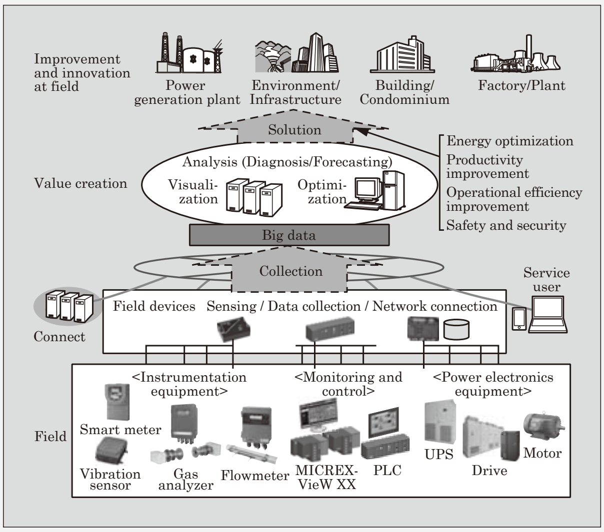


Fig.1 IoT solutions of Fuji Electric

3.1 Fuji Electric's IoT solutions

Fuji Electric possesses a series of technologies and products that cover a wide range including field data sensing, network connectivity, data analytics such as diagnosis, forecasting and optimization, advanced control technologies, and control devices which are basis for implementing these technologies (see Fig. 1).

3.2 IoT concept of Fuji Electric

Figure 2 shows Fuji Electric's IoT concept. The IoT here does not simply refer to things that connect to IP networks. It is a general name for systems that digitize all types of information in customers' fields, including machinery, equipment, lines, and infrastructure, to create new values in cyberspace.

Fuji Electric makes this IoT into a platform and

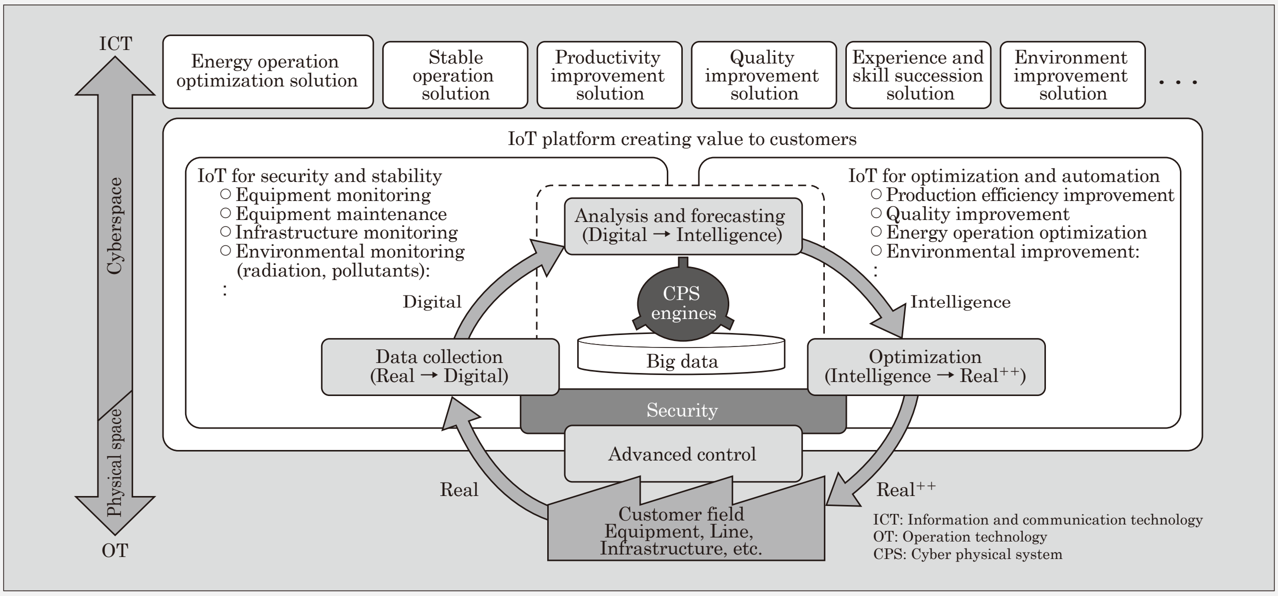


Fig.2 IoT concept of Fuji Electric

provides solutions to optimize energy operation and other solutions for stable operation, productivity improvement, quality improvement, experience and skill succession and environmental improvement as a menu of solutions. Application of the IoT is expanding in a variety of fields including the material industry, assembly industry and logistics.

3.3 Data collection technology

Data collection is the technology that digitizes field information and sends it to an IP network. It is composed of 2 technologies: sensing technology and network connecting technology.

(1) Sensing technology

Fuji Electric has a line-up of such industrial instruments as pressure and differential-pressure transmitters, flowmeters, water level meters, recorders, and controllers. In addition, we are working on developing technology for and commercializing environmental measurement. With the radiation monitoring technology, for example, we have provided distinctive products for personal dosimetry and radiation environment measurement for over 40 years. By combining a wireless new electronic personal dosimeter with a real-time remote monitoring system, a manager can grasp the radiation dose of a worker in real time. This makes it possible for the manager to give appropriate instructions and produce a positive radiation-dose-reducing effect (refer to “Real-Time Remote Monitoring System Utilizing New Electronic Personal Dosimeter” on page 182). We also commercialized the world’s first aerosol*3 analyzer capable of measuring PM2.5 in 2015, and developed a solution for estimating the source of PM2.5 (refer to “Solution for Estimating Generation Source of PM2.5 with ‘Aerosol Analyzer’” on page 176).

(2) Network connection technology

In the future, as the IoT becomes widespread, field devices, machinery, equipment are expected to be increasingly incorporated into it and be autonomously connected to networks. However, measures for connection with cyberspace should be provided also for existing devices and devices that cannot be readily networked for cost reasons. Fuji Electric has commercialized field devices classified into 3 types according to the type of connection with IP networks, and this is shown in Fig. 3.

(a) Group I: Direct type

This type of device connects with an IP network autonomously. Devices such as smart meters, monitoring posts, IT-enabled vending machines, high-functionality drives, medium- and large-capacity uninterruptible power systems (UPSs), monitoring and control systems (refer to “Evolving of Monitoring and Control System ‘MICREX-VieW XX (Double X)’” on page 186 and “Equipment Monitoring System ‘MICREX-VieW PARTNER’ Easily Cooperating with Integrated EMS” on page 193) fall under this group. In the future, we intend to evolve major Fuji Electric products into direct-type devices.

***3: Aerosol**

In general, aerosol refers to a state in which minute particles of liquid or solid are dispersed in the air. The diameter, shape and electrical and chemical characteristics of aerosol particles may vary. In particular, solid particulate matter with a diameter of 2.5 µm or smaller is referred to as PM2.5. It is feared to have adverse effects on human health and is considered as a social problem.

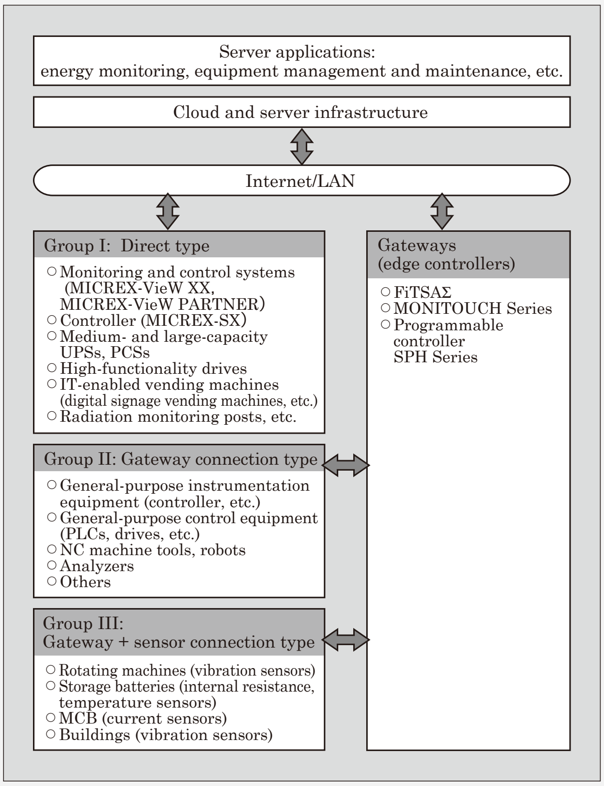


Fig.3 Three types of IP network connectivity

(b) Group Ⅱ: Gateway connection type

This type of device realizes connectivity to IP networks for existing devices (controllers, drives, instrumentation equipment and other general-purpose devices, analyzers) that do not have connectivity to IP networks regardless of whether they are Fuji Electric's products or not. It does this by using the local communication functions of the individual products. As gateway products, Fuji Electric has a line-up of "MONITOUCH," "FiTSAΣ" and programmable controller "SPH Series." These gateway products have connectivity with over 500 types of products of other companies including PLCs, drives, NC machine tools, robots and instrumentation equipment and make significant contributions to incorporating field devices into the IoT (see Fig. 4(a)).

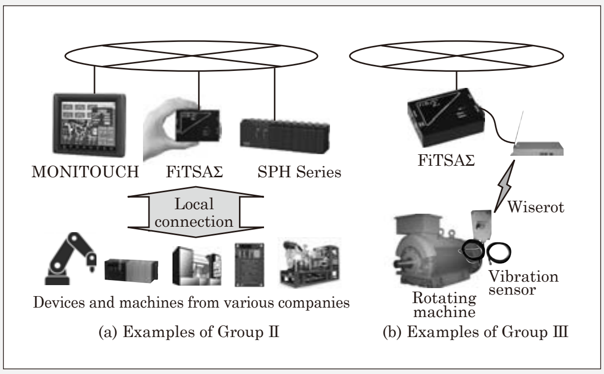


Fig.4 Network connection technologies (Groups II and III)

(c) Group Ⅲ: Gateway + sensor connection type

This type of device connects those without any local communication functions or intelligence in the first place, such as rotating machines, circuit breakers and buildings. Vibration sensors, temperature sensors, current sensors, and other sensors are connected to the gateway to digitize the statuses of the target devices via the sensors. Figure 4(b) shows an example of connection of "Wiserot," a wireless diagnostic system to examine the vibration of a rotating machine.

3.4 CPS engines

Fuji Electric owns a number of technologies such as analysis technology, diagnosis and forecasting technology, optimization technology, advanced control technology and so on. Utilizing these technologies, we offer various solutions such as optimum energy use, stable operation of facilities, productivity and quality improvement. Fuji Electric calls these technologies cyber physical system (CPS) engines and positions them as the core technologies for the IoT platform. These CPS engines are composed of field technologies that Fuji Electric has spent many years developing in the instrumentation and control field and mathematical technologies for industrial applications that support them. This subsection describes the mathematical application technologies.

(1) Diagnostic and forecasting technology

For diagnosis to identify any process abnormality, sensors and measuring systems suited for the purpose must first be selected to collect various pieces of data such as temperature, pressure, vibration and tension. All data obtained in this way are checked to extract correlations and identify data sets that are effective for determining whether a value is normal or abnormal. From these data sets, a diagnostic model is generated and evaluated. By repeating this process, the diagnostic model is developed through learning.

Based on this series of diagnostic model generation technologies, Fuji Electric owns, as proprietary core technologies, structured neural network technology, multi-variable statistical process control technology (MSPC) for batch processes, and sign detection technology based on ensemble forecasting (refer to "Mathematical Application Technology for IoT Solutions" on page 198).

(2) Optimization technology

As an example, an energy management system (EMS) is used for explanation here. An EMS is intended to visualize energy consumption, detect wasted energy, and optimize the operation of energy supply equipment. Various types of know-how are required such as which piece of data to measure by which means and which indicators to use for evaluating the energy-saving effect. To optimally operate energy supply equipment, it is necessary to model it, and this requires an understanding of the characteristics and functions of the equipment.

Fuji Electric has put various methods into practical use: mathematical programming including linear programming, particle swarm optimization*4 (PSO) as a meta-heuristic*5 optimization technology suited for nonlinear optimization problems and differential evolution*6 (DE), which is a latest optimization technology.

(3) Advanced control technology

For advanced control technology, it is important to model the controlled object based on an understanding of it and this model is utilized for materializing various control technologies. For example, it is necessary to select an appropriate control cycle according to the time constant of the object and select a control method in view of the comprehensive characteristics of the object such as presence of any interference between inputs and disturbance characteristics, order and gain. In addition, adjusting the parameters of the control system requires know-how.

As fundamental technologies, Fuji Electric owns PID control*7 technology, model forecasting and control technology for multi-variable systems, control performance monitoring technology for monitoring control performance degradation caused by changes in the characteristics of the controlled object and automatic parameter adjustment technology. One example of this advanced control technology is the ultra-lean combustion control that we developed and commercialized, and it helps to reduce boiler fuel costs (see Section 3.6(6)).

3.5 Cloud structure and security

(1) Cloud structure

Fuji Electric positions the CPS engines and their applied services as the core of its IoT platform.

In the common functional hierarchy of cloud services shown in Table 2, Fuji Electric's group of services is positioned as SaaS. Currently, many cloud vendors have commercialized services in the cloud service layer (PaaS and IaaS) and provide similar functions. However, interfaces with SaaS vary between individual cloud vendors. It is necessary for cloud users to consider the following point in choice of a cloud vendor to expand their business globally.

(a) Availability of servers in areas close to customers
(b) Adequacy of the development environment and support
(c) Cost
(d) Connectivity with the field

(2) Security

In June 2010, malware that makes targeted attacks called Stuxnet was found, and it focused people's attention on cyber attacks against control systems. In response, studies on security measures for control systems and standardization activities were pressed forward rapidly by all of industry, government and academia.

As the IoT become widespread, various field devices come to be more connected than ever to control systems via IP networks for data collection, analysis and value creation. The emergence of new security risks is expected due to the spread of a cloud environment. Hence, we are working on developing technologies to ensure authenticity and integrity of data between control devices in addition to further im-

Table 2 Functional layers of cloud services

Functional layers		Description
SaaS	Software as a Service	Allows use of application services via the Internet.
PaaS	Platform as a Service	Refers to middleware and OS as execution environment for SaaS.
IaaS	Infrastructure as a Service	Provides execution environment (hardware, virtual servers, etc.) for SaaS and PaaS as a service on the Internet.

***4: Particle swarm optimization**

Sometimes abbreviated as PSO. This is one of the optimization methods based on meta-heuristics. In a group of living things, when one individual finds a good place (solution), other individuals in the group gather to search in the surrounding area, or the group go back to a place which one individual recalls as a good place found in the past. Making this behavior into an algorithm increases the probability to reach an optimum solution.

***5: Meta-heuristics**

Empirical knowledge (experimental rule) generally regarded as valid is referred to as a heuristic. Meta-heuristics generically refers to optimization algorithms designed for general applications without being confined to specific problems. It uses empirical knowledge in which behavior of living things or physical phenomena can be simulated to derive optimum answers. The initial value for the solution is corrected while searching for a better solution in a practical time period.

***6: Differential evolution**

Sometimes abbreviated as DE. This is one of the optimization methods based on meta-heuristics. It simulates an evolution system of living things (genes), in which multiple solution candidates interact with each other through mutation and crossover and generates a new solution candidate in the process to search for an optimum solution. The differential between solutions is used in mutation, hence it is called "differential evolution." It allows a solution close to the an optimal one to be found quickly for various types of nonlinear optimization problems.

***7: PID control**

A type of feedback control utilized for temperature control. In order to promptly bring the process variable (PV) closer to the set variable (SV), manipulative value (MV) is adjusted based on the deviation, or the difference between the PV and SV. The MV is determined by combination of the proportional (P) operation, which varies the MV proportional to the current deviation; integral (I) operation, which varies the MV based on the cumulative value of the past deviations; and differential (D) operation, which varies the MV based on the rate of change of the deviation.

proving the existing intrusion detection and defense technologies.

As a security measure for control systems, activities for compliance with the IEC 62443 and construction of a cyber security management system (CSMS) have been carried out up to now. International standardization activities are conducted with a focus on those standards for the IoT security measures and guidelines have been formulated.

Fuji Electric has participated in the Control System Security Center (CSSC[5]), Research & Development Partnership and a corporation approved by the Minister of Economy, Trade and Industry, since its foundation. We have engaged in the construction of security measures as industry-government-academia collaboration in various fields including research and development relating to cyber security, international standardization, public awareness and human resource development.

3.6 Solutions

(1) Cloud-based comprehensive equipment management service

We developed a cloud-based comprehensive equipment management system for life cycle management of customer equipment based on the IoT concept in Fig. 2 and started providing the service in 2015. This service is a cloud service integrating the EMS service, operation monitoring service and maintenance service. Various types of information, such as equipment operating conditions, maintenance and inspection records, energy usage conditions and environmental conditions, are collected in a life cycle from introduction to replacement (disposal) of equipment. They are then used as the basis for diagnosis and optimization by CPS engines to achieve comprehensive management of the equipment conditions (energy efficiency, signs of failures and problems, equipment deterioration). In addition, production efficiency is maximized by having yield improvement, quality control, and determination of manufacturing condition (see Fig. 5).

(2) Approach to logistics solution

Recently, logistics services have become sophisticated as exemplified by online shops' same-day delivery and just-in-time service, which has increased the dependence on vehicle transportation. There are different types of logistics centers such as distribution centers (DCs) and transfer centers (TCs). For DCs, vehicle operation and other operation ef-

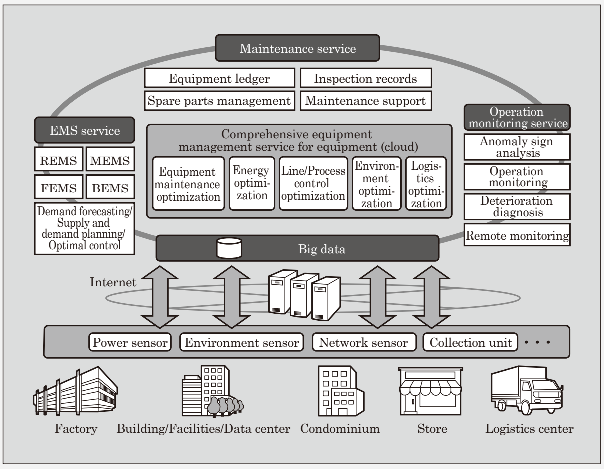


Fig.5 Cloud-based comprehensive equipment management service

ficiency improvement package products are already available from various companies. However, for TCs, which are currently becoming the mainstream, conditions such as transportation time constraints and avoidance of congestion in surrounding areas are so complicated that operating the business by using existing efficiency improvement package products is extremely difficult. For this reason, the reality is that operation and control depend on experienced individuals. Fuji Electric has developed a system for optimizing vehicle guidance in a center mainly for large TCs to propose a solution for improving the dependence on experienced individuals. It lays out the most suitable sensors for individual applications and installation environments to collect information such as locations and routes about vehicles, loads and workers and to use CPS engines for quantity forecasting. In the future, we intend to migrate the system into a cloud environment to make proposals to small- and medium-scale logistics centers (refer to "Solution for Improving Efficiency in Distribution Centers" on page 154).

(3) Approach to plant factory solution

The enforcement of the amended Agricultural Land Act has significantly relaxed the conditions for corporations' entry into agriculture, and as a result many players are joining this field from other categories of business. In particular, new entries into the plant factory*8 business, which allows year-round production, are increasing. Tomatoh Farm Co., Ltd., co-funded by Fuji Electric, was selected as a "Supportive Project for Accelerating the Introduction of Next-generation Greenhouse

***8: Plant factory**

A plant factory is a system producing plants systematically in a closed or semi-closed space with controlled internal environment. There are 2 types. One is the complete artificial lighting type, which controls the environment in a closed space such as inside a building without using sunlight for year-round planned production. The other is the sunlight use type, which basically uses the sunlight in a greenhouse or other semi-closed environment for year-round planned production with supplemental lighting in rainy or cloudy weather or air conditioning during summer.

Horticulture" of the Ministry of Agriculture, Forestry and Fisheries and it started strawberry production in 2014. Fuji Electric has introduced a system that accurately forecasts the yields and the occurrence of cultivation failure from production process data, and then Fuji is working on improving profit, which is a universal challenge for plant factory. This forecasting system uses environmental, farm work and other data input for forecasting based on machine learning. This eliminates the need for prior experiments and mathematization, allowing forecasting operations to be started promptly. In strawberry cultivation, which requires short-period yield forecasting in units of one day, some positive results have already been achieved such as the reduction of an error margin of daily yield forecasting under certain conditions to within ±15% (refer to "Plant Factory Solution with Instrumentation and Control Technology" on page 160).

(4) Approach to solutions to optimize plant operation

Fuji Electric has provided solutions that apply instrumentation and control technology to the fields of steel, chemicals, oil and gas pipelines, incineration and other plants and equipment. Recently, we have been not only proposing solutions that employ new techniques for stable operation, productivity and quality improvement and energy cost reduction but also working on solutions so that experience and skills can be handed on to others.

In steel plants, a drive master controller (DMC) and "f(s)NISDAS" provide a system that collects data on drive and motor statuses from a high-speed drive control system via a network for analysis with an accuracy of msec. They contribute to stable operation and quality improvement.

In chemical and other continuous process plants, we have proposed a plant simulator*9 as an experience and skill succession solution and developed a "navigation function," in which the HMI system guides an operator to the failure cause screen, instead of skilled workers. In addition, we are working on an "operation support system," which helps workers to avoid malfunction by automatically detecting signs of malfunction in processes from big data including plant operation information and operation history and by automatically generating the optimum operation guidance (refer to "Operation Optimization Solutions for Steel Plants" on page 141 and "Instrumentation and Control System Solutions for Optimizing Plant Operation" on page 149).

(5) Approach to equipment maintenance

For long-term and stable operation of production equipment and utility equipment that are becoming increasingly sophisticated, maintenance activities are gaining importance. Fuji Electric has aggregated various services spanning an entire life cycle of equipment into the cloud-based comprehensive equipment management service, of which the equipment maintenance service is deployed in a cloud. The equipment maintenance service provides support with smooth running of the PDCA cycle of a series of maintenance activities (maintenance planning, equipment deterioration prevention, diagnosis and restoration activities) across a life cycle from the introduction to replacement of equipment. Equipment diagnoses by using IoT-enabled sensors such as rotating machine vibration diagnosis, UPS storage battery deterioration diagnosis and operation monitoring of servers, networks and controllers are also provided. Furthermore, not only edge devices to collect field information for plant control systems, but also operation support and learning support via wearable devices are provided (refer to "Service Solutions to Support the Stable Operation of Equipment" on page 165).

(6) Boiler combustion solution

The boiler combustion solution is an advanced control solution provided by Fuji Electric. It improves the combustion efficiency by adding a software package to existing boiler control device and achieves a reduction of approximately 1% in the boiler fuel cost.

Efficiency improvement of boiler equipment has now come close to the limit with mechanical methods. This software package developed by taking a totally new approach has made it possible to achieve further efficiency improvement.

A boiler generates steam and hot water using thermal energy resulting from the combustion of fuel and air. If the amount of air injected is too large, the excess not used for combustion is discharged, which generates thermal loss. Fuji Electric has developed a technology to control combustion with the amount of air reduced to the minimum (ultra-lean air) while suppressing the amount of carbon monoxide (CO) generated, a gas which adversely affects the environment. In this way, we have successfully minimized the thermal loss of boiler combustion for the first time in the world. To this technology, the proprietary optimum combustion software and control logic and a laser CO analyzer capable of high-speed measurement have been

***9: Plant simulator**

The behaviors of equipment and machines to be controlled are modeled individually for simulations, and these models are then combined according to the actual plant to construct a virtual plant on a PC. This allows to simulate the behavior of a plant in various conditions, which is applicable to functional test or operator training in an office.

applied (refer to “Boiler Combustion Solution for Reducing Fuel Costs” on page 170).

4. Future Outlook

4.1 Development into ecosystems

Fuji Electric has demonstrated its strengths in the field based on its instrumentation and control technology. The cloud-based comprehensive equipment management service is a vertical solution system that combines Fuji Electric’s strengths in the field with the IoT. Meanwhile, the ecosystem movement is becoming active around the world. It is intended to link the strengths of one’s own company with those of other companies to create totally new customer value. We will constantly watch such trends and work on creating new customer values including distinctive sensors and the latest IT-enabled vending machines as the start (see Fig. 6).

4.2 IoT platform

Up to now, this paper has described data collection technology and CPS engines as a platform suited for the IoT age in the respective field. Whether as a vertically integrated system or an ecosystem, customer value is often unclear at first. In order to materialize customer value earlier, it is necessary to more easily and quickly repeat the cycle of planning a hypothesis, performing verification and evaluation, and revising the hypothesis. To that end, we will seek to strengthen an IoT platform that allows small start and quick start[*10] and can be improved gradually. Specifically, we will work on the following technologies.

(a) Technology for simple system construction from a small scale
(b) Modularization of services and their conversion into assets and menu enhancement development
(c) Technology for linking data and services in a cloud

4.3 CPS engines

Fuji Electric has been developing distinctive CPS engines as its core technologies. In the future, we plan to systematize and enhance CPS engines in order to create new customer value. In addition, to develop our business by making use of CPS engines, we intend to also focus on education and reinforcement of CPS engine user-engineers.

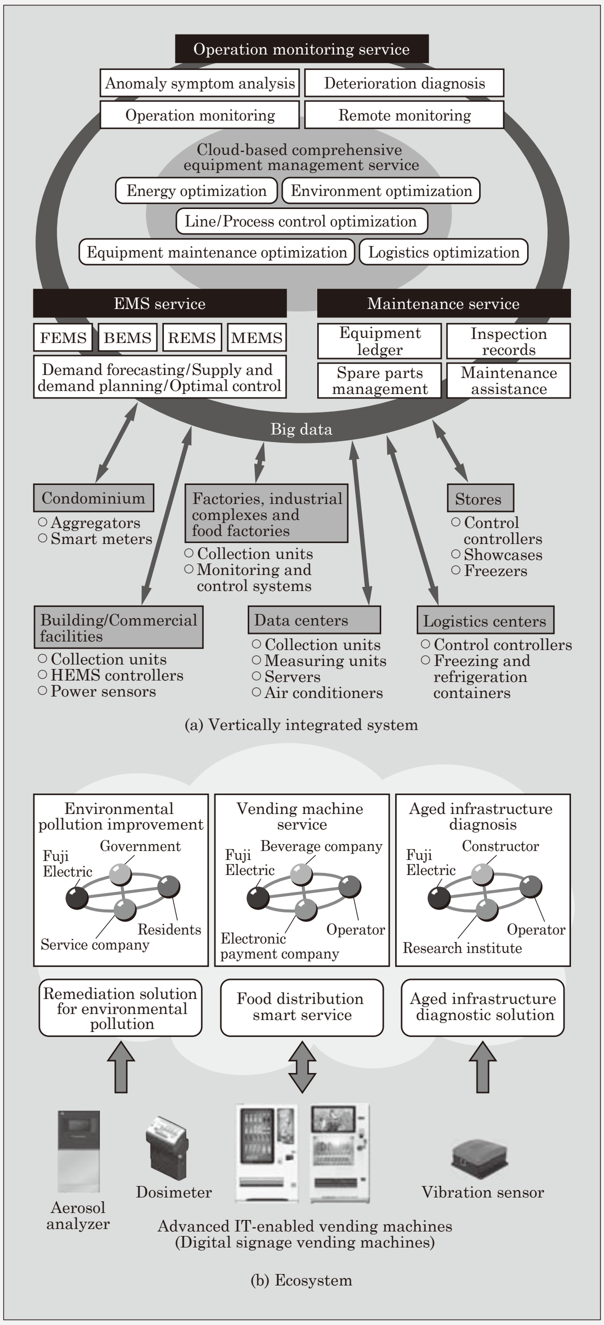


Fig.6 Vertically integrated system and ecosystem

4.4 Strengthening of edge controllers

As systems and services that utilize the IoT become increasingly diversified, the field data collected become larger in volume and more diverse, which leads to increased communication traffic and costs and degradation of real-time response. To resolve these issues, it is becoming increasingly important to divide functions between the field and cyberspace.

***10: Small start and quick start**

It means to select a local area where effect or value is expected in a confident manner (small start) and to develop applications by taking a full advantage of proprietary IoT products with many installation records to verify the effect or value in a short period of time (quick start).

Fuji Electric has its focus on the strengthening of edge controllers for industrial use as high-functionality gateways. Edge controllers are required to have data processing (collection, processing and storage) capabilities and communication protocols with various field devices as basic functions. The function of running CPS engines in real time such as model forecasting control and optimization is also required. These are positioned as applications that can be newly created and updated and engineering support functions are required at the same time. Fuji Electric's edge controller is based on following 3 core technologies: technology utilizing open ICTs, including general purpose microprocessor, real-time OS, general purpose OS (Linux etc.) and embedded security, real-time control technology cultivated through programmable controller development, and engineering supporting technology. Furthermore, we will rise to the challenges including cost, high environmental tolerance, high reliability and high speed required for field devices.

5. Postscript

This paper has presented the current status of and future outlook for Fuji Electric's instrumentation and control solutions in view of the global trends of the IoT.

We intend to continue to expand and enhance the instrumentation and control technology at the core of Fuji Electric's industrial solutions and work for creating new customer value by both vertically integrated systems and ecosystems through the IoT.

References

(1) Kondo, S. et al. Instrumentation and Control Technologies Supporting Solutions: Current Status and Future Outlook. FUJI ELECTRIC REVIEW. 2014, vol.60, no.1, p.4-9.

(2) Germany Trade & Invest. "GTAI-Smart Solutions for a changing world". High-Tech Strategy 2020 Action Plan. http://www.gtai.de/GTAI/Navigation/EN/Invest/Industries/Smarter-business/smart-solutionschanging-world,t=hightech-strategy-2020-action-plan,did=575914.html, (Date of access Sep. 14, 2016).

(3) Industrial Internet Consortium. "Industrial Internet Consortium". Industrial Internet Consortium official website. http://www.iiconsortium.org/, (Date of access Sep. 14, 2016).

(4) Cabinet Public Relations Office of Cabinet Secretariat. "Outline of Japan Revitalization Strategy-Revised in 2015". Prime Minister of Japan and His Cabinet. p.8-10, p.26. http://www.kantei.go.jp/jp/singi/keizaisaisei/pdf/dai1en.pdf, (Date of access Sep. 14, 2016).

(5) Control System Security Center (CSSC). "Backgrounds&objectives". Control System Security Center (CSSC). http://www.css-center.or.jp/en/aboutus/purpose.html, (Date of access Sep. 14, 2016).

Operation Optimization Solutions for Steel Plants

TOMITA, Yoshinori* YOSHIKAWA, Hajime* NARUMI, Katsunori*

ABSTRACT

The materials industry as represented by the steel industry is facing new challenges due to the diversification of customer needs. Operation optimization solutions for steel plants are one of the pillars of a Fuji Electric business model. We are providing solutions based on leading technologies that contribute to creating new value while solving the challenges of achieving stable and safe plant operations, product quality improvements, reduction in specific energy consumption and operation know-how transference, which are among the most important management indicators for corporations.

1. Introduction

New technologies such as the Internet of Things (IoT) and big data analysis have the potential to revolutionize the industrial structure and bring changes to the forms of business of companies. In addition, they may lead to creation of new demand and changes in the cost structure. They are also expected to create new business models in response to the need for further quality improvement that is required for stable and safe operations and after-sales services.

The steel industry has driven the entire industry technologically and economically as one of the representative material industries. It is now faced with new issues such as excessive supply due to a slowdown in economic growth in China, the biggest consumer, and diversification of customer needs for strength enhancement, weight reduction and cost cutting.

This paper presents the operation optimization solutions for steel plants, which Fuji Electric sees as one of the pillars of its business model. Among the most important management indicators for corporations, the focus is placed on stable and safe plant operations, product quality improvements, reduction in specific energy consumption and operation know-how transference and the respective approaches are described.

2. Approach to Stable and Safe Operations of Steel Plants

2.1 Background

Recently, the environment surrounding production equipment has been going through dizzying changes for reasons such as changes in the social and business environments, technological innovation and international standardization. Meanwhile, the importance of stable and safe plant operations is continually increasing. Against this background, Fuji Electric has been making efforts for various approaches contributing to stable and safe operations of plants including steel plants.

2.2 Examples of solutions

(1) Stabilization of operation of oxygen converter gas recovery system

The Linz-Donawitz converter gas (LDG) generated during blowing in a converter is a high-temperature combustible gas consisting primarily of CO and containing a large amount of dust. It poses the risk of explosion in the event of an air inflow as well as a hazard to humans and the risk of environmental pollution if it leaks, which makes it an important control point for stable operations. In addition, LDG is used as fuel for various types of equipment in a steelworks and improvement in its recovery rate is another important management indicator. Fuji Electric has been providing New Control of P0 (NCP0), which minimizes disturbances to keep the pressure at the converter mouth *P0* constant. However, measuring the CO and O_2 concentrations with the conventional sampling-type analyzer, which is used for NCP0, had a problem of recovery loss due to delayed response.

To deal with this problem, Fuji Electric has commercialized the world's first cross stack laser gas analyzer capable of measuring the concentrations of 2 components (CO and O_2) with a single unit. Fuji Electric is promoting its application to an oxygen converter gas recovery system (OG) as shown in Fig. 1. This gas analyzer features excellent response and maintainability and can measure the concentrations of CO and O_2 in LDG simultaneously and at a high speed. Also, the

* Industrial Infrastructure Business Group, Fuji Electric Co., Ltd.

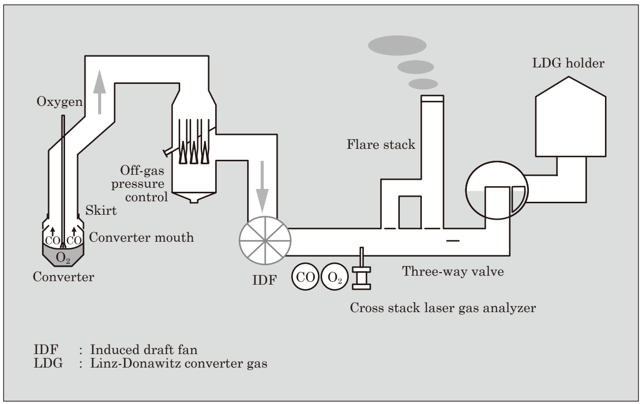


Fig.1 Oxygen converter gas recovery system

LDG recovery rate is significantly better than that of a conventional sampling-type analyzer. Furthermore, an energy center*1 also allows real-time monitoring of the concentrations of the CO and O_2 in LDG, which improves the accuracy of energy supply-demand forecasting for an entire steelworks.

(2) Stabilization of operation of heating furnace equipment

Recently, quantification of safety levels, safety design, safety approval and safety management have been progressing in line with the functional and machine safety standards that started in Europe. Activities have been promoted for ensuring safety for entire systems. In response, in Japan, the JIS B 8415 General safety code for industrial combustion furnaces was revised in November 2008. Fuji Electric has been strengthening its activities for safety to keep up with these trends.

Heating furnace equipment is used for heating material before processing billets and handles and consumes large quantities of fuel. Accordingly, the point is how to improve the combustion efficiency while preventing explosions and adverse effects on humans and environmental pollution due to leakage of toxic gas. The controller of Fuji Electric's information and control system "MICREX-NX" (see Fig. 2) has been approved for SIL3*2 and conforms to the JIS. In addition, it features the capability to accommodate both safety control and regular control in the same controller. This allows a safety circuit, which was conventionally built using hardware, to be realized using software for integration with high-functionality combustion control. This in turn allows the construction of a combustion safety system combining high combustion efficiency and safety with a compact system configuration.

(3) Equipment maintenance optimization with IoT

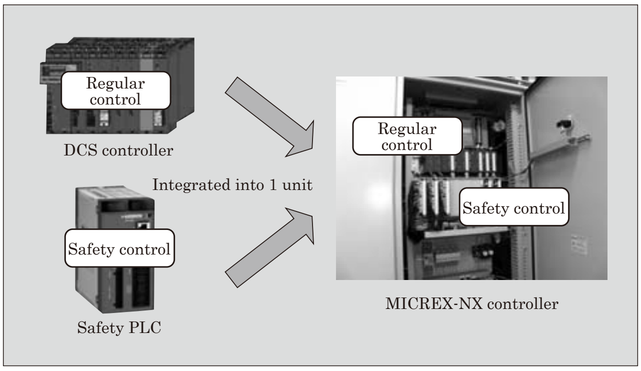


Fig.2 "MICREX-NX" controller

Maintenance of plant equipment and devices can be roughly classified into breakdown maintenance, which is repair after the occurrence of accidents or failures, and preventive maintenance, which is systematically conducted before the occurrence of accidents or failures. For stable and safe operations of plants, preventive maintenance is important. Preventive maintenance can be further classified into time-based maintenance (TBM), which is inspection and repair at regular intervals, and condition-based maintenance (CBM), which is repair and replacement based on the prediction of deterioration conditions and failure location and timing of equipment and devices. Up to now, TBM has been the mainstream but it has posed a challenge of achieving both a reduction in maintenance costs and prevention of accidents and failures. In addition, IT has recently made remarkable progress and equipment maintenance using the IoT is becoming widespread. Accordingly, Fuji Electric started cloud-based equipment maintenance services based on the technologies and track record it has achieved over many years (see Fig. 3). The services provide optimized maintenance by CBM that uses history data of equipment and devices and their analysis algorithm.

The cloud-based equipment maintenance services are a result of integrating operation monitoring, equipment diagnosis, abnormality sign analysis, equipment management support and maintenance work support. These were conventionally constructed with individual systems, but they have been merged into a common cloud environment. This can improve equipment capacity utilization and production efficiency, optimize maintenance plans, improve maintenance operation efficiency, systematize the maintenance know-how, ensure stable plant operation and minimize the life cycle cost. Furthermore, we are working on deterioration diagnosis and life expectancy prediction of drive devices such as motors and inverters, for which prediction of accidents and failures was difficult in the past (refer to "Service Solutions to Support the Stable Operation of Equipment" on page 165).

(4) Operation stabilization of high-speed drive control systems

Many electric motors are used in producing steel

*1: Energy center: Intended for centralized management of large amounts of various types of energy at a steelworks for integrated management of energy saving, labor saving, streamlining, environmental management, etc.

*2: SIL3: refer to "Supplemental explanation 1" on page 205.

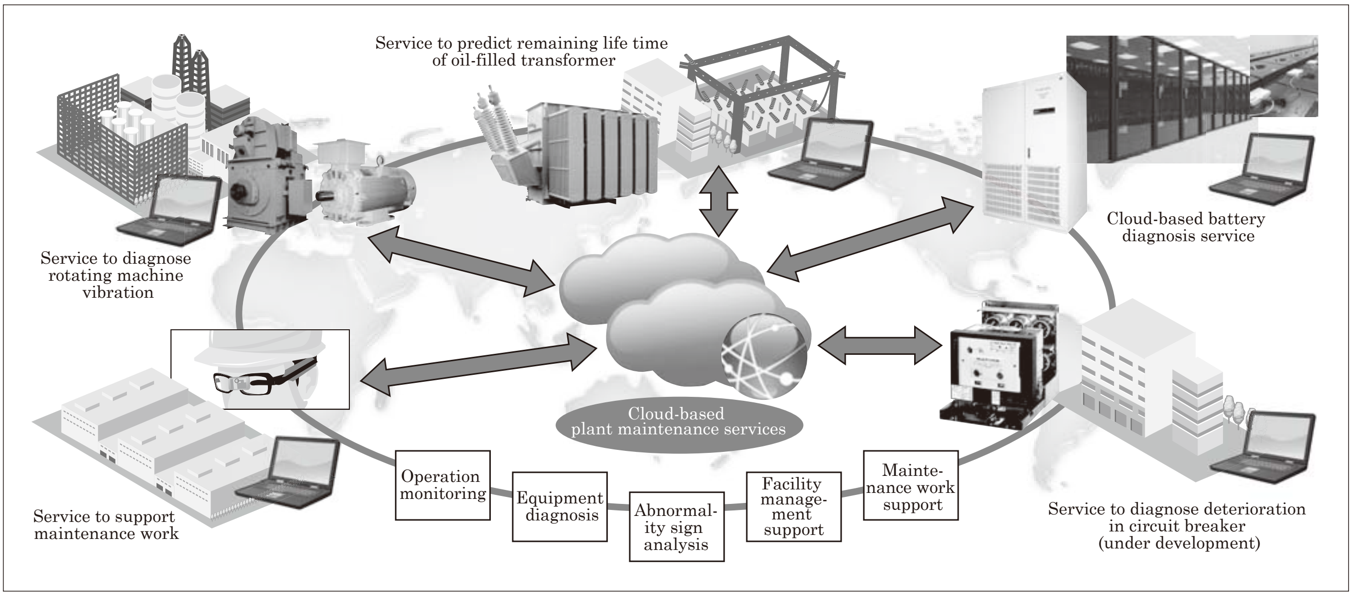


Fig.3 Cloud-based equipment maintenance services

products with shapes and characteristics suited for various applications. In particular, for rolling equipment, annealing equipment and surface treatment equipment for plating, coating, etc., tens to hundreds of electric motors are controlled at high speed and with high precision. Fuji Electric provides these various high-speed drive control systems to help stabilize operations.

Figure 4 shows an example of the configuration of a high-speed drive control system. A drive master controller (DMC) is a controller capable not only of high-speed control of up to 64 drives but also of continuously monitoring the statuses of the drives and electric motors. Connecting a DMC with a maintenance PC via a network allows constant remote monitoring.

The "f(s)NISDAS" and process data collection system (PDCS) are systems used to collect plant operation data. The f(s)NISDAS is connected with a programmable logic controller (PLC) and DMC, which are controllers, via a high-speed network. It can chronologically record plant control information at a high speed and is a useful tool for analyzing device malfunctions and control failures. Meanwhile, the PDCS is a package that records plant operation data for production control and quality assurance for each production lot. Data can be collected for realizing product traceability and stabilizing operations by comparing production instructions and results with operation data to record what took place in which process of the product manufactured.

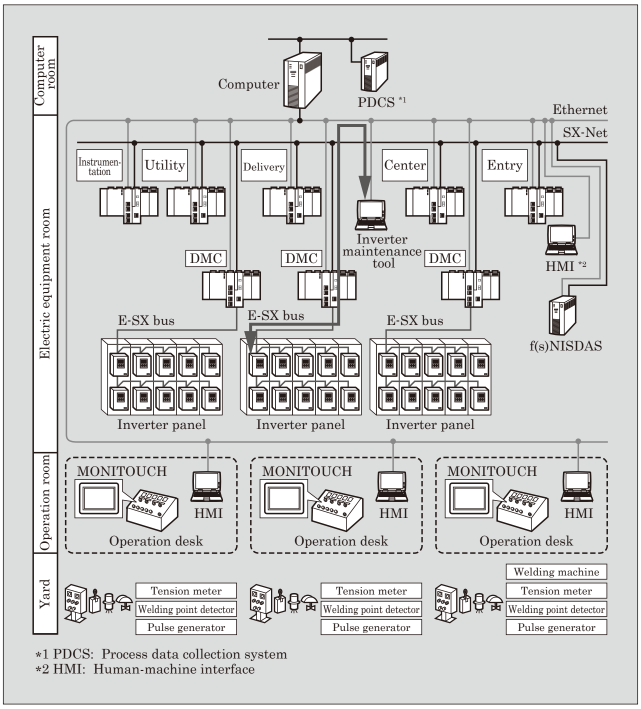


Fig.4 Example of configuration of high-speed drive control system

3. Approach to Product Quality Improvement

3.1 Background

Quality degradation may lead to situations that have a decisive impact on the performance of a company. Recent products are manufactured by using more advanced and complicated technologies than before and ensuring quality across all manufacturing processes is an essential issue in the manufacturing industry.

Accordingly, in order to ensure the quality of each process, it is necessary to acquire quality information, identify and analyze problems and predict and track quality for feeding the results back to the manufacturing processes. A quality improvement cycle from the acquisition of information to feedback can utilize quality data analysis and quality prediction(1).

3.2 Examples of solutions

(1) Quality data analysis

A processing line, which is one of the steel manufacturing processes, includes equipment for various types of processing of coils*3 such as annealing and galvanizing. By welding the trailing end of one coil with the leading end of the next coil, multiple coils are continuously processed at a high speed (over 100 to 1,000 m/min). During coil processing, data are received from many sensors at regular cycles (1 to 10 s). They correspond to certain positions on certain coils and correspondences are indicated in the form of a mesh along the longitudinal direction of coils. Such data are used as the quality data (mesh data). Mesh data were conventionally created manually, though was very cumbersome and prone to many errors.

Fuji Electric provides a PDCS that analyzes the manufacturing and quality information of a processing line and automatically creates mesh data with a resolution of 10 m. It allows not only easy new installation but also simple introduction into existing equipment. Figure 5 shows a functional configuration and the following explains the main features of the PDCS.

(a) Setting registration support function

To make it easier to register equipment information such as the type of quality data to be collected and sensor positions, template Excel*4 sheets are prepared.

(b) Elongation correction function

Coils may be elongated by applying tension to correct any coil distortion or warp, causing discrepancies in the position information of the quality data. To deal with this problem, the percentage of elongation specified for the tension applied is used for correcting the position information of the quality data.

(c) Mesh data graph display and Excel output

Relations between and trends of quality data of different types can be grasped for the individual positions on coils by displaying a graph of the mesh data collected. Items can be specified for Excel output, which allows arbitrary analysis.

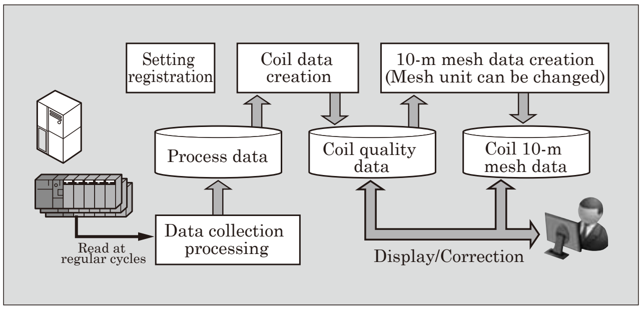


Fig.5 Functional configuration of PDCS

By introducing the PDCS, data between different units of equipment can be automatically collected in real time for each coil. This allows prompt cause investigation and feedback to operations when any abnormality is found in quality. In addition, data can be extracted and analyzed with various conditions such as for each steel grade, which allows easy tuning of operation parameters (annealing and other parameters) when a new plant is launched or when production of a new product is started.

(2) Quality prediction (quality meter for manufacturing lines)

If quality can be predicted based on the current operation data, it significantly contributes to stabilizing quality.

The quality meter for manufacturing lines is a system that is capable of visualizing and predicting the quality state by online quality analysis in a processing line. Figure 6 shows a functional configuration.

(a) Function overview

From the past operation result data, factors are automatically extracted that have close cause-and-effect relationships with the quality to be measured, and they are used as the basis for building a plant model.

By providing this plant model with new operation result data, primary factors that may adversely affect the quality during manufacturing can be extracted and the rate of occurrence of events such as failures can be predicted.

(b) System features

(i) Automatic following of changes in equipment and operation

For quality analysis using a normal plant model, coefficients, etc. need to be revised

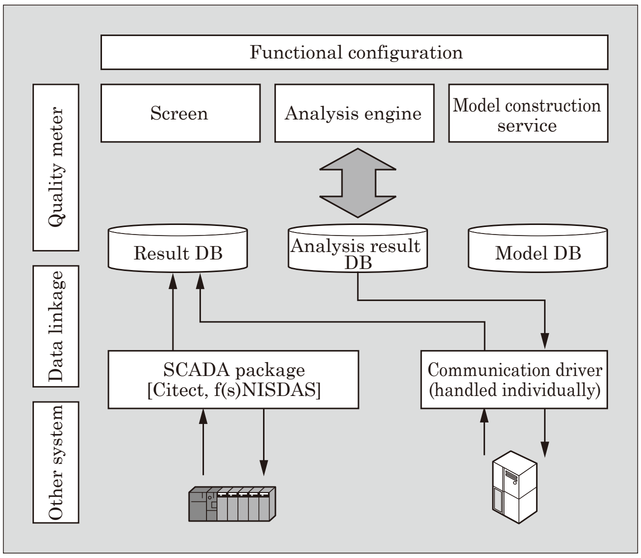


Fig.6 Functional configuration of quality meter for manufacturing lines

---

*3: Coil: Sheet steel rolled thin and wound into circles

*4: Excel: Trademark or registered trademark of Microsoft Corporation

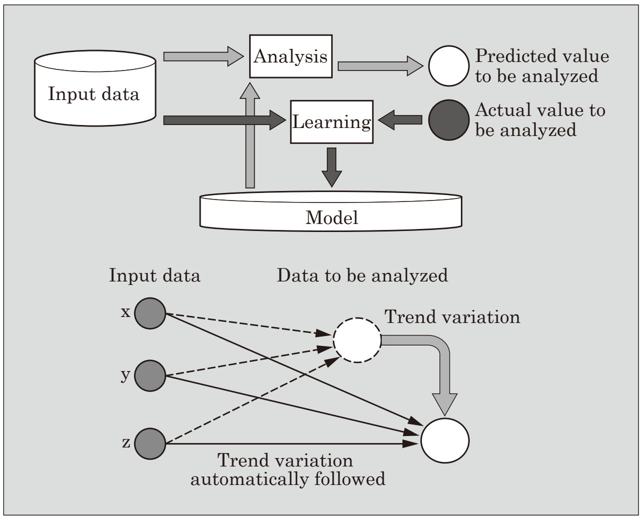


Fig.7 Concept of quality prediction model by Bayesian multivariate analysis technique

according to changes in equipment and operation. This system is equipped with a model reconstruction function based on learning function. It is also capable of analysis with an up-to-the-minute prediction model by constantly following changes in the equipment and operation. Figure 7 shows the concept of a quality prediction model that uses a Bayesian multivariate analysis technique.

(ii) Visualization of analysis results

The cause-and-effect relationships between analysis results or data to be analyzed and input data can be graphically displayed and the screen can be customized according to the characteristics of the data to be analyzed.

4. Approach to Reduction in Specific Energy Consumption (Demonstration in India)

4.1 Background

Energy consumption of the Japanese steel industry accounts for as much as 13% of all energy consumed domestically and almost all steelworks have an energy center intended for saving energy by optimally utilizing it. As a result, the specific energy consumption in the Japanese steel industry is far lower than overseas[(2)]. In addition, overseas steelworks do not implement energy-saving operation by optimum operation of energy for all related equipment but only energy management for the individual units of equipment such as power generation equipment. As international energy saving and environmental measures are expected to progress, in India, among others, energy saving in the respective industrial sectors has been promoted by the Energy Conservation Act enforced in 2001.

4.2 Examples of solutions

In the "Demonstration Project of Technology/System for International Energy Consumption Efficiency etc.," a demonstration project supported by the New Energy and Industrial Technology Development Organization (NEDO), Fuji Electric has provided India with the energy center optimum control technology, which is Japan's leading-edge technology, as a steel EMS solution, to work on the grasping of energy conditions of an entire steelworks and overall optimization of energy demand and supply.

After demonstrating through this project the effect of various systems as measures contributing to future diffusion, we intend to work for diffusion of the energy center optimum control technology in steelworks in India. Figure 8 shows the system configuration in the demonstration project. With the aim of achieving a reduction of energy consumption of 25,400 kL/year in terms of heavy oil and a reduction of greenhouse gas emissions of 71,400 t-CO_2/year (approximately 11% reduction annually respectively), we will apply, of the energy center optimization control technologies, the following 5 major functions to steelworks in India.

(1) Optimum operation technology for power generation equipment

Based on the prediction of generation and usage of various types of energy such as electric power and heavy oil and by-product gas delivery from a gas holder, optimum operation plans in view of the equipment capacity of multiple generators are made for effective use of the by-product gases and maximization of the electric power output.

(2) Optimum operation technology for oxygen equipment

Based on the prediction of oxygen usage, optimum oxygen generation plans for multiple oxygen plants are formulated. This minimizes the electric power energy consumption to reduce the excess oxygen emission rate.

(3) Optimum operation technology for gas holder equipment

Energy-saving operation is realized by minimizing the emission rate of the excess by-product gases and variation of the amount of its delivery from the gas holder.

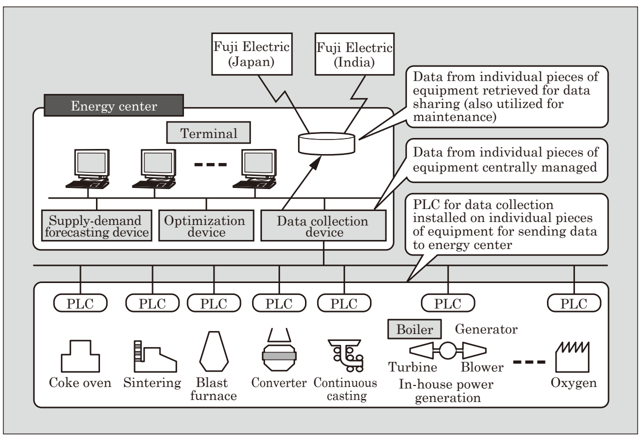


Fig.8 System configuration in demonstration project

(4) Overall optimum operation technology for crude steel production and energy usage

Based on the generation and usage prediction of various types of energy, the energy demand of the plant is met while the crude steel production is maintained and daily and monthly optimum allocation plans are made for the respective types of energy including electric power, by-product gases and steam. This minimizes the energy consumption and greenhouse gas emissions.

(5) Technology for visualizing potential energy savings linked with production plans

By applying our proprietary mathematical modeling technology, how much energy saving is possible for the equipment capacity is analyzed in advance to visualize potential energy savings as compared with the current energy operation (refer to "Mathematical Application Technology for IoT Solutions" on page 198).

5. Approach to Operation Know-How Transference

5.1 Background

Fuji Electric has delivered many monitoring and control systems for steel plants. Many of them have been installed for over 15 years after the delivery and are ready for replacement. For replacement of an existing system, inheritance of the operability and maintainability of the existing model on the latest technical platform and incorporation of the operation know-how into the system provide significant benefits to customers. There are issues including decrease of trained technicians in Japan and prompt development of local engineers required by expansion of local production for local consumption outside Japan and there is a growing need for strengthening of the on-site capabilities by skill succession.

5.2 Examples of solutions

(1) Inheritance of operability and engineerability

The amount of capital investment has been decreasing in recent years and, for gradual replacement of customer assets while keeping the costs low, replacement on the individual layers of a control system (operator station, control network, controller and I/O) in order is required. The latest monitoring and control system "MICREX-VieW XX" released in 2014 is based on concepts including effective utilization of existing assets (refer to "Evolving of Monitoring and Control System 'MICREX-VieW XX (Double X)'" on page 186). It is designed to allow, in a replacement project, migration into a new system while inheriting the operability and engineerability with which the customer is familiar (see Fig. 9). For that purpose, MICREX-VieW XX provides the following functions.

(a) Inheritance of application assets of existing system

The operability and maintainability are inherited by applying (converting) the monitoring screens and controller applications of the existing model to use as applications of the new system.

(b) Connection with existing system network

Gradual replacement can be achieved by connecting the new system with the control network of the existing model to allow monitoring and control.

(2) Abnormality sign detection and avoidance proce-

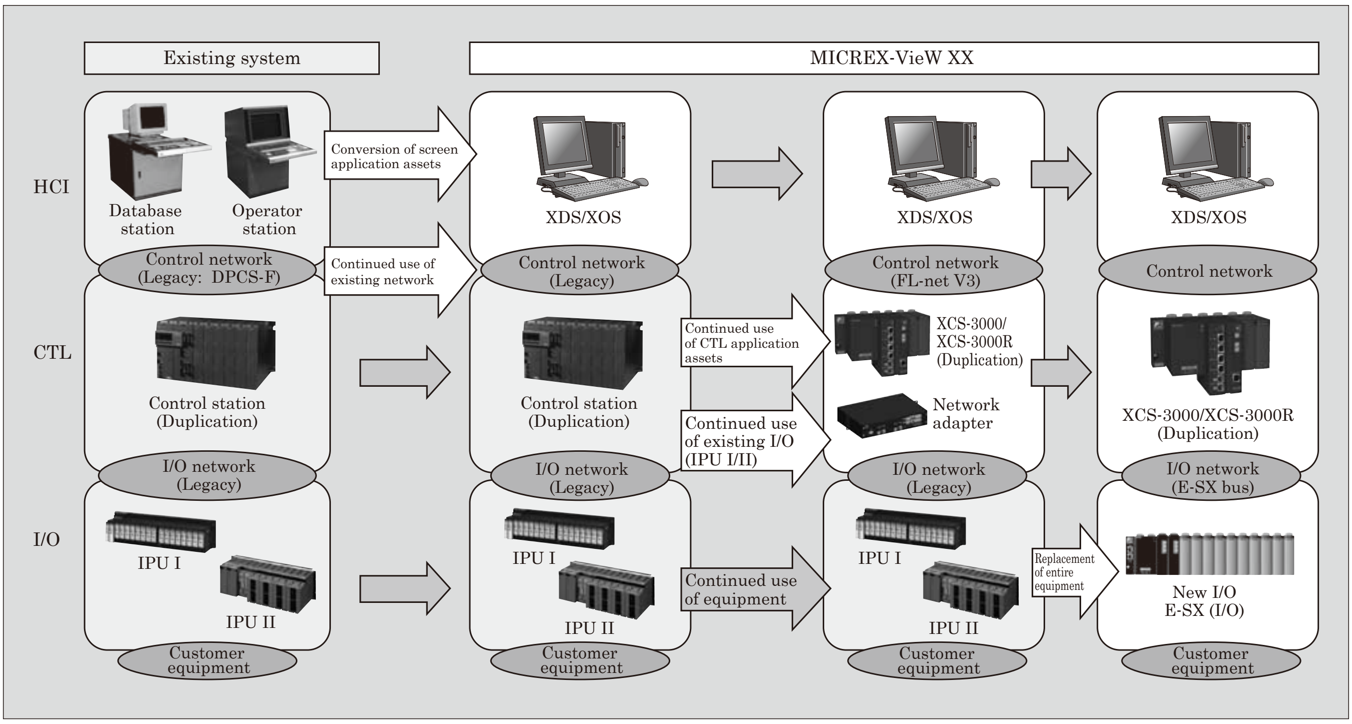


Fig.9 Gradual replacement by MICREX-VieW XX

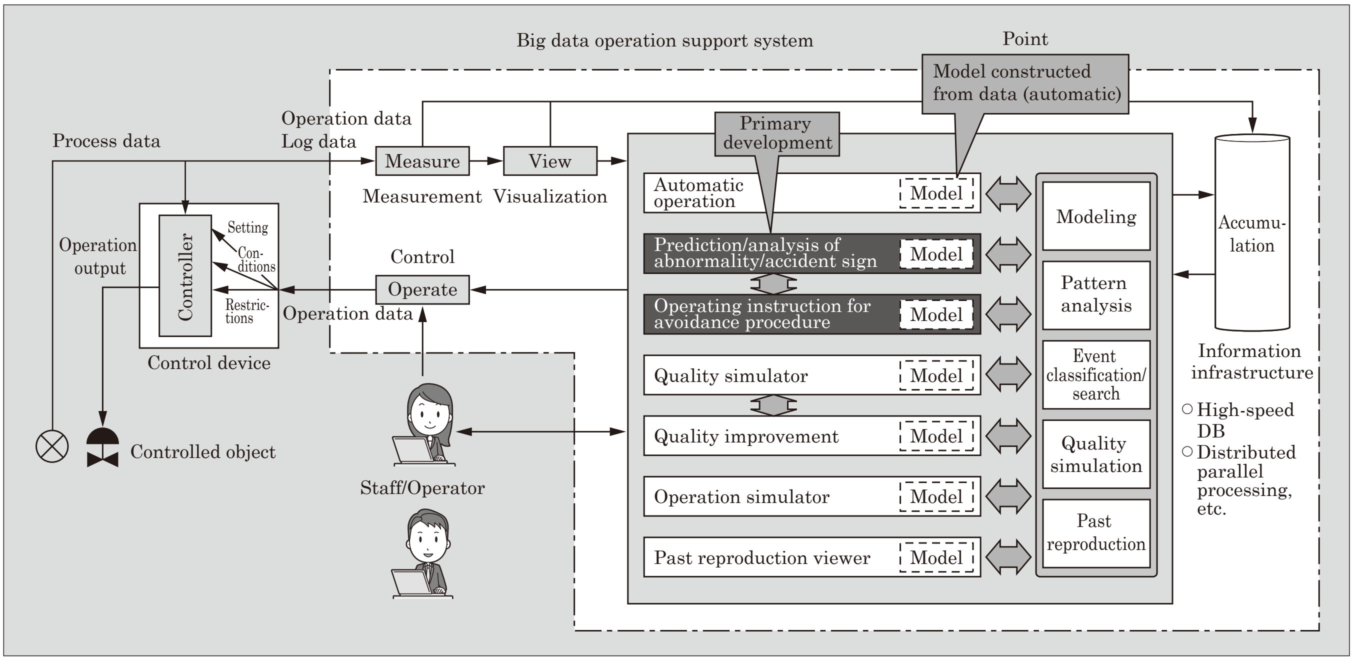


Fig. 10 Overview of operation support system

dure instruction for heating furnace

One of the biggest issues for customers is a shortage of skilled operators. For example, direct checking on the combustion conditions in a heating furnace is difficult and the statuses of various sensors are checked on the monitoring screen during operation. However, the combustion conditions may vary between individual burners because of the effect of the burners themselves and fuel piping. For this reason, incomplete combustion may occur even if the operation looks stable on the screen. For preventing abnormalities like this, in many cases, skilled operators with various types of know-how in relation to operation judge the conditions and take necessary measures. However, aging of skilled operators is progressing, which poses an issue of know-how transference for non-steady-state or emergency operation such as detecting signs of abnormalities in advance to implement avoidance operation.

Over many years of operation, a variety of data (big data) including operation data and operation and alarm logs are accumulated by control and other devices. Fuji Electric makes use of these big data to work on the development of an operation support system (see Fig. 10). This system itself automatically learns adjustment of the fuel flow rate and operation for avoiding abnormalities and facilitates stable operation without depending on operators' experience. Models created from process data of steady-state operation and operation history of operators are compared with the behavior of process data and operation by operators before and after the occurrence of an abnormality. In this way, it analyzes what types of abnormalities can occur along with the changes in the process data and notifies operators of them before actual abnormalities occur, thereby securing a time for abnormality avoidance operation. In addition, it presents the abnormality avoidance operation implemented in the past to allow the plant to be maintained in safe conditions without depending on workers' skills.

(3) Maintenance know-how transference

As with operation, maintenance also has an essential issue of know-how transference. Fuji Electric provides a system of giving support and guidance to workers by connecting in real time the glasses-type wearable device (equipped with a camera and small monitor) worn by an on-site worker with the base in a remote location where a skilled engineer is via the

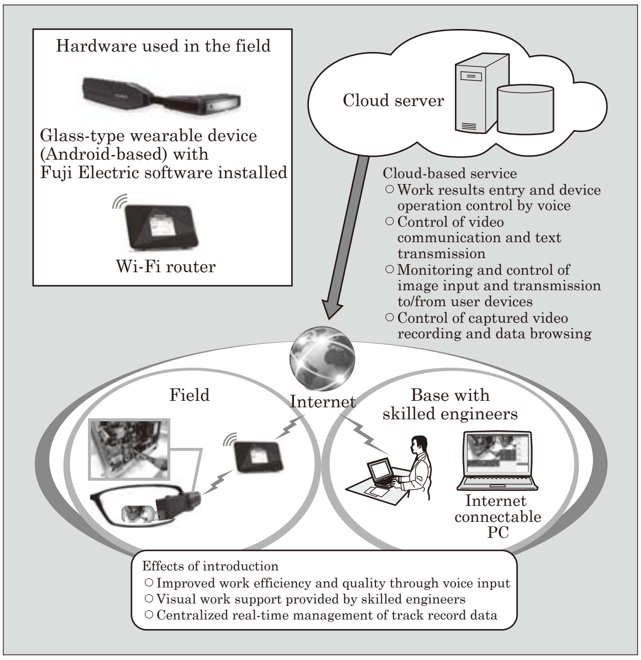


Fig.11 Wearable remote operation support package

Internet (see Fig. 11). The skilled engineer can give work instructions by images and voice while sharing the conditions with the on-site worker through the glasses-type wearable device and the hands-free operation allows the on-site worker to use both hands to work. This contributes to improvement of work quality and efficiency and skill succession (refer to “Service Solutions to Support the Stable Operation of Equipment” on page 165).

6. Postscript

This paper has described operation optimization solutions for steel plants by presenting the current approaches with the focus on stable and safe plant operations, product quality improvements, reduction in specific energy consumption and operation know-how transference. In order to meet the needs that are becoming increasingly sophisticated and complicated, further functional enhancement is required of instrumentation and control systems. For continuing to meet the needs of users, we are committed to making contributions to further added value creation.

References

(1) Shobayashi, N. et al. Instrumentation and Control System Solutions to Support Stable Operation, Energy Efficiency and Environmental Conservation. FUJI ELECTRIC REVIEW. 2014, vol.60, no.1, p.10-15.

(2) Narumi, K. et al. “Steel EMS Package” Optimizing Energy Management at Steelworks. FUJI ELECTRIC REVIEW. 2013, vol.59, no.3, p.165-169.

Instrumentation and Control System Solutions for Optimizing Plant Operation

YOSHIKAWA, Yuzuru* SHU, Kenun ⁑ ONO, Kenichi*

ABSTRACT

Required functionality of instrumentation and control systems has been changing depending on such environmental factors as the optimization of plant operation and generational change in operators. Up until now, these systems performed simple monitoring and control, but recent needs have required functionality capable of quickly responding to trouble and ensuring safe and stable operations. In order to meet these needs, Fuji Electric is providing navigation functions for quickly responding to plant abnormalities, functions for supporting enforced settings and simulation functions for training operators. We are also providing solutions that meet the needs of various business sectors, such as chemical plants, gas and oil pipelines and waste incineration plants.

1. Introduction

Fuji Electric's instrumentation equipment has about 60 years of history and our instrumentation and control systems have more than 40 years of history since 1975 when the first distributed control system (DCS) was launched on the market. Over these years, Fuji Electric has been providing various solutions in order to solve the issues and meet the requests of its customers.

This paper describes Fuji Electric's latest technologies of instrumentation and control systems for plants and the solutions it provides. The target plant facilities are those of chemical plants, gas and oil pipelines and waste incineration plants.

2. Circumstances Surrounding Instrumentation and Control Systems

For plant operation, investments in facility improvement and energy saving have been discussed and made, initially in order to improve production efficiency through automation, and recently in order to address and solve global and regional environmental issues. It is expected in the future that the proliferation of sensors with communication abilities will make it possible to collect information that could not be collected previously, leading to a reform in plant operation.

On the other hand, instrumentation and control systems have been requested to have more abilities for not only monitoring and control but also reliability, scalability and engineering functions for about 30 years since their introduction. Later, along with the development of information technology, the functionality of the entire system has been reinforced through the cooperation with external functions such as manufacturing execute systems (MESs) or product data management (PDM), in order to satisfy various requests from people ranging from top management to workers in the field. Unfortunately, in exchange for the convenience of carrying field data to the outside, security-related problems have arisen. These include unauthorized access from the outside, computer virus issues and the leakage of confidential information through careless data carrying using external media. Consequently, there are increasing needs for ensuring the soundness of instrumentation and control systems. From now on, investments in the Internet of Things (IoT) in instrumentation and control systems are expected to be increased to make efforts to optimize plant operations by means such as having continuous security measures, safe and stable operations and improvements aiming at higher productivity and quality.

3. Issues with and New Functions of Instrumentation and Control Systems

3.1 Issues with instrumentation and control systems

In a plant, the influence of an operation shutdown may spread over an extremely wide area. Therefore, safe and stable operation is the most important issue. Companies have been addressing and solving this issue by evolving their instrumentation and control systems. They have, however, not yet completely eliminated unexpected troubles and safety risks encountered in the field. Finding ways to address such unexpected troubles and safety risks is important to maintain safe and stable operations. Up until now, unexpected troubles have been addressed flexibly by

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

experienced engineers and operators who have know-how accumulated along with the development of DCS. An important issue from now on will be to reinforce the troubleshooting abilities and educating inexperienced engineers and operators. Furthermore, the period of engineering and commissioning tests for system replacement or plant launch, has become shorter, whereas the requirements for quality are becoming severer. Functions supporting these have also come to be required.

3.2 Functions addressing failures in plant operation

In recent years, sophisticated and complex operation control has been achieved through the use of instrumentation and control systems, which promotes automation and labor saving of plant operations. On the other hand, there are unsteady operations such as failures due to aging or wear of plant facilities or recovery work from the maintenance of part of a facility conducted during plant operation. As a result, it is essential to provide measures against alarms. There is another possibility of a secondary failure caused by a failed sensor. In case a failure occurs, it is necessary to immediately replace the sensors or take other measures to avoid a secondary failure. A delay in taking actions may lead to serious damage to plant operations. In conventional systems, the identification of the causes of alarms is mostly left to operators who have much experience and knowledge of past cases and the field, which has raised issues of dependency on individual skills and causes problems in further efforts to save labor.

To solve these issues, Fuji Electric's "MICREX-VieW XX (Double X)" small- and medium-scale monitoring and control system includes a navigation function and a forced setting function. They allow operators to address unsteady procedures occurring during operation by analyzing plant failures or by temporarily avoiding a failure more easily.

(1) Navigation function

The navigation function displays a list of relevant functions on the operation screen or engineering screen based on the actuator name used as a keyword. Previously, an operator autonomously moved to and displayed a relevant screen. This function lists only the screens related to the specified actuator, so that the operator can select one of them to go to a necessary screen easily (see Fig. 1).

Achieving the navigation function requires search information across systems (cross reference) for which data names or memory addresses are used as key data. MICREX-VieW XX generates a cross reference automatically from the data that a user entered on the supported utility screen of an engineering tool.

When an abnormality occurs, even an inexperienced operator can identify the cause of a failure or an alarm easily by using the navigation function. This ensures quick response to failures and thus minimizes

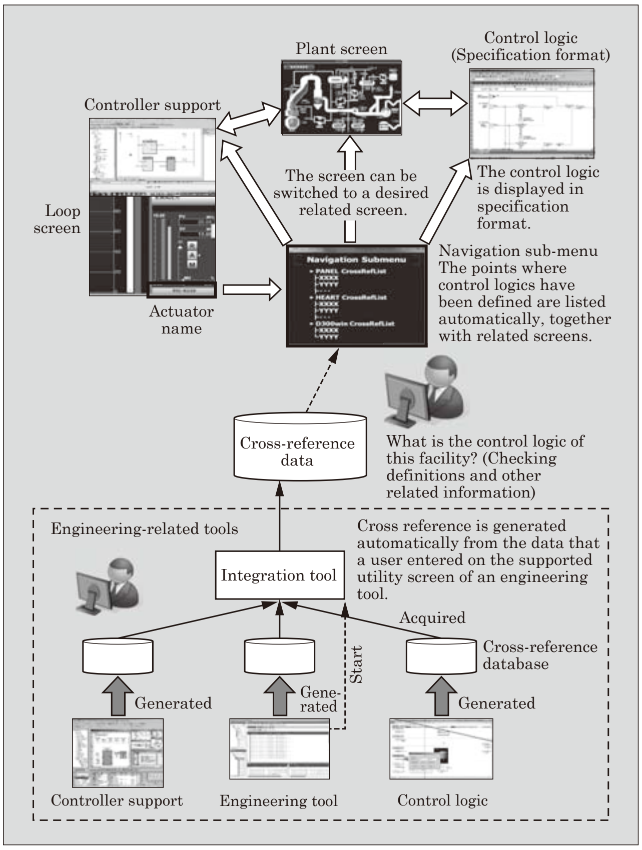


Fig.1 Navigation function

the influence on the plant.

(2) Forced setting function

The forced setting function is intended to temporarily avoid an abnormality from occurring during plant operation or to avoid a secondary failure. It forcefully blocks writing to the memory activated by the control logic that uses the value measured with an abnormally operating sensor and then continues opera-

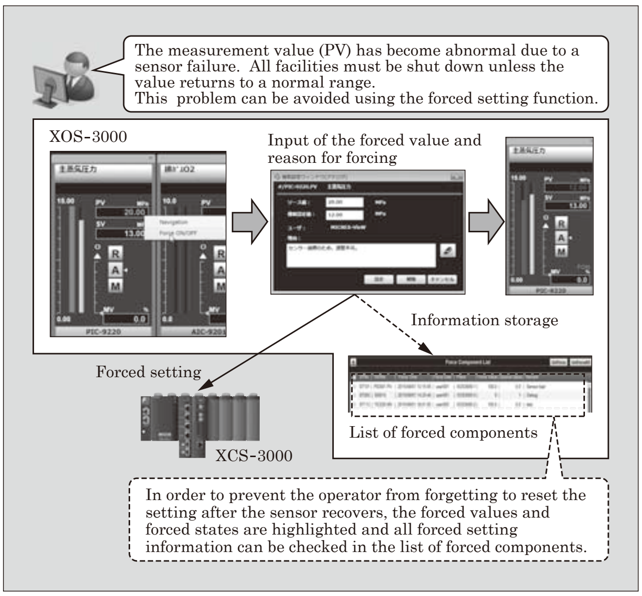


Fig.2 Forced setting function

tion by using a substitute value specified by the user (see Fig. 2). This allows the system to avoid a failed state temporarily without a need for changing the application software in case of sensor abnormality.

Moreover, the operation history stored in the database can be viewed online. In case an abnormality occurs in a plant, the operator can quickly determine the condition and identify the cause using the navigation function described above, and then the operator can use the forced setting function according to their judgment. This can avoid any unnecessary plant shutdown.

3.3 Advanced functions for plant operation optimization

As the competition among plant businesses is heating up, further improvement of productivity and quality has been demanded. For this purpose, all data concerning the life cycle of the plant should be put under unitary management with a database so that the relevant divisions can share them. For example, using these data in a plant simulator can improve the quality of an automatic control program before it is tested in an actual plant.

Fuji Electric provides the DCS "MICREX-NX." Furthermore, we first started providing the plant simulator SIMIT*[1] with the aim of offering the plant management tool COMOS*[2]. Figure 3 shows the digitalization and product lineup of plant engineering.

(1) Integrated data platform

In the life cycle of an entire plant, inadequate engineering and adjustment may lead to a decrease in quality and capacity utilization, resulting in serious negative effects on the cost and time required for the operation and maintenance of the plant.

A commissioning test, in particular, is an important task that may greatly affect the subsequent safe and stable operations of the plant. Most of the time required for it is taken for testing and adjusting the automatic control. Most software bugs found in this phase are made during the engineering period.

Moreover, once the plant starts actually operating, it is difficult to educate operators about unsteady state conditions. In the present circumstances, the operators are not sufficiently educated about the operations assuming plant accidents. Once the plant enters an unsteady state, the influence of insufficient education is great and seriously affects safe and stable operations. A measure to avoid such situation is to incorporate a simulation that replicates an actual plant as closely as possible into the system architecture in every process from specification determination to plant operation. This can significantly reduce unnecessary engineering costs and time.

Such a measure can be achieved by using an integrated data platform that performs unified management of the data related to engineering and operation of the plant.

(2) COMOS plant management tool

COMOS is a tool for having integrated management of all data related to a plant life cycle (such as electric and instrumentation facility, control flow, and facility and piping flow). It can seamlessly operate with MICREX-NX and SIMIT. It can thus provide a digital engineering solution that optimizes the life cycle of an entire plant from design to operation (see Fig. 3). Specifically, based on the data created with COMOS, a simulation model for SIMIT to be used with the control program of MICREX-NX can be generated automatically.

(3) SIMIT plant simulator

SIMIT is a tool that allows engineering through a simulation (see Fig. 4). The major functions are as follows:

(a) Controller simulation function
(b) I/O signal simulation function
(c) Modeling and simulation functions for I/O devices such as sensors, valves and motors
(d) Modeling and simulation functions for entire control targets such as a plant and machinery

Using SIMIT makes it possible to test and adjust the entire facility in a project under conditions similar

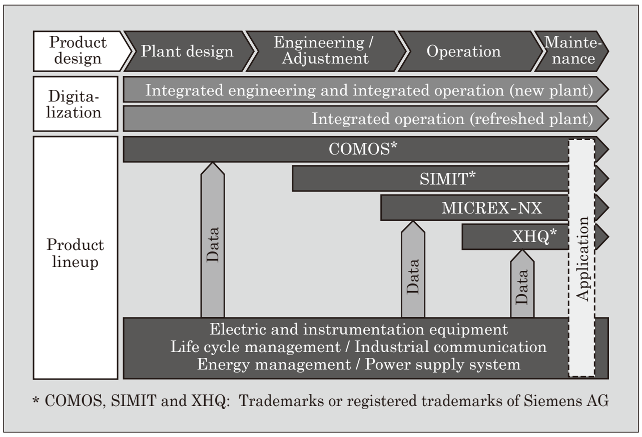


Fig.3 Digitalization and product lineup of plant engineering

*1, 2: COMOS and SIMIT: Trademarks or registered trademarks of Siemens AG

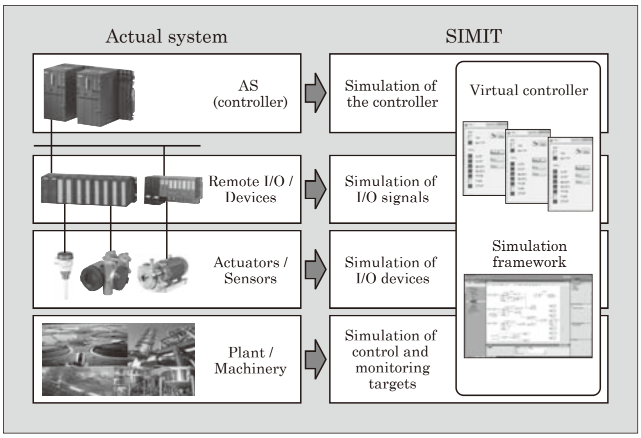


Fig.4 System image of SIMIT

to the actual plant as closely as possible in advance in an office. Therefore, the actual commissioning test can be completed within a shorter period without problems.

Moreover, when SIMIT is combined with a virtual controller (controller emulation tool of SIMIT), it can be used as a training system for operators. You can use the commands of SIMIT (initialize, start, stop, pause, snapshot, etc.) to check the operation in a simulation and then reproduce the process or adjust the simulation speed. By creating the behavior of a plant in an unsteady state on the simulator, this function can be used to educate operators about steps including emergency response.

4. Fuji Electric's Solutions in Various Plants and Facilities

In order to solve the issues of its customers, Fuji Electric provides the MICREX-VieW XX Small- and Medium-Scale Monitoring and Control System[(1)] as well as the MICREX-NX DCS. MICREX-VieW XX provides a function for data cooperation with external systems, as well as the functions of conventional distributed control systems including excellent visibility and operability, electric and instrumentation control integration, high speed and high reliability, highly efficient engineering and high inheritability, especially designed for small- and medium-scale plants. This allows cooperation with an advanced operational support and facility maintenance management system utilizing big data to ensure optimum plant operation (refer to "Evolving of Monitoring and Control System 'MICREX-VieW XX (Double X)'" on page 186).

Furthermore, the supervisory control and data acquisition (SCADA) functionality has been adopted to provide a system that can help to optimize operations depending on the facility scale or required functions of the customer.

4.1 Chemical plants

In the business sector of chemical plants, as the demands for system replacement increase, business operators have a greater awareness of the need for continuous energy saving. This leads to the optimum use of equipment based on predictive diagnosis of the facility or to the study of introducing safety instrumentation regarding facility safety. Investments leading to the IoT have also been sought.

As a mechanism leading to the IoT, Fuji Electric has developed a solution package for electric, instrumentation and computer (EIC) integration. In the chemical industry, a facility is normally divided into instrumentation control system and drive control system. The solution package for EIC integration has achieved monitoring and control of instrumentation and a drive on a single platform by utilizing Fuji Electric's component technologies and network technologies. This means it can also be applied to the field of drive control that requires high-speed control. As a result, time synchronization of field data can be assured easily between instrumentation control and drive control. In addition to the ability to build the foundation for collecting field data, which is important for the IoT, the integration of instrumentation and drive systems will streamline the data flow between facilities, which had conventionally required installation of hard wires or gateways to interface different systems. Furthermore, when the platforms are unified, a common contact person can handle engineering inquiries from customers, providing optimum solutions in consideration of the entire plant.

4.2 Gas and oil pipelines

For gas and oil pipelines, the operation requires central control to efficiently and accurately collect pieces of data to be monitored that have dispersed over a wide area. The requests from customers, however, for communication infrastructure used for data collection have been diversified and it is difficult to use a unified communication infrastructure or protocol to collect all data.

Fuji Electric supports various communication infrastructures by using SCADA such as "MICREX-VieW PARTNER" to collect data dispersed over a wide area (refer to "Equipment Monitoring System 'MICREX-VieW PARTNER' Easily Cooperating with Integrated EMS" on page 193). The demand for field data collection is expected to increase to invest in the IoT in the future. Consequently, we will provide optimum plant operations which transparently handle communication methods and media through a system that satisfies customer needs. Table 1 shows application examples.

4.3 Waste incineration plants

The operation in waste incineration plants has been increasingly outsourced to external entities under a package contract (operation management and maintenance management). Up until now, the data acquired during plant operation were only the data

Table 1 Application examples in sector of gas and oil pipelines

Facility	Communication method	Communication medium
Pipeline for fuel transportation	Tele-metering and tele-control (distance monitoring and control) with analog communication	Communications cable
Pipeline for natural gas transportation	Ethernet* communication	Preferred line of telecoms company, dedicated line for satellite communication (for backup)
City gas grid	Ethernet communication	Dedicated wireless network, dedicated line for telecoms company, Mobile Virtual Network Operator (MVNO)

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

required by municipalities. As the number of cases of package contract increases, it is expected that the external outsourcing entity will collectively collect and manage not only the data requested by municipalities but also the data required for efficient operation of individual waste incineration plants. This will promote the establishment of an IoT environment for optimum monitoring, analysis and operation.

As the first step toward centralized management, Fuji Electric has introduced an EIC integration system for achieving data cooperation between the headquarters mechanism of the outsourcing entity and the waste incineration plants. It also has established an environment for transmitting data to the headquarters mechanism through a public line. This has allowed the headquarters mechanism of the outsourcing entity to analyze the collected data and plan an optimum operation model.

5. Postscript

This paper reviewed the history of instrumentation and control systems and described the present issues being faced, the latest technologies of Fuji Electric and the solutions for respective sectors. Fuji Electric is determined to continue making contributions to optimum plant operations for its customers.

References

(1) Shobayashi, N. et al. Instrumentation and Control System Solutions to Support Stable Operation, Energy Efficiency and Environmental Conservation. FUJI ELECTRIC REVIEW. 2014, vol.60, no.1, p.10-15.

Solution for Improving Efficiency in Distribution Centers

TAKAKI, Hideki*

ABSTRACT

In recent years, distribution centers have become advanced in functionality and large scale in order to meet the needs of various distribution services such as just-in-time service. Meanwhile, distribution center work still relies heavily on manual labor, and thus, such centers are in need of a more efficient system adapted to the actual operation. For transfer centers which have struggled to improve efficiency by using the conventional system, Fuji Electric is providing a distribution solution based on the following 3 functions to eliminate dependence on individual operator skills and improve operation efficiency. The functions include a "transportation amount prediction function" for predicting the amount of transportation arriving and shipping at distribution centers, an "operation support function" for helping develop optimal plans, and a "vehicle guiding function" for completing transportation/delivery operations within time constraints.

1. Introduction

Along with the recent advancements in distribution services, such as same-day delivery at omni channels and Internet shops or just-in-time service, the domestic freight transportation sector has been increasingly dependent on truck (vehicle) transportation. Distribution centers are the key to vehicle operation and management for truck-based distribution services so that the number and amount of investments in them and their total floor space are increasing.

Distribution centers can be categorized based on their types: a transfer center (TC), a distribution center (DC) and a transfer-distribution center (TC/DC). DCs have been provided with package software or systems that enable efficient inventory control and vehicle operation by combining a warehouse management system (WMS) and a vehicle assignment and delivery planning system.

Unfortunately, such conventional package software and systems do not work effectively in large-scale TCs that handle several hundreds of thousands of packages per day and are equipped with 50 or more truck berths.

This paper describes a solution using a system consisting of a "transportation amount prediction function," an "operation support function" and a "vehicle guiding function" that Fuji Electric offers for large-scale TCs.

2. Issues in Distribution Centers

Figure 1 shows an outline of the work in a distribution center. Under the present conditions, most types of work have been relying heavily on manual labor except for sorting and some other tasks.

In a distribution center, there are various disturbances such as vehicle departure and arrival and facility operations, and the amount of transportation varies depending on the time period or loading truck berth. Consequently, in order to improve the operation effi-

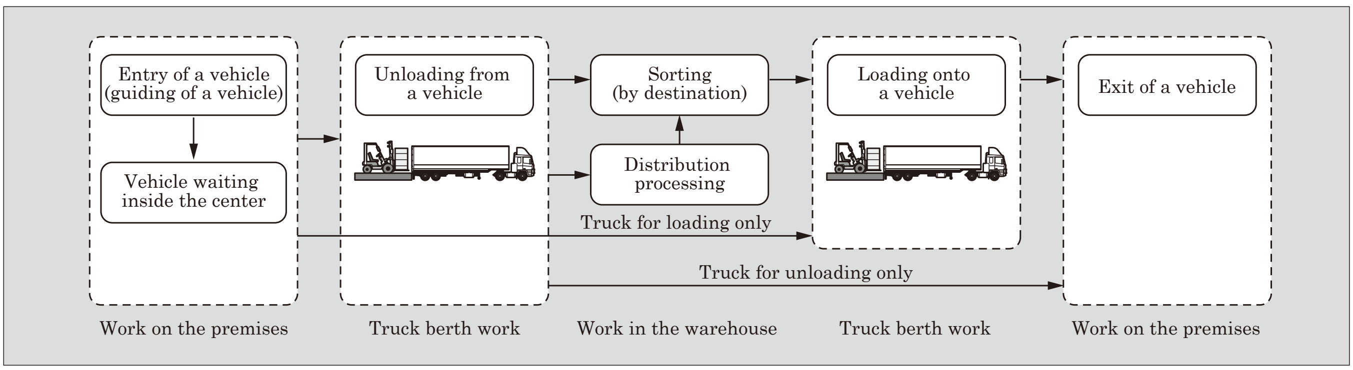


Fig.1 Overview of work in distribution center

* Industrial Infrastructure Business Group, Fuji Electric Co., Ltd.

ciency of the center, it is important to assign labor according to these disturbances and the varying amount of transportation.

The following are 3 major issues in distribution centers (mainly TC):

(1) Eliminating the dependence of distribution center operations on individual operator skills

At DCs, it is possible to know the order quantity determined against the inventory of the center. Since the necessary transportation style can be planned to some extent in advance, it is easy to make an operation plan of the center (workforce, vehicle arrangement).

On the other hand, TCs are positioned at the middle of a distribution network as shown in Fig. 2. The amount of transportation arriving at and departing from the distribution center is unknown until immediately before transportation. The difficulty of predicting the amount of transportation beforehand is apparent when you assume a scene where multiple consumers do Internet shopping at multiple stores and individually specify delivery times and dates including same-day delivery. In many cases, specific staff members in a distribution center make plans related to workforce and vehicle arrangements based on their experience and dependent on individual skills. The level of data visualization (such as operation efficiency or track record of the number of transferred packages) is often insufficient.

(2) Better satisfaction of transportation time constraints

When multiple trucks arrive in a distribution center for loading in the same time period, it is necessary to guide the vehicles in view of moving distances so that all trucks can finish delivering their freight by the scheduled time.

(3) Eliminating heavy traffic of trucks due to a cause that exists inside the distribution center

Recently, distribution centers have been designed to be larger in scale and the amount of arriving and departing transportation sometimes reaches a level of 1 million packages per day (200 trucks/hour). Retaining vehicles in a distribution center due to various factors may cause heavy traffic in the neighborhood roads outside the center, leading to the risk of presenting social problems.

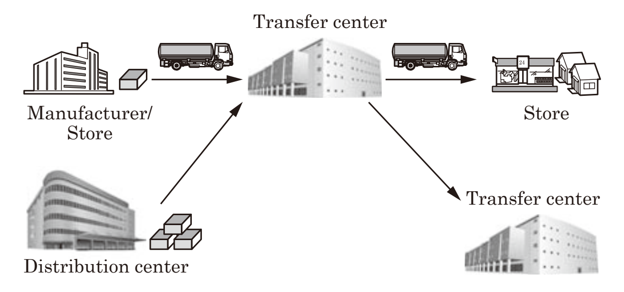


Fig.2 Overview of distribution network

Table 1 Relationship between issues and solutions

Issue to be solved	Distribution solution		
	Major function	Sub function	Collaborating sensors, systems, etc.
○ Eliminating the dependence of distribution center operations on individual operator skills	Operation support	External collaboration	Personnel-related management system (worker information, etc.)
		Workforce planning	Package position sensor Worker position sensor, work record terminal
		Facility operation planning	Facility (PLC, etc.)
○ Better satisfaction of transportation time constraints ○ Eliminating heavy traffic of trucks due to a cause that exists inside the distribution center	Vehicle guiding	External collaboration	Truck operation management system (external system, departure/arrival schedule of trucks)
		Truck state management (position, state)	Vehicle position sensor
		Truck guiding	Truck indicator
○ Eliminating the dependence of distribution center operations on individual operator skills ○ Eliminating heavy traffic of trucks due to a cause that exists inside the distribution center	Transportation amount prediction	–	Transportation track record management system (external system) Vehicle guiding function, operation support function

Table 1 lists the functions of Fuji Electric's distribution solution for solving these issues and improving the operation efficiency of distribution centers.

3. Distribution Solution for Solving the Issues

The distribution solution that Fuji Electric provides for solving the issues described in Chapter 2 uses the following 3 functions to eliminate the dependence on individual operator skills and improve operation efficiency.

The functions include a "transportation amount prediction function" for predicting the amount of transportation arriving at and departing from distribution centers, an "operation support function" for helping the development of optimal plans on workforce and facility operation by using the transportation amount prediction and various sensor information and a "vehicle guiding function" for completing transportation and delivery operations within time constraints and eliminating heavy traffic by combining the 2 functions above.

3.1 Transportation amount prediction function

The transportation amount prediction function predicts the amount of transportation arriving at and departing from a distribution center based on past track records. The predicted amount of transportation is important information that will be used as a base for making vehicle guidance, workforce and facility operation plans in a distribution center.

This function can visualize the difference between the past track record and real-time data. Accurate prediction of the amount of transportation with a daily error of less than 5% can be achieved based on past track record data on the same day of the week in the same month of the previous year or the same day of the week in the previous week of the same year, with a correction made using the real-time data of the same day. Moreover, the amount can be visualized for each destination, and this helps the operation manager of the distribution center to make decisions.

From now on, we will proceed with research and development for more accurate prediction and segmentalized prediction such as by time period. We will do so by applying a combination of further data trend analysis and various prediction techniques (such as exponential smoothing, moving average and regression modeling).

3.2 Operation support function

(1) Workforce planning function

The workforce planning function visualizes the workforce arrangement plan and track record in each workplace or process in a distribution center and collaborates with the vehicle guiding function.

By obtaining worker information in the center through the method described in Section 4.3, the function calculates the work productivity from equation 1 for each work process. It then substitutes the result and the amount of transportation for each time period into equation 2 to make an optimal workforce arrangement plan.

$$\text{Work productivity} = \frac{\text{Number of packages}}{\text{Work rate}} \quad \cdots\cdots\cdots (1)$$

$$\text{Workforce} = \frac{\text{Amount of transportation}}{\text{Work productivity}} \quad \cdots\cdots\cdots\cdots\cdot (2)$$

The workforce plan can be constantly corrected based on real-time data of the amount of transportation and be reflected in work instructions. It is also possible to provide automatic voice instructions when the difference between the predicted amount of transportation and real-time data exceeds a predefined threshold value.

(2) Facility operation planning function

The facility operation planning function visualizes the present operation condition and schedule of each facility in a distribution center and collaborates with the vehicle guiding function.

Facility operation planning can visualize the present condition by receiving a track record of the amount of transportation, facility operation capacity (packages/hour) and a failure and stop state from facilities via power line communication (PLC) or another method. Using the facility operation capacity and transportation amount prediction allows staff members to make a facility operation plan. Note, however, that most facilities in a distribution center do not complete work by themselves. When a sorter is used for sorting work, the loading of a truck after sorting is done manually. Consequently, considering the facility operation plan and workforce plan together can improve the efficiency of the distribution center operation.

3.3 Vehicle guiding function

The vehicle guiding function collaborates with the transportation amount prediction function and operation support function and guides vehicles in an optimal way inside and outside the distribution center. It does so by acquiring vehicle positional information through the method described in Section 4.1.

Even if the transportation amount prediction is accurate and the workforce and facility operation plan is appropriate, it is impossible to improve the operation efficiency of a distribution center unless vehicles are guided properly. The vehicle guiding function is intended to designate a truck berth for each truck for loading or unloading. It is an important function for the efficient operation of a distribution center.

Vehicle guiding is affected by the following factors and this function guides vehicles based on a comprehensive judgment of them.

(1) Factors affecting the guiding of vehicles toward the distribution center

The following 2 factors affect the guiding of vehicles coming from the outside to the inside of a distribution center.

(a) Information on the vacancy inside the distribution center (truck berth, waiting area)

If there is no vacancy in the truck berths and waiting area inside the distribution center or if there is an accident inside the center, trucks arriving near the distribution center cannot enter. Such trucks go around the neighborhood roads or wait on the roads, resulting in harmful effects such as traffic congestion. To solve this problem, it is necessary to give instructions telling drivers to wait or circulate in a remote area.

(b) Priority (time constraint depending on truck destination)

Even when there is a vacancy in the truck berths or other areas of the distribution center, guiding trucks simply in the order of arrival without considering their destinations may lead to there being no vacancy in the truck berths. This would make it impossible to guide a truck with less time to spare for reasons such as it needing to go to a distant destination. Consequently, it is necessary to guide trucks according to the priority based on the amount of transportation of the packages to be unloaded by destination and on the destination of the truck.

(2) Vehicle guiding inside the distribution center

The following 3 factors affect the guiding of vehicles to the truck berths inside the distribution center.

(a) Truck berth setting (unloading berth, destination after loading, etc.) and priority

There are different truck berth settings such as for unloading only or for specific destinations. These settings may also be changed based on time periods. It is necessary to guide trucks according to these settings while considering the priority factors such as packages and destinations.

(b) Vacancy of the truck berths (vacant, no vacancy or to be vacant)

The time when a truck berth becomes vacant is predicted from factors such as the start time of unloading and loading and work productivity. The guiding should consider the period of time that the truck requires to move from the present position to the truck berth.

(c) Amount of transportation of packages to be unloaded by destination (reduction of sorting time)

The guiding should consider equipment configuration including the layout of the truck berths and sorting devices to determine which truck berth can be used for unloading packages to complete sorting and other mechanical operations fastest.

4. Information Acquisition Technologies Supporting Distribution Solution

4.1 Vehicle position and truck berth vacancy information

The purpose of keeping track of vehicle positions and states varies depending on whether a vehicle is inside or outside the distribution center.

When a vehicle is outside the distribution center, it is necessary to determine when the vehicle will arrive at the distribution center and whether it can be guided into the center or not, based on information about the present vehicle position. For this purpose, an accuracy of several meters or less is unnecessary for the location information and generally-used GPS-based positional information (accuracy of about 10 m) is sufficient. Consequently, the solution uses GPS-based positional information services provided by various companies.

On the other hand, when a vehicle is inside the distribution center, it is necessary to recognize and estimate the following conditions to guide vehicles smoothly.

(a) Recognition of the vehicles that enter and exit the center

(b) Recognition of the vacancy of the truck berths

(c) Estimation of the time for guiding the vehicle from the waiting position to the truck berth when the distribution center has large premises

Accordingly, inside the distribution center, the position of a vehicle should be recognized with high accuracy and sensors with the characteristics shown in Table 2 are used to keep track of the positional information. When providing the system as a solution, Fuji Electric recommends loop coil sensors or magnetic detection sensors that are less affected by rain, dust, human access or other factors in the environments where vehicle recognition is conducted.

The system correlates the positional information inside and outside the distribution center with vehicle-specific information (license plate, driver, smartphone, etc.) and uses them for the vehicle guiding function.

4.2 Package positional information inside distribution center

Positional information on packages is not only required for improving the work efficiency in distribution centers but also indispensable for assuring traceability and security.

To acquire such information, you can use the data obtained by reading the barcode attached on each package with a handy terminal or the information detected with distribution equipment such as conveyors or sorters installed in distribution sites.

By using these measures, you can track the packages unloaded at the distribution center until they are transported by several workers or machines and loaded into a truck. Moreover, if a package was transported to a spot other than the scheduled internal route due to an accident or theft, it is necessary to

Table 2 Characteristics of vehicle recognition sensors

Sensor \ Characteristics	Protection against surrounding environment: Dust, dirt, rain, etc. (○: Not affected ×: Affected)	Protection against surrounding environment: Surrounding metal, magnetism (○: Not affected △: Somewhat affected ×: Affected)	Detection characteristics: Responding to metals only (○: Possible ×: Impossible)	Detection characteristics: Passage detection (○: Possible ×: Impossible)	Detection characteristics: Detecting range (○: Wide △: Somewhat narrow ×: Narrow)	Burying construction
Camera	×	○	×	○	○	Unnecessary
Loop coil	○	△	○	○	○	Necessary
Magnetic detection	○	×	○	○	△	Unnecessary
Photoelectric	×	○	×	○	○	Unnecessary
Ultrasonic	×	○	×	×	△	Unnecessary
Illumination detection	×	○	×	×	×	Unnecessary

Table 3 Method of detecting positional information of packages and workers

Characteristics \ Detection method	IMES	BLE	RFID (active)	RFID (passive)	Ultrasonic	Wireless LAN (Wi-Fi)	Acceleration sensor	Camera + Color barcode
Overview	GPS is extended for indoor use	Bluetooth radio waves are used	Radio waves generated from a TAG are used	Radio waves generated from an antenna are used	Sound waves are used instead of radio waves	Radio waves of wireless LAN are used for measurement	Displacement from the initial position of TAG is calculated	Image recognition of color barcodes
Recognition distance (varies depending on obstructions)	About 10 m	About 5 to 10 m	About 10 m	About 3 m or less	About 10 m	About 100 m or less	About 100 m or less	Depending on the environment
Operability	○	△ Battery replacement required	△ Battery replacement required	○	△ Battery replacement required	× Triangulation measurement is not suitable for the recognition of a large amount of targets	× Displacement measurement is not suitable for the recognition of a large amount of targets	△ Image recognition is easily affected by environments
Initial cost (relative level within the table)	Middle to high	Middle	Middle to high	Middle	High	High	High	Low
Running cost (relative level within the table)	High	Middle	High	Middle	High	High	High	Low

○: Best, △: Having room for improvement, ×: Not acceptable

assure security by acquiring positional information. For this purpose, it is essential to constantly acquire positional information inside the distribution center building through the use of the sensor recognition technologies shown in Table 3. These detection methods and mechanisms, however, have advantages and disadvantages. It is necessary to select an optimal detection method with consideration given to costs and the required accuracy of the detection position. Furthermore, it is not realistic in terms of costs and recognition accuracy to use sensors to keep track of all transportation in a large-scale TCs where several hundreds of thousands of packages are transferred.

Fuji Electric therefore proposes a system that is focused on only valuables and insured packages requiring special traceability and security, and can track these inside and outside the distribution center. This is a combination of an indoor messaging system (IMES) that can be used with smartphones or other relatively affordable terminals and Bluetooth Low Energy (BLE).

4.3 Worker information inside distribution center

The following are the reasons why it is necessary to grasp information relating to workers inside the distribution center:

(1) Efficiency improvement through the management of work track record

The acquired work track record is visualized and used for calculating productivity or a key performance indicator (KPI) to improve work efficiency.

As with the traceability information of packages, improving efficiency thorough the management of work track records is generally done by grasping work track records using handy terminals or wearable terminals. There are many cases where this track record information is used for writing daily reports or collecting and aggregating track records to create the base data for efficiency improvement.

(2) Work efficiency improvement through the analysis of work traffic paths

In order to keep track of workforce information, it is necessary to acquire the work track record of workers and their time-based positional information while they are working.

Analyzing the work traffic paths makes it possible to find waste during operation and improve efficiency. With conventional systems, acquiring the work traffic paths required on-site behavior observation or analysis cases recorded with a camera. The targets for tracing the work traffic paths in this system are around 100 people and this number is significantly smaller compared with the number of packages that reaches several hundreds of thousands. Consequently, there is an advantage that the sensors described in Section 4.2 can be used for collecting the data automatically.

5. Summary

Introducing Fuji Electric’s distribution system enables visualization of various kinds of information, and vehicles can be guided accurately based on this information. This leads to a solution allowing even inexperienced distribution center operators to operate the center at a level equivalent to highly experienced operators. This paper mainly focused on large-scale TCs; however, this solution is beneficial also for small- and medium-scale distribution centers and companies operating EC sites. EC site operating companies can enjoy reduced distribution costs and other advantages by using traceability information and efficiency-improved distribution centers through the introduction of a distribution solution provided by Fuji Electric.

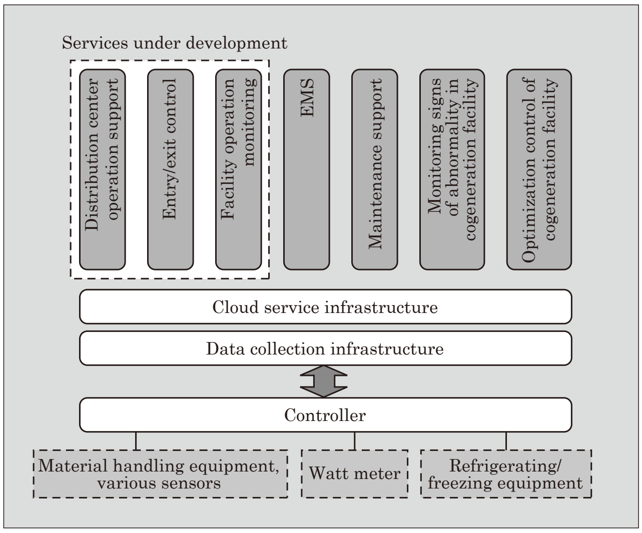


Fig.3 Overview of Fuji Electric's cloud service

Furthermore, we have enabled selective introduction of the necessary functions to reduce introduction costs and propose a solution available even for small- and medium-scale distribution centers.

We plan to provide a solution using the cloud service shown in Fig. 3 in the future. We will also connect the system described in this paper with the facility operation monitoring service or the entry and exit control service that can keep track of the field condition of a distribution center. We will then provide a solution as a distribution center operation support service.

6. Postscript

This paper described a solution for improving efficiency in distribution centers. The demands for the services of distribution, transportation and delivery are expected to become further advanced and diversified in the future. We intend to propose solutions through technological development that satisfies market needs such as predicting the transportation amount and analyzing human traffic paths.

Plant Factory Solution with Instrumentation and Control Technology

NAGASE, Kazuya*　SHIRAKI, Takashi‡　IWASAKI, Hidenari⁂

ABSTRACT

In recent years, plant factories have been attracting attention due to agricultural production instability resulting from the shrinkage in the farming population and abnormal weather. Against this backdrop, Fuji Electric has been offering plant factory solutions specializing in a complex environmental control system, which controls multiple environmental factors, such as temperature and humidity. We are currently advancing in the development of technologies for production process data forecasting systems that cooperate with the complex environmental control system. Among these technologies, we have developed a crop yield forecasting function for strawberry farmers, which is capable of forecasting crop yields up to one week in advance. This technology is expected to improve profitability by helping reduce sales loss and facilitating the effective use of human resources. In the future, we plan to pursue the development of technologies that can deal with differences in plant varieties and crops.

1. Introduction

In recent years, plant factories have been attracting attention due to agricultural production instability resulting from the shrinkage in the farming population and abnormal weather. Plant factories are facilities capable of year-round production by carrying out sophisticated control of temperature, humidity, CO_2 concentration, and other growing environmental conditions.

Fuji Electric has been offering plant factory solutions including equipment featuring a composite climate control system, which controls multiple environmental factors such as temperature and humidity. One major practical example is a type of plant factory that uses sunlight, and it is owned by Tomatoh Farm Co., Ltd. and was constructed in Tomakomai City, Hokkaido in 2014. We have delivered a composite climate control system, electric distribution facility, environmental measurement equipment, refrigeration equipment and the “D-BOX” cold storage container for logistics.

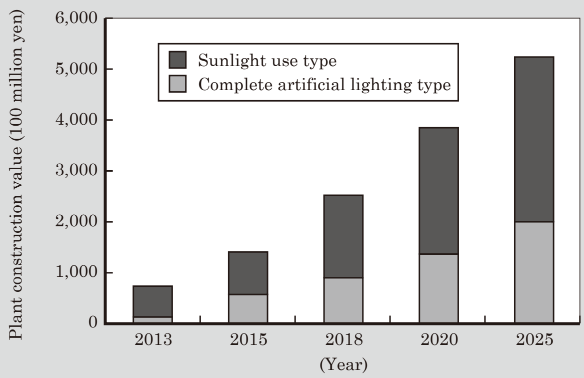
This paper describes trends in the plant factory market, outlines the Tomatoh Farm plant factory and presents plant factory solutions that make use of instrumentation and control technology.

2. Trends in Plant Factory Market

The amended “Agricultural Land Act,” enforced in December 2009, has significantly relaxed the conditions for corporations’ entry into agriculture. It has accelerated the entry of players from other categories of business and they are becoming increasingly diverse. In particular, new entries into the plant factory business, which allows year-round production, are increasing and the market is expected to grow significantly. Figure 1 shows an estimate of the plant construction value of plant factories in Japan. In 2025, the total value is estimated to reach 524.7 billion yen, about 3.5 times that in 2015.

Plant factories can be roughly classified into those that use sunlight and those that use complete artificial lighting. While sunlight use-type factories use sunlight in greenhouses to control the environment in the facilities, complete artificial lighting-type factories are facilities in a closed environment with artificial lighting such as fluorescent lamps and LEDs used as the light sources.

Operation of plant factories essentially requires controlling air conditioning and liquid feeding equip-



Source: Shusaku Hayakawa, Yuichi Owada, “Present Condition Surrounding Plant Factories in Japan and Future Prospects,” Deloitte Tohmatsu Group, 2014

Fig.1 Estimate of plant construction value of plant factories in Japan

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

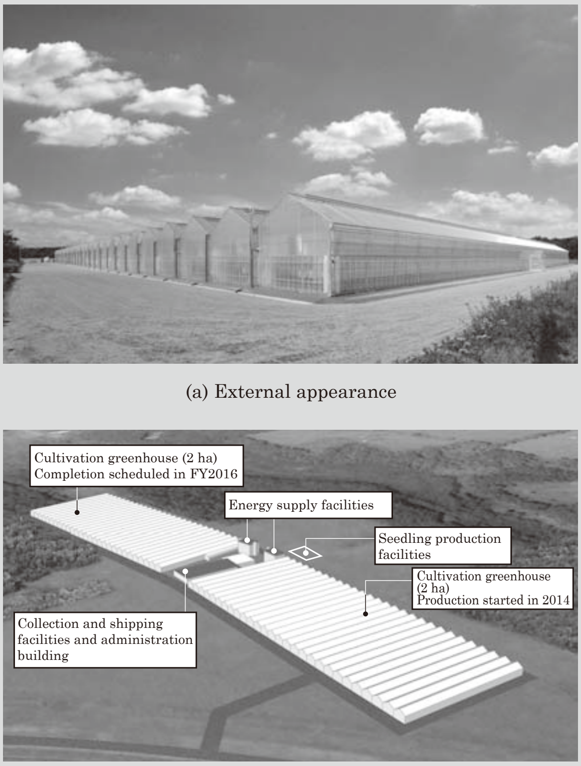
ment to achieve appropriate environmental conditions, as well as measuring the environment in the facilities. To this end, the instrumentation and control technology of Fuji Electric can be effectively applied.

Fuji Electric's plant factory solutions are offered on an engineering, procurement and construction (EPC) basis, in which all of the design, procurement and construction processes of plant factories are undertaken, and the main component is a composite climate control system.

3. Outline of Tomatoh Farm

Tomatoh Farm is a plant factory located in the Tomakomai East Area in Tomakomai City, Hokkaido. It is operated by Tomatoh Farm Co., Ltd., a company co-funded by Fuji Electric, Shimizu Corporation, Ushio Inc., financial institutions, and other companies. It has been selected as a "Supportive Project for Accelerating the Introduction of Next-generation Greenhouse Horticulture" of the Ministry of Agriculture, Forestry and Fisheries and started strawberry cultivation in 2014. Figure 2 shows the appearance of Tomatoh Farm and rendering of the entire factory.

A greenhouse in Tomatoh Farm has an area of approximately 2 ha (width 8 m × depth 93 m × eaves height 4 m × 28 structures in a row), which is divided into 7 areas for production and environmental management for the individual areas. The cultivation method is elevated bed water culture (free flowing with granulated rock wool medium). A cropping type combining non-remontant strawberries that can be produced from winter to early summer (variety: Tochiotome and Benihoppe) and remontant strawberries (variety: Suzuakane) has been employed to build a system for year-round production of strawberries.



(a) External appearance

(b) Rendering of entire factory

Fig.2 Appearance of Tomatoh Farm and rendering of entire factory

The seedling raising facilities have one complete artificial lighting-type seedling raising facility for raising cultured seedlings, pipe houses for raising parent vines by elevated bed water culture (250 m^2 × 2) and pipe houses for bench seedling raising (166 m^2 × 4). In the pipe houses for raising bench seedlings, small plants of non-remontant strawberries are cultivated in pots by inserting seedlings to use for production in cultivation greenhouses.

The energy supply facilities are comprised of a wood chip boiler and heat pump chiller. Cold water is supplied in summer and hot water in winter to be used for air conditioning and heating in the cultivation greenhouses.

We plan to add a cultivation greenhouse and energy supply facilities by the end of FY2016 to increase the greenhouse area to a total of 4 ha.

4. Environment Control at Tomatoh Farm

4.1 System overview and features

The environment in the cultivation greenhouses of Tomatoh Farm is controlled by using a composite climate control system. Figure 3 shows the configuration of the system.

The system is configured with a selection of Fuji Electric's products: various types of measuring instruments including the "FTNE" dual element temperature sensors and the "ZFP" CO_2 concentration analyzers, control equipment such as air-conditioning systems and liquid feeding equipment and "MICREX-SX" programmable controllers. The measurement items include the temperature and humidity, CO_2 concen-

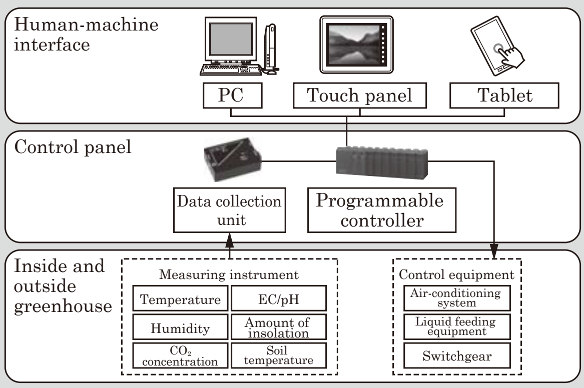


Fig.3 Configuration of composite climate control system at Tomatoh Farm

tration, amount of insolation, electrical conductivity (EC) and pH of the liquid supply and culture medium temperature in the greenhouse. The temperature and humidity, amount of insolation, wind velocity and wind direction outside the greenhouse and rainfall and snowfall are also detected. Based on the environmental data measured, the environment in the greenhouse is controlled to realize year-round production. The settings of the environmental control are configured by using a PC in the administration building. The control equipment can be operated from the "MONITOUCH" touch panel and tablet devices.

The cultivation greenhouse is divided into 7 areas and independent control can be provided for each area. Control functions include heating (snow melting), humidification, ventilation, thermal insulation, light supplementation, light shielding, CO_2 supply, air circulation and liquid feeding functions, and the functions can be activated individually or in a combined manner.

The functions meet the operating conditions for the peculiar weather conditions in Hokkaido, such as ventilation in an environment with a low external temperature and switching between air cooling and heating while the temperature greatly varies between night and day.

4.2 Issues

To improve profitability, the key issues are labor saving and improvement of the yield per unit area, in addition to energy saving by improving the current control system. Tomatoh Farm accumulates environmental data, growth survey data, yield data. We aim to build a comprehensive production system by conducting analysis for improving the yields for the individual varieties while linking between the respective types of data.

5. Production Process Data Prediction System

Table 1 shows products demanded by the market and technologies required for resolving the issues in plant factories. Fuji Electric is systematically working on the development of products and technologies to resolve the issues for the purpose of improving the profitability of plant factories. Of those, this paper presents the system to predict production process data and the yield prediction function, which is one of its applications.

5.1 Configuration

As a product for addressing the issues with plant factories, we are developing a system to predict production process data. It is intended to improve the profitability of plant factories by predicting the content, scale and timing of the farm work that will need to be done in the future.

Decisions on whether or not to carry out work or the amount of work traditionally depended on the results of daily checks and intuition of skilled farmers. At plant factories, however, skilled farmers themselves cannot check all of the areas. In addition, variation due to environmental fluctuations and other reasons makes it difficult to use intuition to make work decisions. For this reason, a pressing issue was to develop technology allowing work decisions to be made based on objective and quantitative data.

Figure 4 shows the configuration of the production process data prediction system. The following describes the flow of processing in this system.

(1) Input function

Table 1 Market demands for resolving issues with plant factories (products and technologies required)

Issue	Product	Technology required
Energy saving	Environmental control system	○Technology for optimizing operation of equipment according to the environment and production ○Technology for efficiently realizing an environment suited for cultivation
Labor saving	Production automation system	○Technology for automating the state management, harvesting and conveyance of crops
Yield improvement	Environmental control system	○Technology for equalizing temperature, humidity, CO_2 and wind velocity distribution in facilities ○Cultivation fundamental technology for grasping relationships between various parameters in environment and work and yields in environment and work
	Indoor air quality improvement system	○Technology for improving cleanliness of air in facilities
	Production process data prediction system	○Technology for predicting outbreak of diseases and insect pests, occurrence of cultivation failures and cultivation yields

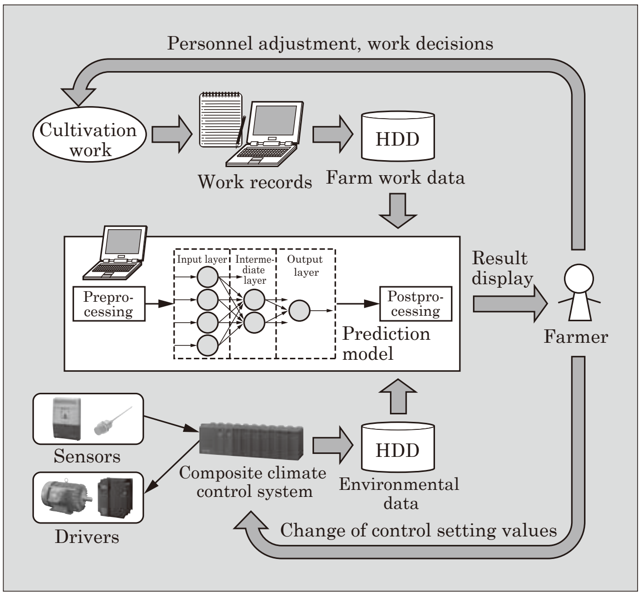


Fig.4 Configuration of production process data prediction system

Data for inputting into the prediction model are prepared. Data include environmental data and farm work data.

(a) Environmental data

Environmental data include time-series data such as temperature, humidity, amount of insolation and CO_2 concentration and are acquired from the environmental control system.

(b) Farm work data

Farm work data are inputted daily data including the yield and whether or not tending work was carried out.

(2) Preprocessing function

Various data are processed and converted into usable data type to create a prediction model using such conversion methods as standardization of data formats and sampling periods, completion of missing values and merging of data.

(3) Prediction function

The prediction function consists of the process of generating prediction models and the process of utilizing the models.

(a) Generation of prediction models

Past data are used to generate prediction models. the prediction model is generated by learning the data to be predicted such as the yield as the objective variable and the data relevant to the prediction target such as the environmental data as the explanatory variable.

(b) Utilization of prediction models

By inputting the explanatory variable data into the prediction model generated, the system can output the result of the prediction target in real time.

(4) Post-processing and display function

By changing the unit or other data attributes and using integration or other calculation techniques, the prediction result data are processed and converted into a format that allows farmers to easily make work decisions, which are displayed on the screen. Farmers can use the displayed content as reference when deciding whether or not to carry out the work relevant to the prediction target.

5.2 Prediction targets and prediction models

The following are prediction targets desired in cultivation management.

(a) Emergence of diseases and insect pests

Powdery mildew, gray mold, anthracnose, red spiders, mites and plant lice

(b) Occurrence of cultivation failures

High temperature injuries, low temperature injuries, fruit deformation and tip burn

(c) Yield and cultivation work timing

Yield, timing of leaf pruning, flower picking, fruit thinning and mulching

The quantities of generation and implementation and timing of prediction targets are influenced by complex and natural factors such as the temperature, humidity, amount of insolation, amount of photosynthesis, growing period, growing condition of seedlings, amount of relevant work, soil components and activities of bees. In addition, influence quantities of the individual factors may greatly vary depending on the types of crops (strawberries), varieties (Tochiotome, Benihoppe), equipment conditions (soil or water culture, lighting condition, location). For that reason, mathematization by advance experiment using the individual factors as the conditions requires an enormous amount of man-hours.

The production process data prediction system uses a method based on machine learning. While prediction techniques using complicated formulae such as regression formulae requires complicated parameter setting, using this technique can significantly reduce the man-hours for changing the conditions because it does not require complicated formulae.

The following describes the data required for prediction. Acquisition of data that satisfy the following 2 requirements leads to smooth starting of prediction.

(a) Generation of prediction model: A few months' worth of data have been acquired in advance

(b) Utilization of prediction model: The data can be automatically acquired at constant intervals

Once a prediction model with similar conditions has been prepared, utilization of the prediction model can be started without the need for providing a data acquisition period in advance. For farm work data, inputting by means of a recording tool allows automatic acquisition of data.

5.3 Yield prediction function

As an application of the production process data prediction system, we are developing a function of predicting strawberry yields.

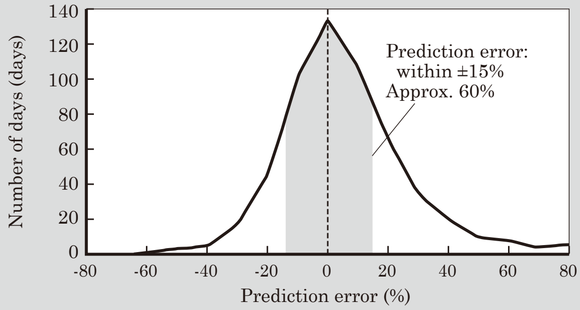
For improving profitability of a plant factory by reducing sales loss and improving work efficiency, the error between the predicted and actual yields should preferably be as small as possible. With strawberries, in particular, the shelf life after harvesting is very short, and yield prediction is required to be predicted in short-period of time, e.g. one day.

Yield prediction is processed according to the flow of the production process data prediction system described in Section 5.2. A prediction model is generated from the past data by using data such as the temperature and amount of insolation as the explanatory variables and the yield of one day as the objective variable. This allows prediction and display of the yield of one day.

In addition, the yield prediction model employs prediction data of the environment in the greenhouse based on the weekly weather forecast, which allows yield prediction for up to the following one week.

Farmers can use the predicted values as reference to provide the shipping volumes to customers, which raises expectations for profitability improvement by reducing the sales loss. Furthermore, estimating the amount of work such as harvesting can lead to profitability improvement by effective use of human resources.

Figure 5 shows the result of prediction of yield in a certain area at Tomatoh Farm. It has been confirmed that about 60% of all days have the error limited to within ±15%.



$$\text{Prediction error} = \left(\frac{\text{3-day moving average of predicted yield}}{\text{3-day moving average of actual yield}} - 1 \right) \times 100$$

Fig. 5 Result of yield prediction

We aim at improvement of the prediction accuracy and application to other crops by constructing even more advanced prediction technology. We also intend to improve customer value at plant factories by combining mathematical application technologies at which Fuji Electric excels, such as anomaly diagnosis and optimization technologies, and linking with business management and control systems and other systems.

6. Postscript

This paper has described plant factory solutions that make use of instrumentation and control technology. Fuji Electric is committed to making continued efforts for comprehensive technology development by utilizing its core technologies including heating and cooling, control and mathematical application technologies for strengthening solutions.

Service Solutions to Support the Stable Operation of Equipment

KITATANI, Yasuharu*　FUJITA, Fumihiko‡　DAITO, Takeshi‡

ABSTRACT

In order to achieve production plans, it is necessary to carry out maintenance activities that reduce equipment failure and ensure stable operation. The maintenance activities are basically involved in implementing the maintenance PDCA cycle that consists of activities to formulate maintenance plans with consideration of time and cost, continually monitor equipment conditions and solve problems as they arise, throughout the life cycle of equipment. Fuji Electric is providing cloud-based equipment maintenance services that utilize IoT. These services support stable operation through equipment maintenance. The information required for the maintenance PDCA cycle is managed in an integrated manner by linking equipment maintenance records, operation monitoring functions and equipment diagnostic functions.

1. Introduction

Quality and cost as well as production per hour may greatly vary depending on the equipment introduced. Accordingly, production plans depend on the equipment capacity and adequately utilizing the equipment capacity is important.

Fuji Electric is providing cloud-based comprehensive equipment management services that integrate the energy management system (EMS), maintenance and operation monitoring services in a cloud. Of those services, this paper presents the cloud-based equipment maintenance services, which are service solutions that support stable operation of equipment.

2. Stable Operation of Equipment Achieved with Equipment Maintenance

In maintenance activities to extend the operation period by reducing instances of equipment failure and ensure efficient and stable production, the key is to first formulate maintenance plans when equipment is introduced. However, carrying out as scheduled the maintenance plans made in advance is difficult as the operation period becomes longer. To deal with this situation, it is necessary to formulate maintenance plans with consideration of time and cost and carry out activities including soundness checks and deterioration diagnosis of the equipment according to the plans as well as prevention of and recovery from equipment degradation throughout the life cycle from introduction to replacement (disposal) of the equipment.

These activities are called a maintenance PDCA cycle as shown in Fig. 1.

(1) Formulation of maintenance plans

The intervals of general and detailed inspection, timing of replacement of limited-life parts, timing of preventive maintenance including overhauls and timing of replacement of the entire equipment are organized into maintenance plans based on the equipment-specific management criteria. To calculate the maintenance costs for each fiscal year, maintenance plans in consideration of equalization between fiscal years are formulated.

(2) Maintenance work

Maintenance work includes breakdown maintenance to deal with unexpected failure as well as preventive maintenance. To identify the cause of any failure in a short time, advance arrangements such as education of maintenance workers, preparation

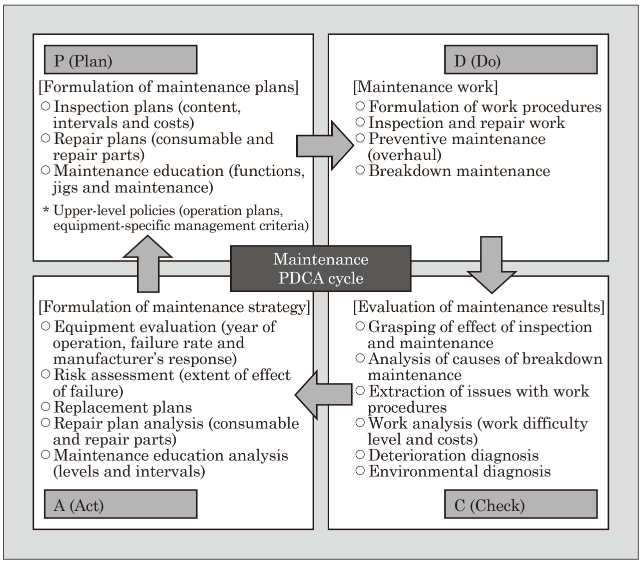


Fig.1 Outline of maintenance PDCA cycle

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

of tools and cooperation with the manufacturer are required. With machinery and equipment, failures caused by degradation due to cumulative operating time or repeated stress are common and management of failure history (description and cause of the failure and response history) and sharing of information are required.

(3) Evaluation of maintenance results

To evaluate maintenance results, the effect of work based on the maintenance plans must be grasped. In addition, the results of environmental diagnosis and deterioration diagnosis are also required because the progress of degradation depends on the installation environment and operating (load) conditions.

(4) Formulation of maintenance strategy

To formulate the maintenance strategy, the workers must assess the risk related to stable operation of the equipment. For pieces of equipment that may greatly affect production activities if they break down, equipment replacement must be considered based on the maintenance evaluation (year of operation, failure rate and manufacturer's response) in addition to reviewing the content of maintenance.

3. Cloud-Based Equipment Maintenance Services Utilizing IoT

Fuji Electric provides cloud-based equipment maintenance services for supporting maintenance activities. The information required for the maintenance PDCA cycle is managed in an integrated manner by linking equipment maintenance records, operation monitoring functions and equipment diagnostic functions to support stable operation of the equipment with equipment maintenance. This chapter describes equipment maintenance services that make use of the Internet of Things (IoT), edge devices, work support and security measures.

3.1 Easy-to-understand equipment maintenance records achieved with hierarchization

Equipment maintenance records provide a system of managing the installation location, operation history, inspection plans, failure reports, replacement parts inventory information, deterioration diagnosis results, etc. based on equipment ledgers (year of delivery, manufacturer information, maintenance contact, consumable parts list, etc.). The maintenance PDCA cycle is run by accumulating and using these types of information.

The basic functions required of equipment maintenance records include ease of information updating. The information in the equipment maintenance records must be updated every time the equipment is partially replaced due to aging. In addition, to deal with generation changes of persons in charge of management, a data structure that allows intuitive operation and a management system that can be easily understood are required. Accordingly, the equipment ledgers of equipment maintenance records provided by Fuji Electric have a hierarchical (tree) management structure corresponding with the actual locations such as "site → building → line → equipment → device." Figure 2 presents an overview of an equipment ledger in a map format. After selecting equipment from the location information, information relating to maintenance such as the basic information, inspection information and failure information of the equipment can be viewed and updated.

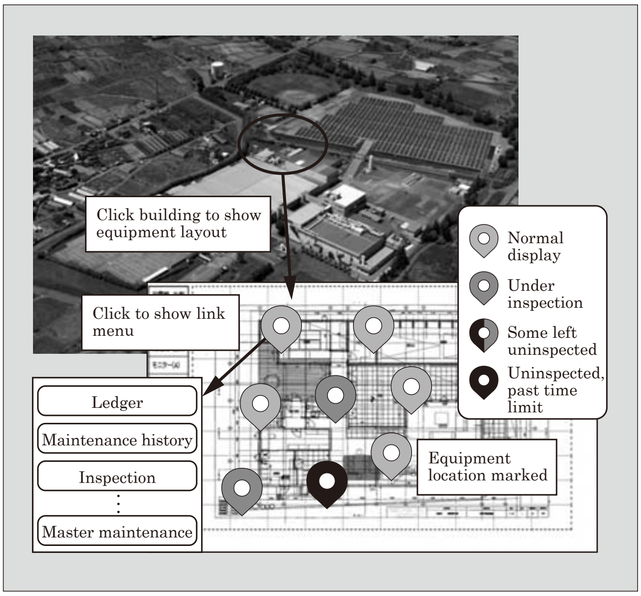


Fig.2 Overview of equipment ledger in map format

3.2 Operation monitoring and equipment diagnostic functions

Fuji Electric's cloud-based equipment maintenance services have the operation monitoring functions linked with the equipment diagnostic functions as described earlier and allow workers to accurately grasp the details of any equipment that shows signs of hindering plant operation. In addition, the operation monitoring screen and equipment diagnosis screen for an arbitrary piece of equipment can be viewed on one display, which makes it easy for workers to simultaneously monitor more than one piece of priority equipment.

(1) Operation monitoring functions with multi-overview

The items to be focused on in plant monitoring may change depending on the season, content of production, failure history, etc. For that reason, it is essential to have a multi-overview function that allows overall monitoring and partial detailed monitoring to be combined freely when monitoring a plant. Figure 3 shows a sample screen with a multi-view display of energy monitoring, plant monitoring, equipment diagnosis and equipment parts management. The main features are as follows:

Fig.3 Example of multi-overview monitoring screen

(a) Screens can be managed in a hierarchical manner according to the purpose of monitoring.

(b) To compare between screens with different management systems, arbitrary screens can be selected for multi-view display without the need for developing software.

(2) Control system monitoring function

To stably operate equipment in an industrial plant, it is necessary not only to monitor the state of the equipment but also to compare the configuration information, performance information, operation information, etc. of the control system in a combined manner. For example, in order to predict intermittent failure, the cause of which is difficult to identify, various types of information such as the server CPU load variation, resource conditions including the memory resources and disk space and operating conditions of the controller are monitored on a daily basis. Fuji Electric makes various proposals for preventing intermittent failure by appropriately strengthening the resources based on a prediction. Table 1 shows examples of monitoring items.

Table 1 Examples of monitoring items

Target		Monitoring item
System information	Server	Cumulative operating time and outage time of system
		System and server logs
		Usage rate (CPU, memory, disk) and process statuses
		Numbers of executed jobs, error jobs, etc.
	Controller	Configuration information (configuration, quantity, versions, serial numbers)
		Cumulative operating time and outage time of system
		Major and minor failure information
	Network	System and network counters
		Registered memory area data
	Peripheral equipment	Uptime and numbers of relay activations and deactivations
		Operating delay time and number of communication errors
Environmental data		Temperature and humidity

(3) Rotating machine equipment diagnostic function

Vibration diagnosis, which is a type of equipment diagnosis offered by Fuji Electric, provides constant diagnosis for the soundness of equipment based on information from the vibration sensor installed on important rotating machine equipment. When any error is detected, an alarm is displayed on the monitoring screen and an e-mail message is sent to the specified contacts. One effect of introduction is that it saves the labor of measuring the vibration of rotating machine equipment which is usually performed by maintenance workers who go around the site. In addition, abnormal vibrations can be detected promptly and this helps to reduce operation loss and ensure manufacturing quality.

The vibration sensor uses a specified low-power radio to send measurement data, which minimizes the length of the signal cable and makes it easy to install the sensor on existing equipment.

Figure 4 shows an example of vibration diagnosis linked with plant monitoring.

(4) Diagnostic function for valve-regulated lead-acid batteries

Fuji Electric's lead-acid battery diagnosis provides diagnosis to check for signs of any rapid characteristic deterioration of valve-regulated lead-acid batteries of uninterruptible power systems (UPSs) that cannot be detected by inspections that are carried out once or twice a year. Using sensors mounted on a valve-regulated lead-acid battery, the voltage, internal resistance and temperature are continuously measured for each cell and the characteristic variations are visualized. The main features are as follows:

(a) For communication between a sensor and edge device BRM (battery remote checker), 2.4 GHz wireless communication is used. This allows sensors to be easily installed on a valve-regulated lead-acid battery of up to 192 cells.

(b) The cloud-based operation makes it easier to

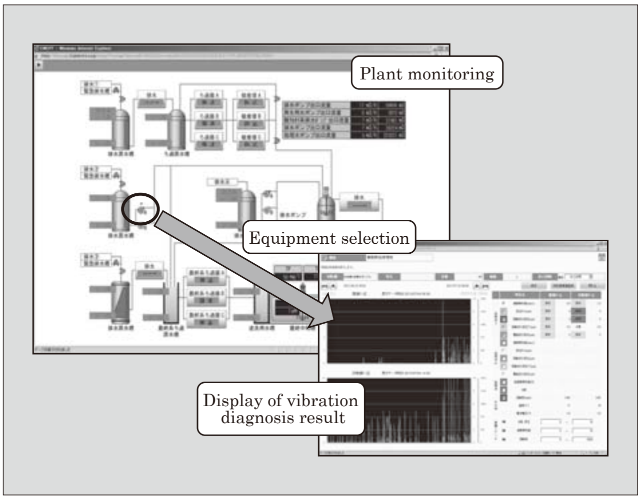


Fig.4 Vibration diagnosis linked with plant monitoring

share information.

(c) A maintenance contract can be made available in which a replacement is immediately prepared and installed when deterioration of the valve-regulated lead-acid battery is detected.

3.3 Edge devices for industrial plants

There are a variety of edge devices used on production sites for different purposes such as devices for collecting data from PIO signals and connecting with transmission lines. This section describes an edge device connected to the control LAN of the control system to collect operation data of devices that constitute the control system. The edge device automatically collects operation data from controllers that constitute the control system such as a distributed control system (DCS) and programmable logic controller (PLC) and PCs connected with the control LAN and stores them in network-attached storage (NAS) and cloud. Figure 5 shows a connection configuration of the edge device for industrial plants.

(1) Communication and data collection to support various networks

The edge device for industrial plants is capable of selecting multiple communication modules such as FL-net-compliant LAN, Ethernet[*1], DPCS-F and PE-link[*2]. It also has communication protocols compatible with the networks to be connected with, which allows collection of data from target devices including legacy devices. Furthermore, environmental data such as temperature and humidity, which are essential to prediction of failure due to aging, can be collected.

(2) Data accumulation and analysis

The collected data are accumulated in the NAS to prevent data loss. Data that cover a long time period are accumulated in a cloud to be used for analysis of resource insufficiency, etc.

(3) PC support tool

Definition of types of data to be collected and collection intervals can be easily configured by connecting a PC support tool. Maintenance workers can use this PC support tool to refer to the data before and after occurrence of failure for identifying the cause of the failure.

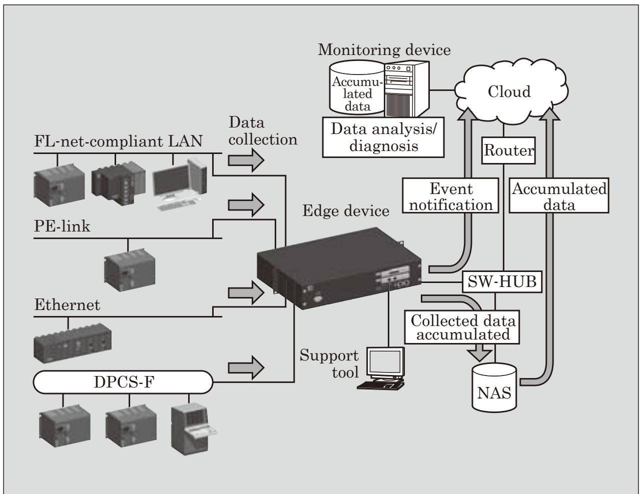


Fig.5 Connection configuration of edge device for industrial plants

3.4 Work support

The IoT covers maintenance workers as well as devices. The wearable device provided by Fuji Electric is in the form of glasses equipped with a camera and small monitor as shown in Fig. 6, which enables maintenance workers to send what they are seeing to the headquarters as a video without being aware of it. It also allows them to view the drawings required and receive remote work support from the headquarters while using bi-directional audio communication in a hands-free manner. The following are examples of use.

(1) Storage of work history

Work reports mainly include the results of work. For that reason, the submitted work check lists alone do not allow the manager to easily and completely grasp whether the work is carried out according to the procedure and the reports are correct. If the maintenance workers wear the wearable devices and keep the recording function activated, the work history can be stored without the need for them to be aware of it.

(2) Inspection support

In preventive maintenance work, an inspection procedure manual, etc. must be prepared in advance to check the soundness of the equipment based on the inspection check sheet. Introduction of the wearable device allows the inspection items on the check sheet to be shown on the small monitor according to the procedure. By using this, the results of inspection are input by voice and the inspection items can be confirmed and the results of inspection input in a complete hands-free manner. Furthermore, if the inspection procedure is unclear, the help function can be used to play a video of work procedure, etc., which allows smooth execution of inspection work.

(3) Learning support

The inspection support function described above

Fig.6 Example of how glasses-type wearable device is worn

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

*2: DPCS-F, PE-link: Fuji Electric's control networks

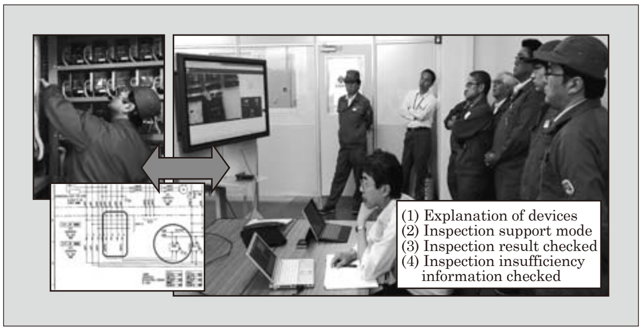


Fig.7 Practical training with inspection practice behavior remotely monitored

can also be used for self-learning of equipment inspection methods in maintenance worker education and training. The actual inspection can be practiced by playing the video as many times as necessary to check the inspection procedure and the techniques can be reliably acquired. How the inspection is carried out can be checked by the instructor using the monitor installed in the headquarters to give detailed advice. Figure 7 shows how the remote monitoring practical training for inspection behavior is given.

3.5 Security measures

The cloud-based equipment maintenance services provided by Fuji Electric ensure security of Web applications so that customers can use the services without anxiety.

(1) Ensured safety of installation environment

Possible risks relating to cloud services include deliberate attacks and suspension of services due to loss of power. As measures against deliberate attacks, server installation location zoning and authentication systems have been introduced. To deal with loss of power in disaster situations, UPSs have been employed to ensure safety of the installation environment.

(2) Ensured safety of cloud system

Safety measures in the network and service infrastructure are as shown below.

(a) Network

Communications are encrypted for protection against data leakage caused by wiretapping.

(b) ID management

An ID system that does not allow identification of personal information is used. Passwords required for accessing the cloud services are encrypted for storage to build a system that prevents viewing by other users.

(c) SQL statements (database language) and OS commands

Many cloud systems linked with databases create SQL statements based on the information input by the users to operate the databases. Any inadequacy in how the SQL statements are built may lead to an abuse of databases. To address this vulnerability, the actual values are not directly input into SQL statements but replaced by temporary symbols to indirectly assign the actual values. To deal with the vulnerability to illegitimate execution of OS commands of the Web server due to attacks from outside, measures have been taken such as avoidance of using a language function that allows similar direct operation.

4. Postscript

This paper has described service solutions that support stable operation of equipment. Utilization of the IoT realizes further stable operation and reduction of operation costs of plants and equipment and has a great potential. We intend to make use of the IoT to further enhance the functions of the cloud-based equipment maintenance services, thereby contributing to stable operation of customer equipment.

Boiler Combustion Solution for Reducing Fuel Costs

INAMURA, Yasuo* OZAWA, Shuji ⁑ AKAO, Kozo*

ABSTRACT

Fuji Electric has launched a boiler combustion solution that is capable of reducing fuel costs by about 1% by improving combustion efficiency and reducing the heat loss of boiler exhaust gas. The solution decrease the O_2 concentration of boiler exhaust gas from 2.40% to 0.86% by applying ultra-low excess air ratio combustion control that supremely reduces oxygen fuel ratio. This results in a reduction of fuel cost by approximately 28 million yen a year at a 450 t/h boiler. Combining this solution with a laser CO analyzer capable of taking real-time measurements can suppresses CO concentration in boiler exhaust gas to meet environmental standards. Trial runs were conducted with a heat source boiler and good results were obtained.

1. Introduction

The basic policy in the “Long-term Energy Supply and Demand Outlook” of the Agency for Natural Resources and Energy stipulates that it is necessary to improve energy savings and enhance the efficiency of thermal power stations, while achieving safety, stable supply, economic efficiency and environmental compatibility. Furthermore, the energy-saving measures in the industrial sector are aiming to reduce fuel usage (heavy oil equivalent) 10.42 million kL by 2030 by adopting innovative technologies with comprehensive energy management for plants and factories utilizing the Internet of Things (IoT) and high-efficiency equipment installations such as high-performance boilers.

It is against this backdrop that Fuji Electric launched its boiler combustion solution in November 2015. The adoption of ultra-low excess air ratio combustion control (a technology previously not possible) has enabled the improvement of boiler combustion efficiency and the reduction of boiler fuel costs by approximately 1%.

2. Boiler Combustion Solution

The improvement of boiler energy efficiency was mostly supported by mechanical methods. For example, these included increasing the capacity of boilers, increasing the temperature and pressure of the boiler outlet main steam, and increasing the exhaust heat recovery. However, these methods have just about reached their limit. The boiler combustion solution is different than conventional methods in that it complements the conventional boiler control system with the addition of a software package and laser CO analyzer, enabling it to improve boiler combustion efficiency, i.e., boiler efficiency.

2.1 Boiler control and optimum combustion

Boilers are installed in many different types of places such as steam power plants that include businesses for supplying electricity, power producers and suppliers (PPSs) and independent power producers (IPPs), as well as private-use steam power stations for sending electricity and steam to the facilities inside factories and businesses, and heat supply facilities for producing steam and hot water.

In addition, boilers need to be able to supply a stable amount of steam at the regulated pressure and temperature even when the operating conditions of load-side equipment change. There are many boiler control methods available, and the most common methods are shown in Fig. 1.

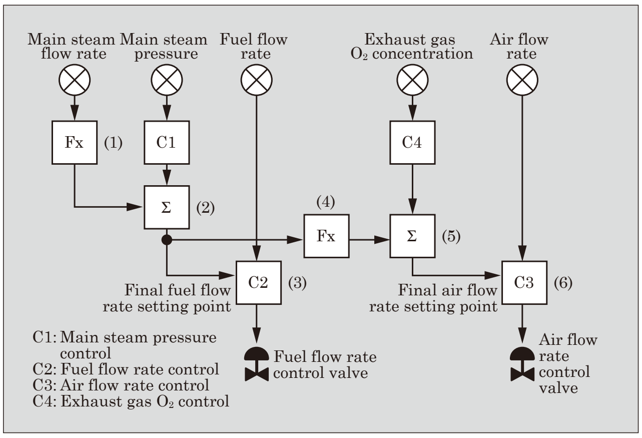


Fig.1 Basic block diagram of boiler automatic combustion control

* Corporate R&D Headquarters, Fuji Electric Co., Ltd.

⁑ Industrial Infrastructure Business Group, Fuji Electric Co., Ltd.

(1) Calculation of the fuel flow rate control setting value (see Fig. 1 (1))

Since the boiler outlet main steam flow rate signal initially changes when there is a change in the amount of steam used on the load-side of the boiler, the amount of fuel necessary for generating steam is calculated from this signal, and this value becomes the setting point for fuel flow rate control. When the main boiler outlet steam flow rate signal changes due to a fluctuation in the boiler load, the setting point of the fuel flow rate changes immediately, and this helps to improve fuel control.

(2) Final fuel flow rate setting point (see Fig. 1 (2))

The main steam pressure control value is calculated so that the boiler outlet main steam pressure complies with the specified setting point. The setting point for the fuel flow rate is configured by the boiler outlet main steam flow rate signal in order to improve control, but this signal is compensated via the output of the main steam pressure control value calculation in order to obtain the final fuel flow rate setting point. In this manner, it is possible to implement the boiler outlet main steam pressure control for maintaining boiler outlet steam pressure at a constant value, while also improving the fuel control at times of boiler load fluctuation.

(3) Boiler fuel control (see Fig. 1 (3))

Based on the final fuel flow rate setting point, the fuel flow rate control value is calculated and the boiler fuel is controlled.

(4) Air flow rate setting (see Fig. 1 (4))

The proper amount of air is calculated so as to burn the fuel that corresponds to the final fuel flow rate setting value, and the value of this calculation becomes the air flow rate setting point.

(5) Final air flow rate setting (see Fig. 1 (5))

The control value for the O_2 concentration in the boiler exhaust gas is calculated, and the final air flow rate setting point is obtained by additionally adjusting the air flow rate setting point so that the exhaust gas O_2 concentration becomes the control target value.

(6) Boiler air control (see Fig. 1 (6))

Based on the final air flow rate setting point, the air flow rate control value is calculated and the boiler air volume is controlled.

2.2 Structure and features of boiler combustion solution

The theoretical air volume and excess air ratio are very important components of boiler combustion. The theoretical air volume in the boiler combustion represents the amount of air used when complete combustion is carried out with fuel and air mixed in an ideal state. However, actual boilers emit more CO and black smoke than the environmental standard value due to the incomplete combustion even when the theoretical air volume is supplied to the boiler. Therefore, it is necessary to supply the boiler with an amount of air in excess of the theoretical air volume so that the amount of CO and black smoke emissions do not exceed the environmental standard value. As shown in Formula 1, the excess air ratio is the ratio between the actual amount of air supplied to the boiler and the theoretical air volume.

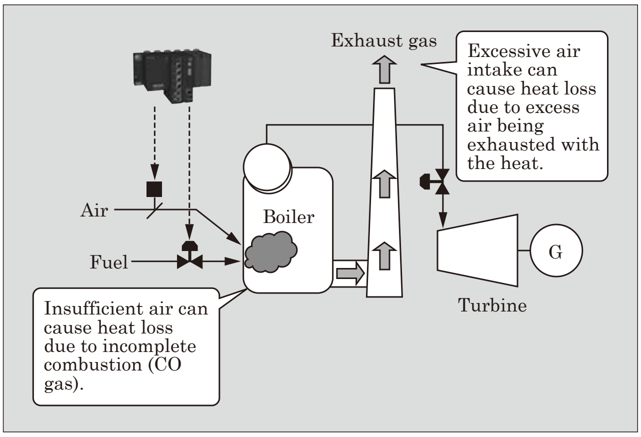


Fig.2 Heat loss in boiler combustion

$$\text{Excess air ratio} = \frac{\text{Actual amount of supplied air}}{\text{Theoretical air volume}} \quad \text{...(1)}$$

The heat loss in boiler combustion shown in Fig. 2 is largely influenced by the excess air ratio. For instance, if the amount of air supplied to the boiler exceeds the proper amount for burning the fuel (i.e., the excess air ratio is too large), there will be extra air that does not contribute to combustion, and this air will take away from the heat energy inside the boiler, thus causing heat loss to occur since the heat energy will be emitted from the smokestack as exhaust gas. On the other hand, if the amount of air supplied to the boiler is insufficient for burning the fuel (i.e., the excess air ratio is too small), CO and black smoke will occur due to incomplete combustion, and heat loss will occur due to incomplete combustion since these will be emitted from the smokestack as exhaust gas.

Our boiler combustion solution minimizes heat loss, while improving the heating efficiency of the boiler. Figure 3 shows the optimum combustion zone for the boiler. This figure is a graph that shows the relationship between excess air induced heat loss and incomplete combustion induced heat loss.

As shown in the figure, the zone for minimizing the total heat loss (i.e., the combination of heat loss due to both excess air and incomplete combustion) is in the ultra-low excess air ratio combustion zone located to the left of the conventional air ratio combustion zone.

This concept has been known for a long time, but up until now, the technology for successively and stably implementing continuous automatic operation in this region did not exist. However, Fuji Electric has established a technology by combining our uniquely developed combustion calculation with our quick-response laser CO analyzer. We will now describe the basic way of thinking regarding this technology.

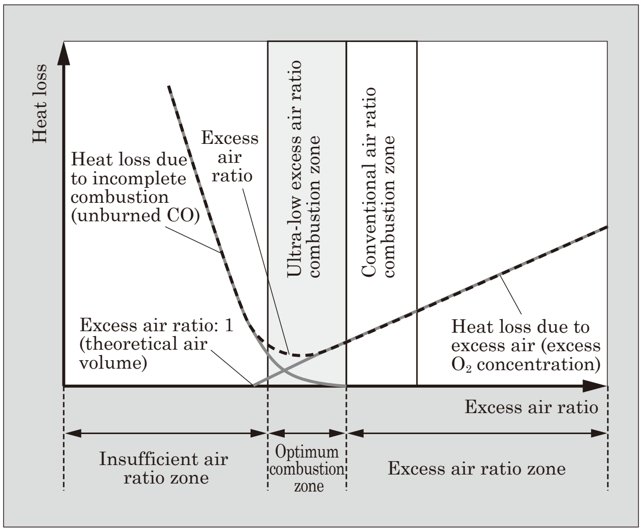


Fig.3 Optimum combustion zone for boiler

Excess air induced heat loss and incomplete combustion induced heat loss can generally be represented by Formula (2) and Formula (3).

$$L_{\text{air}} = \frac{1}{0.21} C_{\text{PA}} (T_{\text{o}} - T_{\text{I}}) (G \times O_2) \quad \text{(2)}$$

$$L_{\text{co}} = G \times CO \times H_{\text{co}} \quad \text{(3)}$$

L_{air} : Heat loss due to excess air
L_{co} : Heat loss due to incomplete combustion
C_{PA} : Specific heat of air (kJ/Nm^3·K)
T_{o} : Air temperature in the boiler exhaust gas (K)
T_{I} : Forced draft fan inlet air temperature (K)
G : Boiler exhaust gas flow rate (Nm^3/h)
O_2 : Boiler exhaust gas O_2 concentration (%)
CO : Boiler exhaust gas CO concentration (ppm)
H_{co} : Quantity of heat of CO (kJ/Nm^3)

The exhaust gas flow rate G can be determined by the calculation to the extent that the components of the fuel are known in advance. However, since there is variation in the components of the fuel used in actual boilers, the components are not consistently constant. Furthermore, there are also cases of mixed-fuel combustion. Therefore, the optimum heat loss calculation used in Formula (2) and Formula (3) is not practical since too many parameters need to be determined and assigned.

Fuji Electric has developed a proprietary control logic that makes use of a theoretical formula for combustion based on thermodynamics and combustion reactions, both of which have never been applied to conventional boiler control. During on-site testing, this control logic automatically set multiple parameters that needed to be determined and assigned for each steam load of the boiler, while also facilitating practical combustion inside the ultra-low excess air ratio combustion zone.

The boiler combustion solution has the following features.

(a) Applicable regardless of the type of boiler fuel or use of mix-fuel combustion.
(b) Capable of control at the optimum excess air ratio for every boiler load.
(c) Capable of suppressing CO emissions in the boiler exhaust gas to maintain compliance with environmental standards.
(d) Capable of preventing abnormal increases in the CO in the boiler exhaust gas. Combustion in the ultra-low excess air ratio combustion zone is susceptible to there being an excess amount of CO in the boiler exhaust gas due to insufficient air when there is temporary fluctuation in the excess air ratio. As a countermeasure against this, the boiler combustion solution makes use of a laser CO analyzer that is capable of high-speed measurement of the CO concentration in the boiler exhaust gas, while also employing control software (boiler exhaust gas CO abnormality high-blocking control) for suppressing the CO concentration in the boiler exhaust gas to a value below the prescribed upper limit in the case of every boiler behavior.
(e) Capable of being installed regardless of the manufacturer of existing boiler control systems, and does not require significant remodel to existing boiler combustion control systems.

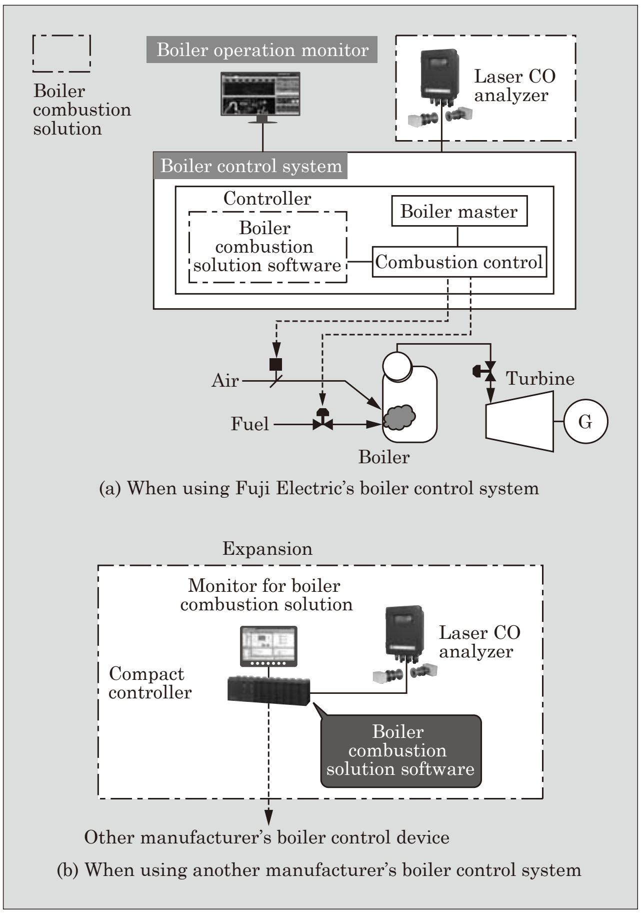


Fig.4 Installation method for boiler combustion solution

The installation method for the boiler combustion solution is shown in Fig. 4.

2.3 High-speed measurement of CO concentration

In this boiler combustion solution, high-speed measurement of the CO concentration in the boiler exhaust gas is an important functionality for achieving ultra-low excess air ratio combustion.

(1) Boiler exhaust gas CO abnormality high-blocking control

Boiler combustion solutions burn the fuel in the boiler in a state of ultra-low excess air, and implement control while continuously producing extremely small amounts of incomplete combustion inside the furnace on a regular basis. Furthermore, as shown in Fig. 3, incomplete combustion increases like a cubic curve if the excess air ratio falls below a certain threshold (increase in the concentration of exhaust gas CO), and black smoke is generated if below a certain excess air ratio.

Therefore, even if boiler behavior is represented by the following 3 scenarios, the prevention of excessive incomplete combustion using the high-speed response laser CO analyzer can be referred to as boiler exhaust gas CO abnormality high-blocking control.

(a) When the boiler burner is ignited and there is a temporary change in the balance between the amount of fuel and air in the boiler

(b) When automatic control is implemented for the fuel and air amount as a result of a change in the calorific value of the fuel, and there is a temporary change in the excess air ratio, regardless of there being no fluctuation in the steam load of the boiler

(c) When the air and fuel amount is controlled via air-rich (excessive air) control in order to prevent black smoke from occurring, and there is a temporary change in direction that makes the excess air ratio decrease at times of sudden increase in the steam load of the boiler

(2) Optimum combustion logic computation

In addition to the above mentioned boiler exhaust gas CO abnormality high-blocking control, the CO concentration signal is also used as follows in ultra-low excess air ratio combustion control to reduce the amount of fuel.

(a) Calculation of optimum excess air ratio

(b) Control for suppressing boiler exhaust gas CO to meet environmental standards

2.4 Laser CO analyzer

Fuji Electric's laser gas analyzers were the first of its kind on the Japanese market and have obtained a proven track record for quality. Figure 5 shows the configuration of the laser CO analyzer. It has the following features.

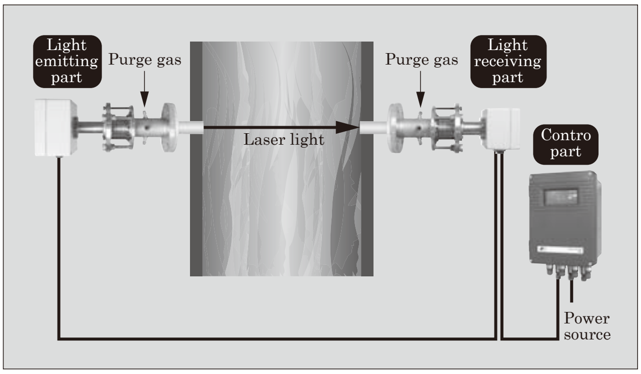


Fig.5 Configuration of laser CO analyzer

(1) High-speed response

Since the sensor component is directly inserted into the exhaust gas duct of the boiler, there are no time delays due to gas sampling, and as such, changes in the gas concentration inside the gas duct are detected instantly (Response time: 1 to 2 seconds).

(2) Easy maintenance

The direct-insert system makes daily maintenance, such as filter replacement in the gas sampling system, unnecessary, and calibration work only needs to be performed once every 6 months.

(3) Low interference of other gases on the CO measurement

Since the infrared wavelengths absorbed by the CO gas do not overlap with the wavelengths of other gases or moisture, this gas analyzer is theoretically not susceptible to interference from other gases.

3. Results of Boiler Combustion Solution Trial Run in Heat Source Boiler

In March 2016, a heat source boiler with a boiler capacity of 450 t/h was newly installed in Paris by RCU as a wide-ranging infrastructure installation for supplying hot water at a pressure of 1.5 MPa. The boiler combustion solution was employed for this installation. Good results were obtained in the automatic control test, and up until now, the solution has been utilized smoothly.

Good results have also been obtained in both the automatic control test for ultra-low excess air ratio combustion and the emergency stop test for the boiler combustion solution.

3.1 Overview of trial run equipment

Since the control device of the boiler was manufactured by another company, the Fuji Electric compact controller, which comes equipped with a software package for controlling boiler combustion, was designed so that it could be stored in the wall-mounted panel. This panel is compact with a height of 760 mm, a width of 600 mm, and a depth of 300 mm. In addition, the signals for communicating with the boiler control system consist of approximately 10 control and interlock signals and 20 monitoring signals, thus establishing process I/O connectivity.

Table 1 Boiler overall specifications

Item	Specification
Boiler capacity	450 t/h (max.) hot water
Boiler outlet main steam pressure	1.5 MPa (max.)
Boiler outlet main steam temperature	171 °C (max.)
Fuel	Natural gas
Boiler exhaust gas temperature	176 °C (max.)
Natural gas flow rate	36,830 Nm^3/h (max.)

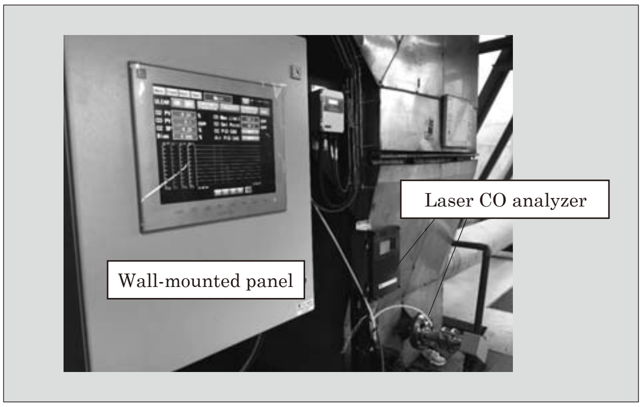


Fig.6 Installation state of wall-mounted panel and laser CO analyzer

Table 1 shows the basic overview of the specification of the boiler, and Fig. 6 shows the installation state of the wall-mounted panel that houses the boiler combustion solution, as well as the laser CO analyzer.

3.2 Trial run results

(1) Automatic control test for ultra-low excess air ratio combustion

Figure 7 shows the results of activating the boiler combustion solution and implementing the automatic control test for ultra-low excess air ratio combustion at a burner load of 50%.

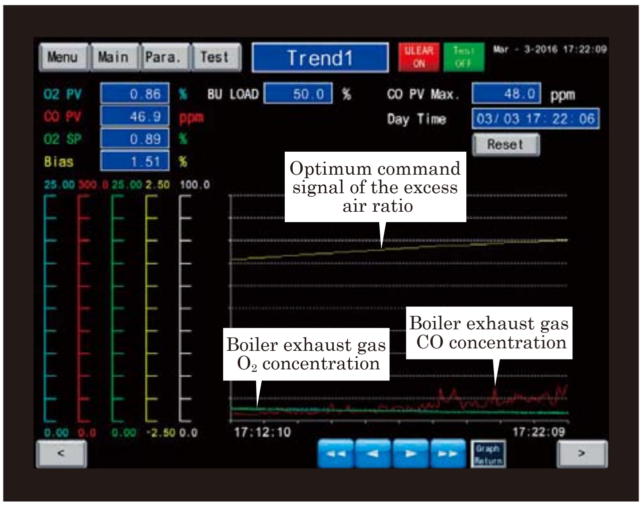


Fig.7 Automatic control test results for ultra-low excess air ratio combustion

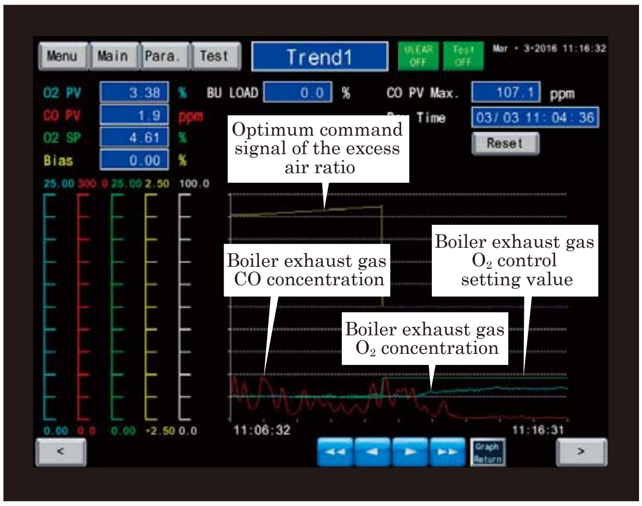


Fig.8 Emergency stop test results for boiler combustion solution

Since the boiler exhaust gas O_2 concentration is reduced from 2.40% to 0.86%, improvements in exhaust gas heat loss account for a reduction in yearly fuel costs by approximately 28 million yen.

(2) Emergency stop test for the boiler combustion solution

Figure 8 shows the results of the emergency stop test in which the boiler combustion solution was immediately stopped. The boiler combustion solution takes fully into account the safety of boiler plants, and as such, it undergoes emergency stop when there is a malfunction with related equipment, disconnection of I/O cables, abnormality in the maximum upper and lower limits of a process, control mode failure, etc. When the boiler combustion solution undergoes emergency stop and is disconnected from the boiler control system, the system is automatically restored to the boiler exhaust gas O_2 control state that existed previous to employing the boiler combustion solution so that control can continue to be implemented via the excess air ratio.

Figure 8 shows trend charts for process values that were recorded in the results of the boiler combustion solution trial run. Some of the values include the optimum command signal value of the excess air ratio, the boiler exhaust gas O_2 concentration and boiler exhaust gas CO concentration. The center portion of the chart shows continuous control in a state in which the boiler combustion solution undergoes emergency stop and the optimum command signal of the excess air ratio simultaneously drops sharply, while the value of the boiler exhaust gas CO concentration is nullified and the boiler exhaust gas O_2 concentration rises.

4. Postscript

We have described the boiler combustion solution for decreasing fuel costs. We are currently developing systems that utilize IoT and are offering our customers, including those who are located far distances away, services for monitoring the state of boiler combustion and for performing maintenance, while also continuing to pursue the development of tools that support mutual information exchange. In the future, we plan to develop high added-value information and control systems, as well as solution packaged software suites and services so that we can provide new value for our customers.

Solution for Estimating Generation Source of PM 2.5 with "Aerosol Analyzer"

KOIZUMI, Kazuhiro* TAKEDA, Naoki* NAKAMURA, Yusuke ‡

ABSTRACT

In recent years, air pollution has become a concern due to fine particles (PM 2.5) that have a diameter of 2.5 µm or less. In particular, pollution has become a serious problem in Asia, and in the future, it is expected that effective measures to reduce PM 2.5 will be sought and adopted in earnest. Fuji Electric's "Aerosol Analyzer" is capable of automatically analyzing the main components of PM 2.5. Since the measured component data includes information concerning the sources of origin of the PM 2.5, it is expected that the estimation of the main sources of origin through data analysis will contribute to creating effective measures of mitigation. Measurement examples in Kawasaki City and in China showed that it is possible to estimate the approximate location of the sources of origin.

1. Introduction

Aerosol (fine particles suspended in the air) has a significant impact on air pollution, and as a result, there has been an advance in countermeasures and analysis techniques for assessing the state of aerosol. The important parameters of aerosol include its particle size (diameter of the particle) and components. Aerosol has a particle size that ranges from several nm to 100 µm. Among the different sizes, aerosol with a particle size of 2.5 µm or less is referred to as PM 2.5. Since PM 2.5 is capable of penetrating deep inside the lungs, there are concerns about its health effects. Therefore, environmental standards*[1] were announced regarding PM 2.5 in Japan in 2009.

There are various components of PM 2.5, but the main components include inorganic ion components such as sulfates (mainly sulfate ion: SO_4^{2-}) and nitrates (mainly nitrate ion: NO_3^-), organic matter and black carbon (elemental carbon). Black carbon and some organic matters are referred to as primary generated aerosols since they are contained in the exhaust gas of diesel engines and are directly emitted from the sources of origin. On the other hand, sulfates and nitrates are referred to as secondary generated aerosols since they are generated by the chemical reactions in the atmosphere caused by precursors such as the SO_2 and NO_x, which are emitted from the sources of origin. Since the components of PM 2.5 provide very important information that is useful in the elucidation of the sources of origin, local governments are being required to perform component analysis in addition to conventional PM 2.5 mass concentration measurement activities.

Component analysis of PM 2.5 is generally performed by a filter based method based on a standard measurement method. The filter based method is performed via manual analysis of PM 2.5 collected in a filter. As a result, this method requires a lot of time and cost, and it needs to be implemented often due to the limited time of measurement periods. It is against this backdrop that Fuji Electric has developed and released an "Aerosol Analyzer" as a device for measuring the main components of PM 2.5. It is capable of automatic operation at all stages of the analysis process from sampling to measurement. In this paper, we will describe the features of the aerosol analyzer and introduce its measurement principles, while also providing some measurement examples and describing its uses as a solution for estimating the generation source of PM 2.5.

*1: Environmental standard: A yearly average of 15 µg/m³ or less, and a daily average of 35 µg/m³ or less

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

2. "Aerosol Analyzer"

2.1 Features

Figure 1 shows the external appearance of the aerosol analyzer. The aerosol analyzer is capable of implementing real-time quantitative analysis of the main components of PM 2.5.

(1) Three-component simultaneous measurement via compound analysis

The compound analysis combines light scattering, laser-induced incandescence (LII) and mass spectrometry to enable simultaneous measurement of sulfates, nitrates and black carbon.

(2) Real-time component analysis

The measurement period for component analysis

Fig.1 “Aerosol Analyzer”

that used to take more than 8 hours using the filter based method can now be done in 15 minutes.

(3) Quantitative analysis of the components

PM 2.5 is collected with high-efficiency using a particulate trap that adopts micro electro mechanical systems (MEMS) technology, thus making it possible to implement quantitative analysis, which is something that was difficult to do in the past.

(4) Display and operation via touch screen

Major operations can be performed using the touch screen that is mounted to the front surface of the aerosol analyzer. In addition to displaying measurement values, it is also possible to monitor the operation status, as well as display alarms.

2.2 Specifications

Table 1 shows the main specifications of the aerosol analyzer.

2.3 Measurement principles

The aerosol analyzer consists of an LII component and mass spectrometry component. Figure 2 shows the measurement principles.

The LII component measures the mass concentration of PM 2.5 and black carbon. It detects the scattered light and incandescent light that comes from the aerosol contained in the air sample when the air sample is irradiated with a high powered infrared laser. The mass concentration of PM 2.5 is determined by measuring the particle size and number of particles from the intensity and frequency of the scattered light. At the same time, the mass concentration of black carbon contained in the PM 2.5 is determined from the intensity and frequency of the incandescent light.

The mass spectrometry component measures the mass concentration of the sulfates and nitrates of the ion components contained in PM 2.5. There are 2 methods available for implementing online mass spectrometry of the components of PM 2.5. These include a laser desorption/ionization mass spectrometry method that implements mass spectrometry via direct laser ionization, as well as a thermal desorption electron ionization mass spectrometry method that implements mass spectrometry via electron ionization after performing thermal vaporization using collected PM 2.5. Though the laser desorption/ionization mass spectrometry method is highly sensitive, quantitative analysis is difficult to be conducted due to the variation in ionization efficiency among components. On the

Table 1 Main specifications of “Aerosol Analyzer”

Item	Specification
Measurement target	○Mass concentration of the PM 2.5 ○Mass concentration of black carbon contained in the PM 2.5 ○Mass concentration of the sulfates contained in the PM 2.5 ○Mass concentration of the nitrates contained in the PM 2.5
Measurement method	○Light scattering method: Mass concentration of the PM 2.5 ○Laser-induced incandescence: Mass concentration of black carbon ○Mass spectrometry: Mass concentration of sulfates and nitrates
Measurement range*	○PM 2.5: 0 to 100 μg/m³ or 0 to 1,000 μg/m³ ○Black carbon: 0 to 30 μg/m³ or 0 to 300 μg/m³ ○Sulfates: 0 to 30 μg/m³ or 0 to 300 μg/m³ ○Nitrates: 0 to 30 μg/m³ or 0 to 300 μg/m³
Sampling amount	Approx. 2.0 L/min
Power supply voltage*	100 V AC ±10%, 50 Hz/60 Hz ±5% or 220 V AC ±10%, 50 Hz ±5%
Power consumption	Approx. 1 kVA (Max. 1.5 kVA)
Dimensions	Main unit: W 640 × H 1,740 × D 828 (mm)
Mass	Main unit: Approx. 320 kg
Accessories	Scroll pump, UPS, chiller and others

* Measurement range, power supply voltage: Selected at time of purchase

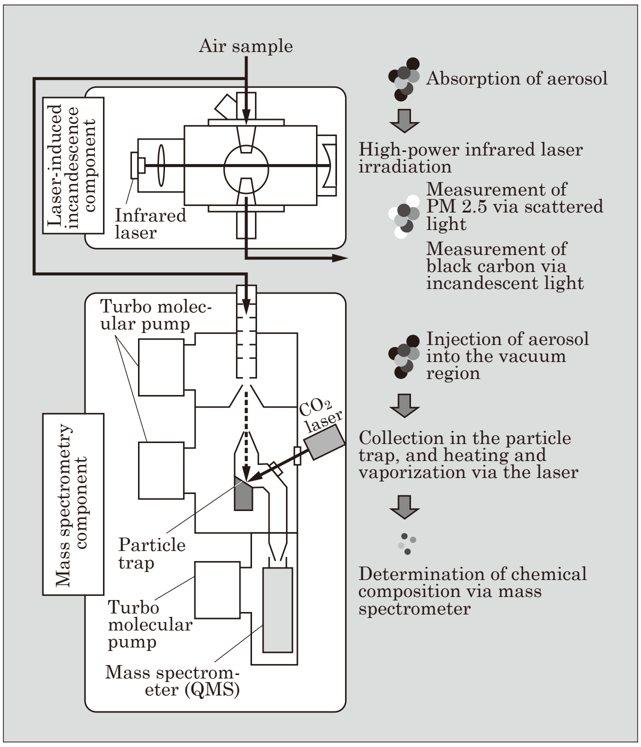


Fig.2 “Aerosol Analyzer” measurement principles other hand, the thermal desorption electron ionization mass spectrometry method exhibits good quantitativeness regardless of selectivity in ionization. The aerosol analyzer adopts the thermal desorption electron ionization mass spectrometry method from the standpoint of quantitatively analyzing the PM 2.5 contained in the utilized air sample.

When the air sample is injected into the vacuum chamber of the mass spectrometry component, the gas in the air sample is removed and only PM 2.5 is collected into the particle trap. The particle trap has a uniquely developed structure that was created using MEMS technology, and it achieves a high collection efficiency of at least 90%(1). The external appearance of the particle trap is shown in Fig. 3. The collection portion of the particle trap is composed of a 100 µm square lattice-like structure. By superimposing multiple lattice-like plates, PM 2.5 moves quickly through a vacuum while repeatedly colliding against the inner wall of the particle trap, thus depriving the kinetic energy, while enabling collection. This PM 2.5 is irradiated with the high powered infrared laser (CO_2 laser) to create heat and vaporization, and after undergoing ionization via the electron-ion source, quantitative analysis is performed for the sulfates and nitrates utilizing a quadrupole mass spectrometer (QMS).

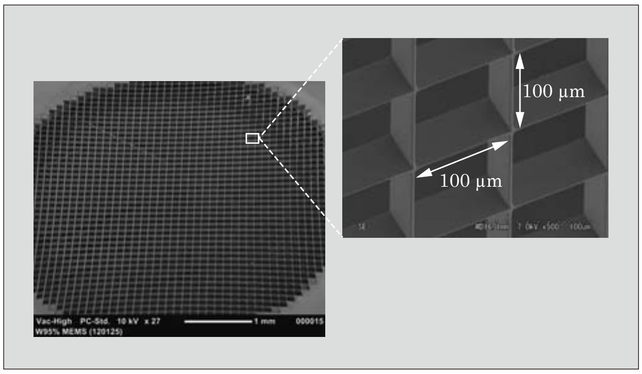


Fig.3 External appearance of particle trap

2.4 Measurement examples

We implemented a field evaluation with the help of local governments. We installed an aerosol analyzer at an ambient air pollution monitoring station as part of a joint research project (Kawasaki City Environmental Technology Industry-Academia-Public-Private Collaboration Research Pilot Project) implemented with Kawasaki City from FY2013 to FY2015. As a result, we were able to verify the measurement performance and maintainability of the analyzer. Figure 4 shows the results of carrying out a compara-

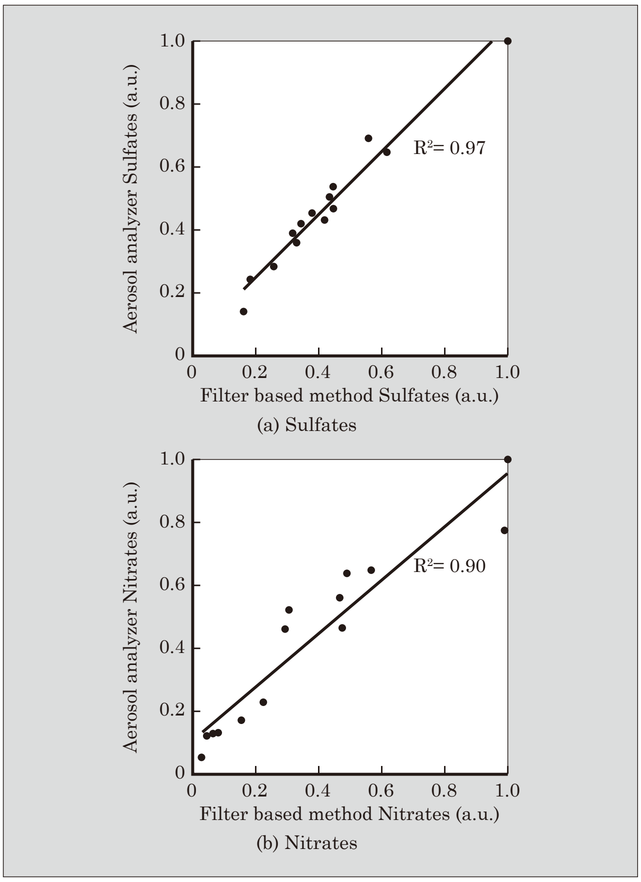


Fig.4 Results of comparative evaluation with filter based method

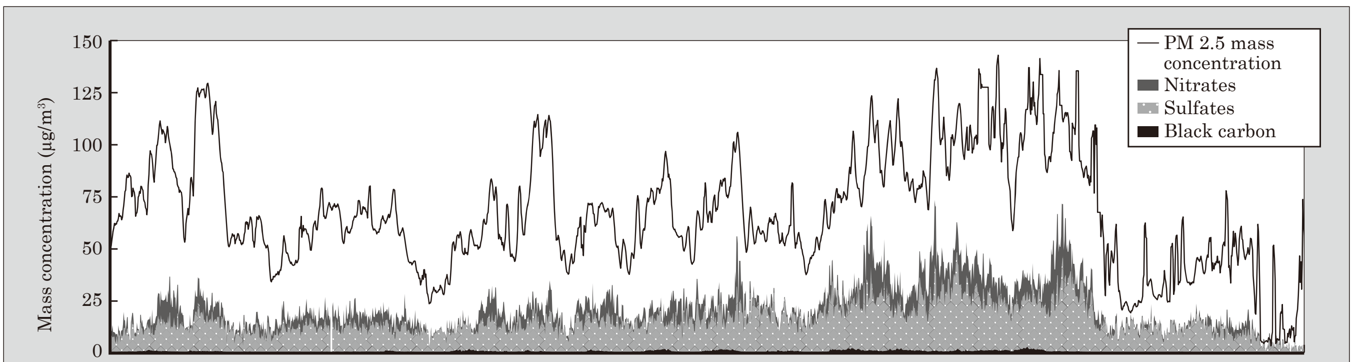


Fig.5 Measurement example in China

tive evaluation with the filter based method in regard to sulfates and nitrates. The determination coefficient R^2 in the analysis of the aerosol analyzer and the filter based method demonstrated a high correlation of 0.9 or higher for each.

Furthermore, the field evaluation was not only carried out in Japan, but also overseas. Figure 5 shows an example of continuous measurement being implemented in China. We confirmed that continuous real-time measurement can be implemented smoothly even in high concentration environments where the mass concentration of PM 2.5 exceeds 100 μg/m³.

3. Solution for Estimating Generation Source of PM 2.5

3.1 Need for estimating generation source

In China, pollution has become a serious problem, and as a result, measures are being taken in earnest to reduce PM 2.5. The Air Pollution Prevention Action Plan (announced by China's State Council in September 2013) has set a goal of reducing the yearly average PM 2.5 concentration by approximately 15% to 25% when compared with the year 2012. The goal is intended to be achieved by the year 2017 for the regions of Beijing, Tianjin and Hebei, as well as the various regions around the Yangtze River Delta and Pearl River Delta. According to the PM 2.5 source apportionment for Beijing (announced in April 2014) conducted by the Beijing Municipal Environmental Protection Bureau, the main occurrence factors for PM 2.5 include automobiles (31%), coal combustion (22%), industrial production (18%), dust (14%) and others (14%). Furthermore, air pollution has been shown to improve significantly when traffic restrictions and factory shutdowns are imposed at the time of hosting important international conferences and sporting events. However, these types of restrictions cannot be imposed long term because of their impact on economic activities.

In order to strike a balance between solving environmental problems and achieving sustainable economic growth, it is important to understand the conditions of occurrence and to take effective measures against the sources of occurrence. As a result, there has been rapidly increasing demand for instrumentation equipment that not only supports measurement of PM 2.5, but also facilitates reduction measures through analysis of generation sources. Therefore, we have been working on the development of a system for estimating the generation sources of PM 2.5. The system estimates generation sources by analyzing various data in combination, which includes the measurement data from the aerosol analyzer, data on precursors and meteorological data. Figure 6 shows the configuration of the system.

3.2 Overview of generation source analysis technology

In the analysis of generation sources, emphasis is placed on the generation process of secondary generated aerosols (sulfates and nitrates), and estimation of generation sources is performed based on the differences in the lifetime and diffusion process of secondary generated aerosols and their precursors in the atmosphere. Gaseous precursors spread via atmospheric circulation immediately after being emitted regardless of the location of their generation sources, but the concentration of these substances decreases gradually as they are mixed in with the surrounding air. On the other hand, PM 2.5 is mainly removed from the atmosphere via precipitation such as rain or snow, and as a result, it can remain in the atmosphere and travel long distances for periods of over one week depending on environmental conditions, such as when it does not rain.

Therefore, the correlation between the secondary generated aerosol concentration and precursor gas concentration is analyzed, and if there is high correlation in these concentration changes, it is estimated that the generation source is in the vicinity of the place of measurement (approximately less than 100 km). If the correlation is low, this means that the generation source is located at a remote distance from the place of measurement (approximately 100 km or more), and in such a case, it is estimated that advection will likely occur from outside of the region. As mentioned above, since the influence of the weather is large, analysis needs to be done in consideration of meteorological data.

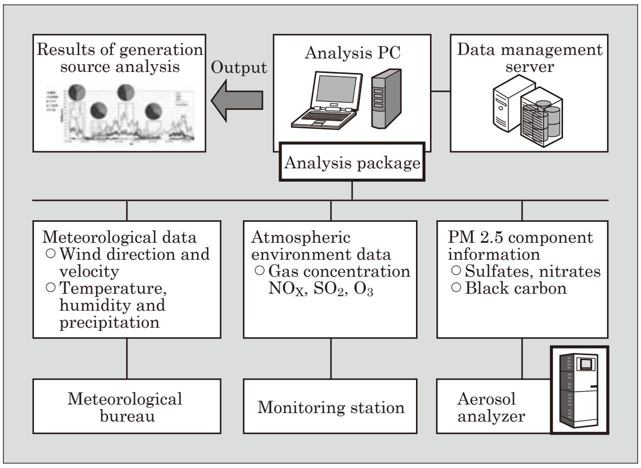


Fig.6 Configuration of system for estimating generation sources of PM 2.5

3.3 Analysis case examples

An analysis case example of sulfate and its precursor SO_2 is shown in Fig. 7. Figure 7(a) and Figure 7(b) show data measured in different regions. The aerosol analyzer was used to obtain the measurement data for the sulfate, but a separate gas analyzer was used to obtain the measurement data for the SO_2.

Figure 7(a) shows the correlation in the concentration changes of the sulfates and SO_2 cannot be seen. In such a case as this, it can be estimated that the

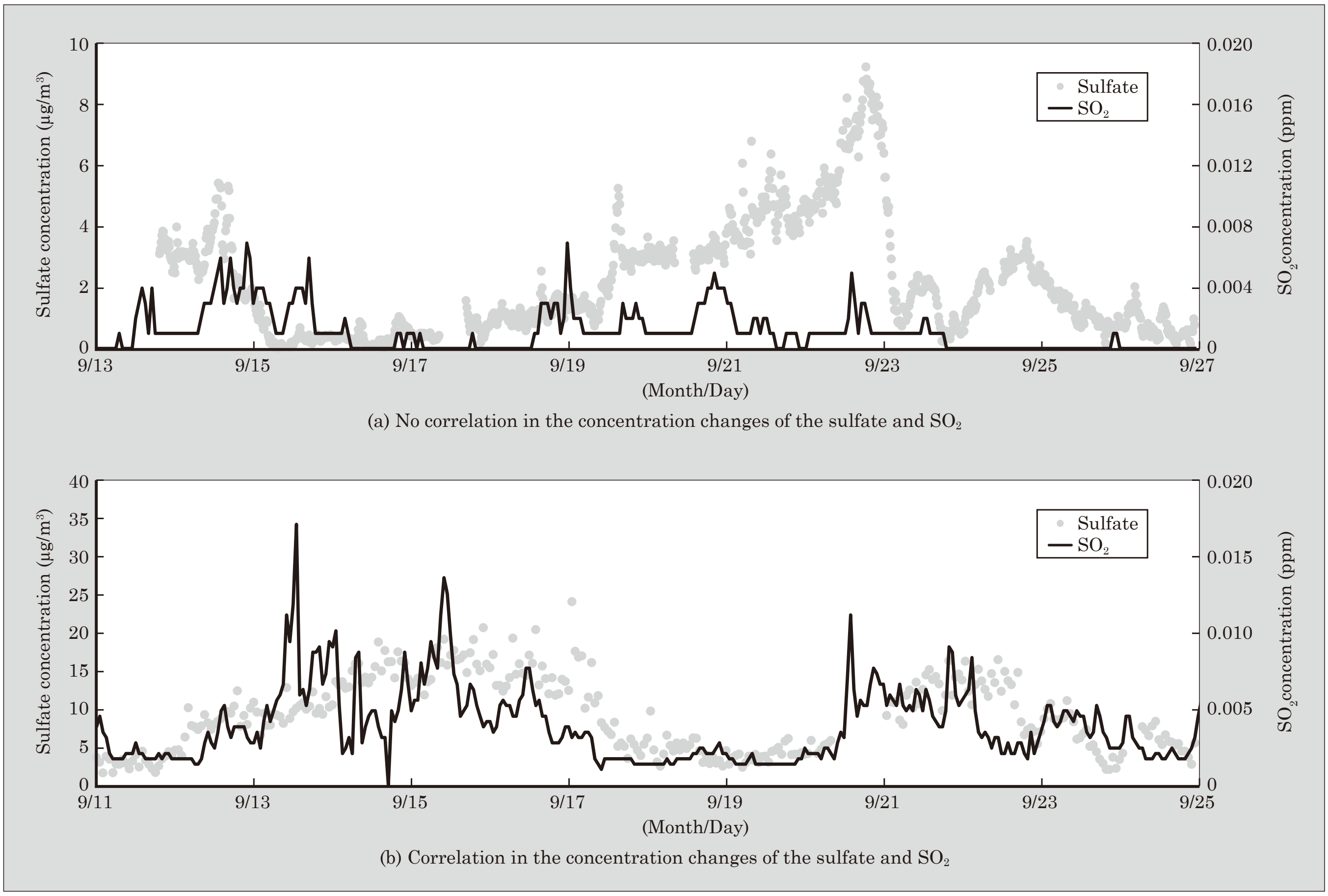


Fig.7 Analysis case example of sulfates and SO_2

generation source of the sulfates is located at a remote distance from the place of measurement. The weather during this period was mostly sunny, and the weather map showed a migratory anticyclone moving from west to east, and as a result, it could be estimated that much of the aerosol would be carried via advection from the west due to westerlies.

Figure 7(b) shows the motion that the concentration of the sulfates followed in contrast to the concentration of the SO_2, and the correlation in the concentration changes of the sulfates and SO_2 is also observable. In such a case as this, it can be estimated that the generation source of the sulfates exists in the vicinity of the place of measurement. The weather during this period was sunny or cloudy, and since the wind was nearly always blowing from the north-west, it could be estimated that the main generation source was a coal-fired power plant located several tens of kilometers north-west of the place of measurement.

3.4 Future developments

As described above, it is possible to estimate generation sources by analyzing the correlation between secondary generated aerosols and precursors. The current state of the analysis is limited to rough estimation, but by increasing the number of places of measurement by installing multiple aerosol analyzers in the applicable regions, analysis can be performed in combination with various data such as the operation data of major factories and power plants, traffic data and topographical information. By doing this, we believe that we will be able to estimate generation sources in detail. Furthermore, we are planning to implement a demonstration project of the system for estimating the generation sources of PM 2.5 in cooperation with local governments.

4. Postscript

In this paper, we have described our “aerosol analyzer,” which is capable of implementing real-time quantitative analysis of the main components of PM 2.5, as well as introduced our solution for estimating the generation sources of PM 2.5 with the aerosol analyzer. PM 2.5 not only influences air pollution, but also greatly impacts climate change such as global warming, and as a result, it needs to be dealt with on a worldwide scale. In the future, we plan to provide an instrumentation solution based on a foundational technology for accurately measuring fine particles, and we believe this solution will contribute to the conservation of the world’s environment and the sustainable development of society.

References

(1) Takegawa, N. et al. "Evaluation of a New Particle Trap in a Laser Desorption Mass Spectrometer for Online Measurement of Aerosol Composition." Aerosol Science and Technology, 46.4 (2012) : p.428-443.

Real-Time Remote Monitoring System Utilizing New Electronic Personal Dosimeter

NAKASHIMA, Sadao* MAEKAWA, Osamu* ABE, Shigeru*

ABSTRACT

Conventional radiation exposure management methods included sounding a dosimeter alarm when a measured value reaches a pre-set exposure dose level to prevent further exposure. Meanwhile, the real-time remote monitoring system enables managers to monitor the exposure dose of workers in real time and give workers appropriate instructions before the alarm of the pre-set level is raised to prevent unnecessary exposure. The new electronic personal dosimeter developed by Fuji Electric can use cloud servers, web applications, and Wi-Fi compliant general-purpose access points, allowing constructing a real-time remote monitoring system with low initial investment.

1. Introduction

Fuji Electric has been focusing on developing radiation management solutions, and in particular, we have been maintaining the top market share in the Japan for its electronic personal dosimeters for use in nuclear power plants.

In order to manage exposure to radiation, workers are required to wear a personal dosimeter, which comes in 2 different types: a passive-type and an active-type. Passive-type personal dosimeters require that a special device be used approximately once a month to analyze the exposure dose. In contrast to this, active-type personal dosimeters are capable of real-time measurement of exposure doses, and they help workers avoid unnecessary exposure doses through raising an alarm, etc.

The real-time remote monitoring system comes equipped with an active-type personal dosimeter, and this enables managers to monitor the exposure dose and give workers appropriate instructions even when the display of the dosimeter cannot be verified due to working conditions. As a result, it can be expected that the exposure dose will be reduced even further.

In this paper, we will introduce the real-time remote monitoring system, which can be easily adopted in hospitals, laboratories, universities and other places that are equipped with a Wi-Fi network.

2. Real-Time Remote Monitoring System

Radiation management requires that "economic and social factors be taken into consideration, reduce every dose as low as reasonably achievable" based on the concept of ALARA (as low as reasonably achievable), a key guiding principle recommended by the International Commission on Radiological Protection (ICRP) in 2007 . In order to achieve this, the exposure dose must be actively reduced. However, the conventional radiation exposure management method included raising a dosimeter alarm to notify workers when the measured value reaches the pre-set exposure dose level to prevent further exposure. As a result, exposure needed to be tolerated until raising the alarm.

On the other hand, the real-time remote monitoring system enables managers to monitor the exposure dose of workers in real time and give workers appropriate instructions before the exposure dose reaches the pre-set level at which an alarm is raised. Therefore, unlike conventional systems, where action could only be taken after being exposed, this system enables taking measures to avoid unnecessary doses of exposure by alerting workers to locations of unexpectedly high dose rates either before or during the process of work. There are already some cases in the United States where the adoption of the real-time remote monitoring system has contributed significantly in reducing the exposure dose of workers, and we believe that the use of this system will also become widely adopted in Japan in the future.

2.1 System configuration

The real-time remote monitoring system connects approximately 10 dosimeters to 1 repeater; and in a typical configuration it transmits measurement data on the aggregated exposure dose and dose rate to a server in real-time. An installed repeater monitors the entire area by spanning the regions covered by each unit. The repeater communicates with dosimeters in its network and other repeaters wirelessly, and transmits data to the wireless master unit. The

* Industrial Infrastructure Business Group, Fuji Electric Co., Ltd.

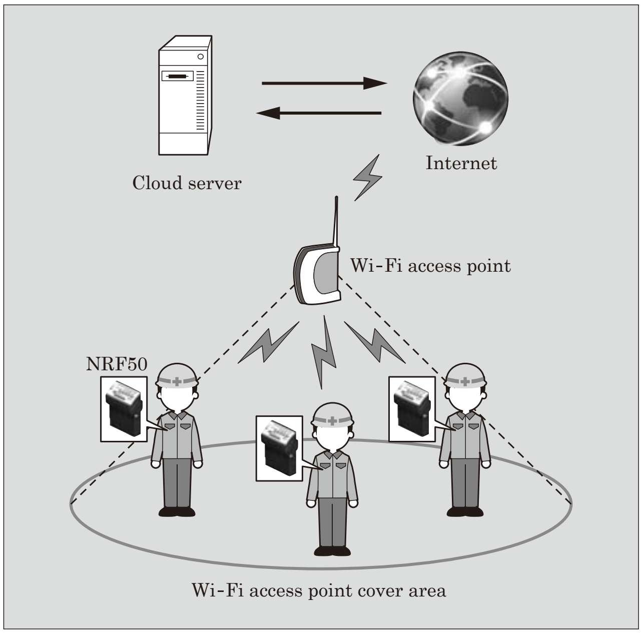


Fig.1 Configuration example for the real-time remote monitoring system using Wi-Fi

wireless master unit connects to higher-level networks using Ethernet*1 or other protocols to transmit the data. However, the adoption of the system requires a substantial amount of time and cost since the use of wireless is restricted to frequency bands that comply with each individual country's regulations; opening a wireless base station requires registration application; and dedicated equipment needs to be procured to begin operations. Therefore, Fuji Electric is proposing to construct a Wi-Fi*2 based real-time remote monitoring system for hospitals, laboratories and universities. Since a Wi-Fi compliant general-purpose access point can be procured inexpensively, initial investment can be kept low. Furthermore, by utilizing a cloud server and web application, operations can be commenced without the need of purchasing new equipment. A configuration example for the system that utilizes Wi-Fi is shown in Fig. 1.

2.2 Function overview

All information and data can be managed collectively through the web application or management software installed in the operation terminal on the network. The data for the applicable area's dosimeter, area monitor and camera can be checked by displaying a list.

The real-time remote monitoring system is not only capable of confirming worker exposure dose data in real time and on-site dose rate data, but can also reflect dose rate data into work-site maps and confirm on-site camera images. Therefore, instructions to evacuate or move locations can be quickly given to workers. In addition, by utilizing the benefit of real-time data acquisition, incidents of overexposure can be prevented for areas of unusually high radiation doses and for workers who cannot personally check their dosimeters. Furthermore, the accumulation of daily records and data can be helpful in creating efficient work plans and establishing restricted access areas.

2.3 New electronic personal dosimeter

The new electronic personal dosimeter "NRF50" developed by Fuji Electric is the core instrumentation device of the real-time remote monitoring system; and it was developed based on our rich experience of understanding and fulfilling customer needs. As main features, the device comes equipped with a wireless module integrated structure, an easy-to-see display and an emergency call button.

In addition to having high measurement accuracy, a personal dosimeter is required to be compact, lightweight and support long-time operation so that workers can wear it while working. Accordingly, the NRF50 was developed to meet these requirements using the following technologies:

(a) A compact design that achieves a built-in wireless module instead of the conventional external unit
(b) A sensor shield design that prevents wireless interference on measurement performance
(c) Optimization for the power circuit design and operation sequence that enables measuring for 8 hours or more while operating the wireless module, without replacing batteries

The external appearance of the NRF50 is shown in Fig. 2, and the major specifications are shown in Table 1.

(1) Wireless module

In conventional real-time remote monitoring systems, the wireless module is incorporated into the system by mounting a wireless attachment to an existing dosimeter. Existing dosimeters have the benefit

Fig.2 "NRF50"

*1: Ethernet is a trademark or registered trademark of Fuji Xerox Co., Ltd.
*2: Wi-Fi is a trademark or registered trademark of Wi-Fi Alliance.

Table 1 “NRF50” specifications

Item	Specification
Measurement type	Gamma ray
Detector	Silicon semiconductor
Measurement range	1 μSv to 10 Sv
Energy characteristic	± 20% (50 keV to 6 MeV)
Directional characteristic	± 20% (Cs-137, 0° to 75°)
	± 50% (Am-241, 0° to 75°)
Indication error	± 10% (Cs-137)
Waterproof performance	IP65, IP67
Alarm volume	90 to 100 dB (at distance of 30 cm)
Communication functions	Electromagnetic induction, infrared, USB, Bluetooth, 900 MHz/Wi-Fi
Data storage	Max. 4,000 items (date, dose, dose rate, status)
Temperature	−10 °C to +50 °C
Humidity	up to 95% RH
Battery	2 AA batteries
Continuous operating time*	2,500 hours or more
Dimensions	W 60 × D 29 × H 105 (mm)
Weight	Approx. 170 g (including batteries and clip)

*When new AA alkaline batteries are used, and the alarm and Wi-Fi are not in use.

of being used as standalone units, but they are bulky and heavy. Therefore, the NRF50 is not based on an attachment, but is an integrated unit with the wireless module built into the unit body.

The mounted wireless module supports selection of Wi-Fi or 900-MHz wireless, and in the future, we plan to add other frequency bands for the wireless. The data transmission cycle can be set to 2, 4, 10, 30 or 60 seconds. The Wi-Fi module is compliant with the WPA, WPA2 and WEP encryption standards. When using 2 AA alkaline batteries, the unit can be used for 8 hours or more at a data transmission cycle of 10 seconds.

(2) Display

In order to improve visibility, it adopted dot type LCD with a display area of W 43.5 × H 16.3 (mm) to display numbers as large as possible. The display is nearly twice as large as those of other companies. Furthermore, it also comes equipped with a white, red and orange colored backlight, and alarms can be easily notified to workers by indicating the configured display.

(3) Emergency call button

The most distinctive feature not available with conventional products is the adoption of an emergency call button. Emergency messages can be transmitted to the server via wireless telemetry by simply pressing this button. In addition, enforced emergency alarms can be sent from the server to workers.

Fig.3 Heart rate meter

2.4 Application examples

In addition to managing exposure doses with the real-time remote monitoring system, the use of the functionality of the new electronic personal dosimeter enables supervisors to manage the safety of workers with more care and precision.

(1) Abnormality detection in worker’s body

Since the unit comes with a built-in acceleration sensor, it can detect the state in which a worker who is wearing the dosimeter is unable to move. It is also able to detect when workers collapse, which is something that can happen unexpectedly. By including this type of information into the remote monitoring system, it has now become possible to respond to urgent time-sensitive situations.

(2) Worker heart rate monitoring

Since the unit is equipped with Bluetooth*3, it can be connected to the heart rate meter (see Fig. 3) manufactured by POLAR. By constantly monitoring the heart rate of workers who have chronic diseases, unexpected situations can be prevented before they happen.

(3) Simple area monitor

The dosimeter has a lower sensitivity than detectors used by conventional area monitors. Furthermore, since the unit is calibrated for managing the exposure dose while it is being worn on the body, scenarios in which the unit is installed somewhere to measure aggregated doses and dose rates have not been considered. However, it is capable of detecting sudden increases in dose rates, and as a result, it can be used as a simple area monitor. Since the NRF50 can be operated while power is supplied through a USB cable from an external device, it can be incorporated into real-time remote monitoring systems as an area monitor without concern for battery life.

3. Future Outlook

Currently, only the “NRF50” is available as a device compatible with this real-time remote monitoring system, but we plan to expand the lineup for the series by releasing the “NRF51” as a unit capable of measuring gamma ray and neutron, and the “NRF54” as a

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

unit capable of measuring gamma ray and beta ray. Moreover, in the United States, by using other wireless frequencies in addition to 900 MHz,

it is expected that the unit can be used domestically and abroad in outdoor decontamination work and in countermeasures to terrorism by radioactive material. Furthermore, it can be expected that there will be an expansion of use in European countries with the acquisition of the CE marking.

4. Postscript

In this paper, we described the real-time remote monitoring system that utilizes the new electronic personal dosimeter. We plan to continue to offer a wide range of solutions that incorporate system engineering technologies based on customer needs.

Evolving of Monitoring and Control System “MICREX-VieW XX (Double X)”

NAGATSUKA, Kazuhito* SATO, Yoshikuni* SASANO, Kisaburo ‡

ABSTRACT

The small-and medium-scale monitoring and control system “MICREX-VieW XX” has continued to evolve to meet the various needs of customers ever since its debut in the market. We have recently added to it some new system configurations that can contain all-in-one stations for high cost performance and a remote-monitoring system. Existing systems can also be easily upgraded using the dedicated migration controller “XCS-3000R,” a migration tool and a network adapter. In addition, we are currently developing functionality for IoT applications that make it possible to expand the applicable range of plant monitoring, to record and save long-term monitoring data, to execute applications via connection with the Internet, and to ensure enhanced security.

1. Introduction

The “MICREX-VieW XX (Double X[(1)(2)])” is a small- and medium-scale monitoring and control system achieving safe and stable plant operation. Since its market launch in June 2014, it has been widely applied to business sectors including steel, food, chemical and environment. This paper describes the continuous evolution of the MICREX-VieW XX that allows communication link with higher- and lower-level systems, provides system architecture to address the age of Internet of Things (IoT) in monitoring and control systems such as large-capacity communication, and offers solutions to satisfy the needs of customers.

2. “MICREX-VieW XX”

2.1 Positioning

Figure 1 shows the position map of the monitoring and control systems offered by Fuji Electric. Monitoring and control systems vary from small-scale systems used for line or cell control to large-scale systems that monitor and control an entire plant.

The “MICREX-VieW Series” offers a lineup consisting of the “MICREX-VieW XX,” “MICREX-VieW FOCUS” and “MICREX-VieW Compact” that can be selected according to the scale and applicable range of the system. All of these systems provide high continuity and commonality by sharing application assets, engineering tools, controller platforms and I/Os.

The MICREX-VieW XX is a system covering from small- to medium-large scales and can be used for a wide range of applications, mainly for line or cell control, from high-speed control of electric machinery to multi-point measurement control.

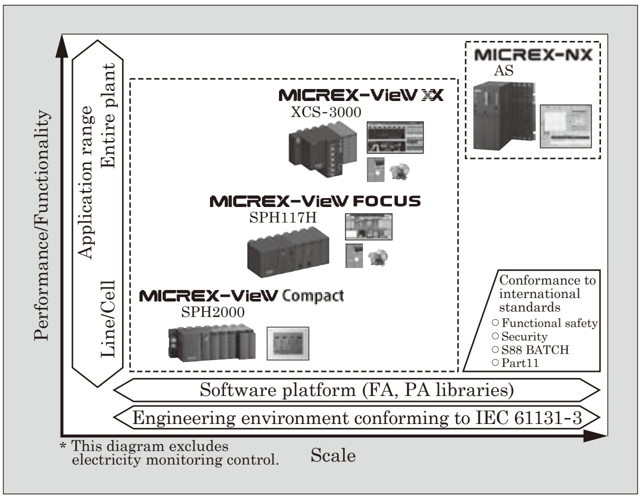


Fig.1 Position map of monitoring and control systems offered by Fuji Electric

The MICREX-VieW XX has been providing solutions to satisfy various needs of customers by solving the following problems with conventional systems.

2.2 Problems with conventional systems

With conventional monitoring and control systems, when the scale of the monitoring target became large in the factory automation (FA) or process automation (PA) sectors, it was difficult to use the existing control system architecture and engineering tools (including created applications) as they were. This made it necessary to connect multiple systems via gateways or modify engineering tools, raising the problem of increased cost of introducing and maintaining a monitoring and control system. There is a new problem of ensuring a smooth link with and inheriting existing application

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

assets which is required to continue stable plant operation after a facility upgrade.

Another challenge is to satisfy various needs while achieving stable plant operation, such as to expand the applicable range of monitoring, to record long-term history of alarms and operations, and to execute applications via an Internet connection.

3. Enhanced Functionality of “MICREX-VieW XX”

In addition to the standard system configurations of the MICREX-VieW XX (single configuration and redundant configuration), this section describes system configurations that use all-in-one stations for high cost performance and that allow easy remote monitoring operations from anywhere.

3.1 Various system architectures

(1) Standard system configuration

Figure 2 shows the standard system configuration (single configuration). Figure 3 shows the completely redundant system configuration. This is one of the

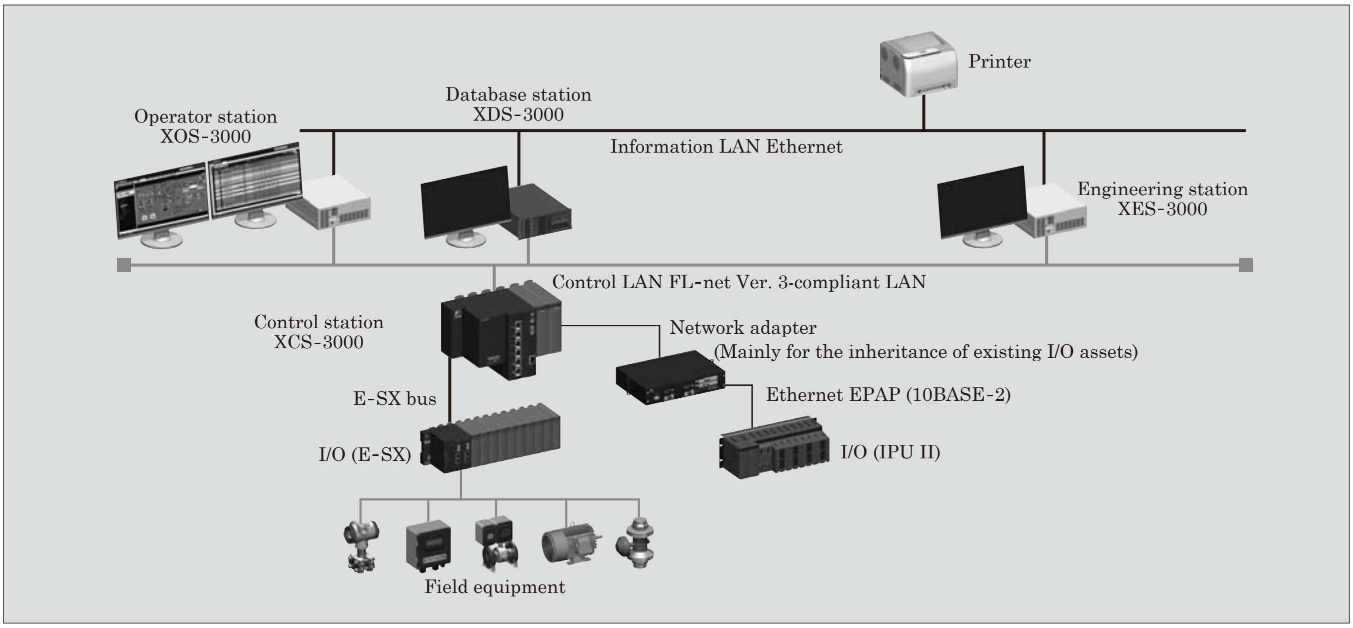


Fig.2 Standard system configuration (single configuration)

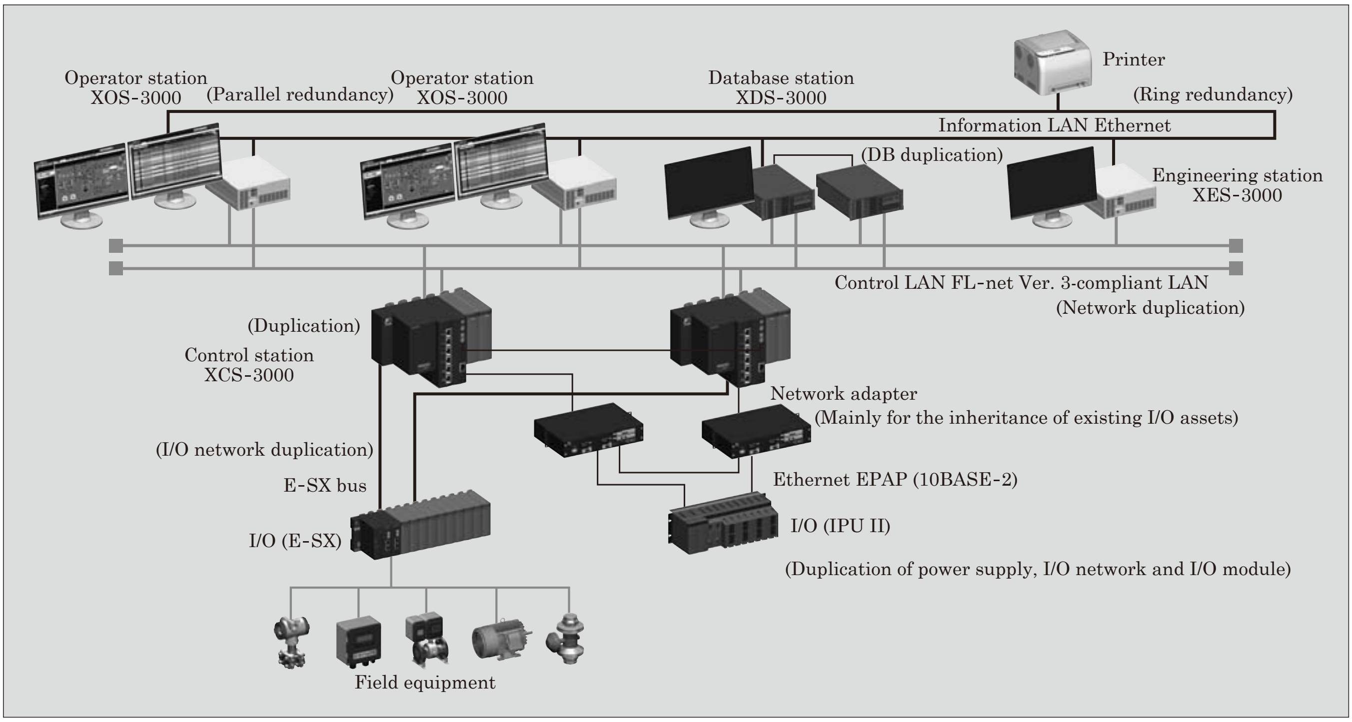


Fig.3 Standard system configuration (completely redundant configuration)

redundant configurations in which every component is designed to be redundant to achieve high reliability. These are typical system configurations of the MICREX-VieW XX.

A scalable and high-cost performance system can be built according to customer requests, from a compact system based on a single configuration of each component to a highly reliable redundant system employing dual installation of components (such as a control station) and a network using dual line or ring topology. The use of a network adapter makes it easy to inherit the assets of I/O or other existing hardware.

(2) System configuration using all-in-one station

Figure 4 shows a system configuration using the all-in-one station "XAL-3000." This system configuration uses the XAL-3000 and is intended for relatively small-scale systems with the 10 or fewer "XCS-3000" control stations. The XAL-3000 can achieve function-

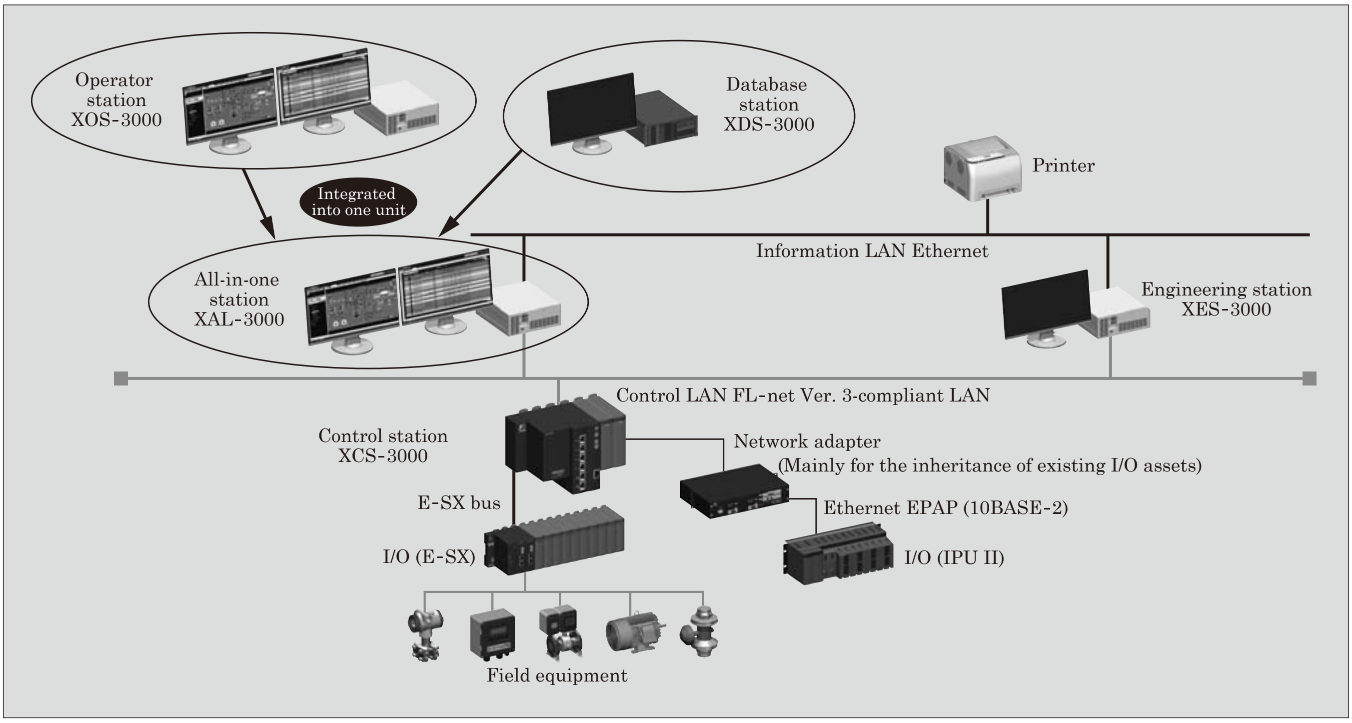


Fig.4 System configuration using all-in-one station

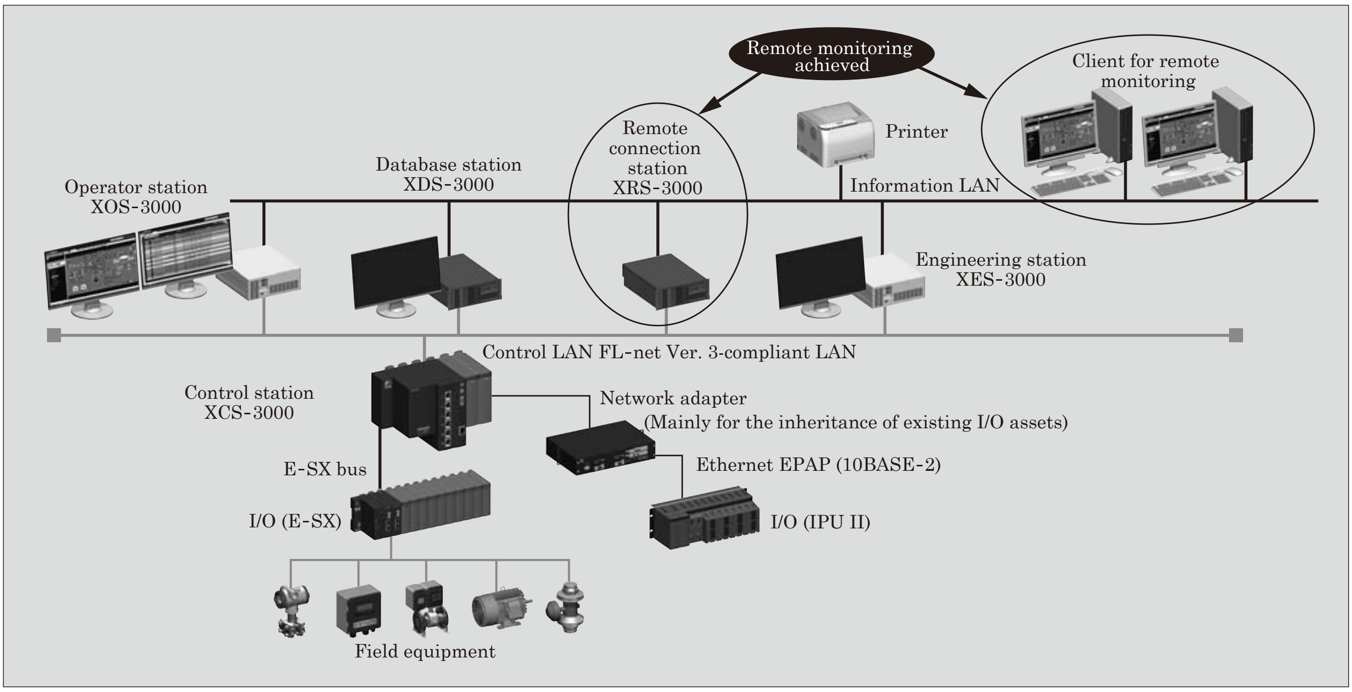


Fig.5 Remote monitoring system configuration

ality of both the operator station "XOS-3000" and database station "XDS-3000."

In order to improve database reliability and to reduce costs due to the increase in the XAL-3000 units, the system is configured with the 2 XAL-3000 units arranged side-by-side and then combined with the XOS-3000, which is less expensive than the XAL-3000. This allows the user to build a monitoring system providing high-cost performance as well as high reliability.

(3) Configuration of remote monitoring system

Figure 5 shows a configuration of a remote monitoring system. This is a configuration of a system that enables remote monitoring operation with a general-purpose PC in an office some distance away from the site.

To perform remote monitoring, install the "XRS-3000," which is a remote connection station with server functionality, on the control LAN, connect the client to the information LAN, and use the Windows*1 Remote Desktop function on the client. The client can be a portable notebook computer or tablet computer with Full HD display.

In this way, plant monitoring operations equivalent to the XOS-3000 can be achieved easily from anywhere. Furthermore, since a single XRS-3000 can connect up to 4 computers, the introduction and maintenance costs can be reduced.

3.2 Enhanced asset inheritance

Aging monitoring and control system should be reliably upgraded within a short period of time without affecting the plant operation. Consequently, many plants upgrade their systems partially through several steps (see Fig. 6).

The MICREX-VieW XX includes the "XCS-3000R" and a migration tool for inheriting the application assets of existing controllers and a network adapter for inheriting the assets of existing hardware. This allows it to provide flexible system upgrades satisfying the needs during upgrades described above. Such assets can then be utilized effectively to achieve data collection or data interchange with higher-level systems.

(1) "XCS-3000R"

The XCS-3000R is a controller dedicated to migration. While using the latest hardware as with the XCS-3000, it has an emulator function on the controller platform common to the XCS-3000 in order to run the programs of existing controllers as they are (see Fig. 7). The emulator function includes various mechanisms to continuously use existing applications, such as program execution control, virtual address space

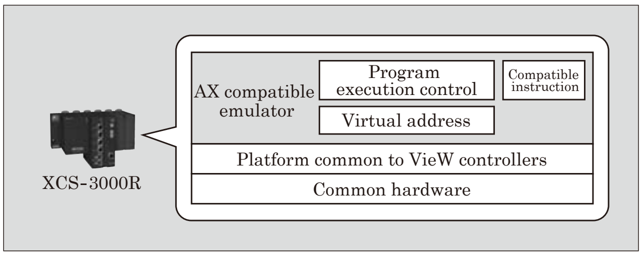


Fig.7 Conceptual drawing of "XCS-3000R"

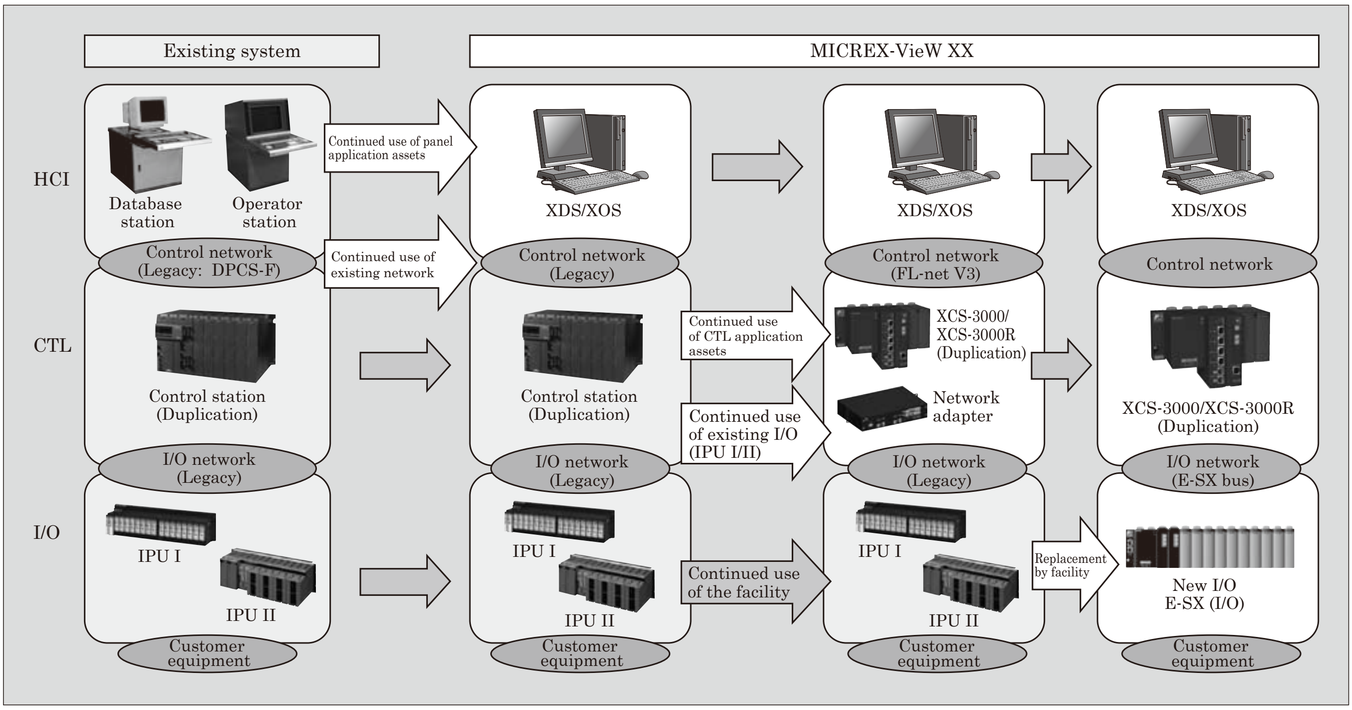


Fig.6 Example of upgrading an existing system through several steps

*1: Windows: A trademark or a registered trademark of Microsoft Corporation management and compatible instructions.

By using the XCS-3000R, users can continue to use their existing facility, application assets and familiar engineering environments, while replacing the aging controllers smoothly.

(2) Migration tool

The migration tool is used to inherit the application assets of users. It allows inheritance of application assets created with the conventional controller engineering tool "FPROCES-C."

As shown in Fig. 8, the migration tool is used together with the latest migration controller XCS-3000R. This allows users to upgrade to the latest controller and I/O equipment while continuously using their existing application assets and familiar controller engineering tools. Moreover, users can improve the operation stability of the entire system while upgrading the system with no stress and applying the latest technologies.

(3) Network adapter

The network adapter is equipment used to connect existing I/O equipment and control network to the XCS-3000/XCS-3000R to allow hardware assets to be inherited.

The network adapter can connect networks shown in Table 1 and can be flexibly used in different system configurations required for upgrade. This allows users to establish a flexible upgrade plan in accordance with the life cycle of the facility such as a controller and I/O equipment as shown in Fig. 6. Consequently, users can upgrade to the latest system in several steps while reducing the total system cost and upgrade period. For example, since the network adapter supports FL-net, it can be combined with the built-in FL-net of the XCS-3000 to create a system configuration with a dual FL-net line. By connecting the network adapter to an existing control LAN and connecting the XCS-3000 to the control LAN of a new system, users can connect to both old and new monitoring systems so that they can add and build a new system while effectively utilizing the existing system.

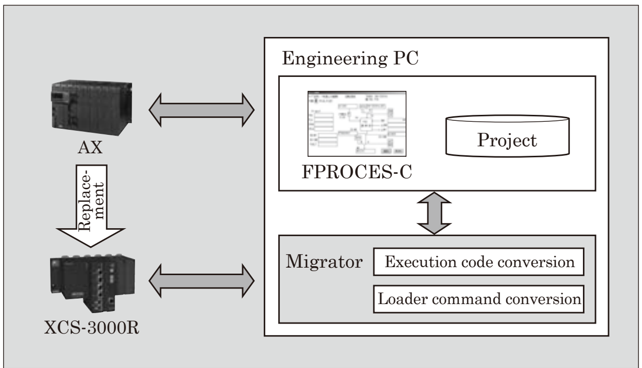


Fig.8 Conceptual drawing of migration tool

Table 1 Networks supported by network adapter

Type	Network to be connected
Control network	FL-net
	DPCS-F
	PE-link
I/O network	Ethernet EPAP (IPU II)
	T-link

4. Evolved Functionality of "MICREX-VieW XX"

The evolution of IoT technologies has been making it possible to collect various types of data from many devices and equipment that had not transmitted data previously. Customers have become more aware of the need to collect and utilize the information obtained through IoT. This poses a challenge for plants since they have to deal with a larger amount of data than before while their scales remain the same. For the MICREX-VieW XX, we have been developing functionality that makes it possible to expand the applicable range of monitoring to handle a larger amount of plant data, to record and save long-term monitoring data including alarm and operation histories, to execute applications via an Internet connection, and to ensure enhanced security.

4.1 Faster data collection performance for handling larger amount of data

With the XCS-3000, the Gigabit Ethernet network, which was conventionally provided as a separate communication module, has been incorporated within the CPU module, resulting in a remarkable improvement in real-time data collection performance. Moreover, the number of TAGs and I/Os that can be handled with the MICREX-VieW XX has been increased. These improvements have enabled high-speed collection of real-time data synchronized with the control cycle, so that users can check the plant conditions in more detail. Combining real-time data with historical or various other types of data and applying Fuji Electric's data analysis technology makes it possible to conduct various operations, including failure prediction, preventive maintenance of facilities, advanced energy management and flexible production planning.

4.2 Long-term storage (archive) technologies

Historical data handled with the MICREX-VieW XX, including the history of alarms and operations, trend data and reports, are stored for one year as important records of target facilities and processes for easy reference. In recent years, these historical data have been attracting attention because various analyses of these data provide new findings that may lead to stable operation or improved efficiency of the plant. Consequently, the solution of efficiently accumulating historical data for a long period of time is being desired.

For the MICREX-VieW XX, we have been developing the archive station "XAS-3000" as a system that

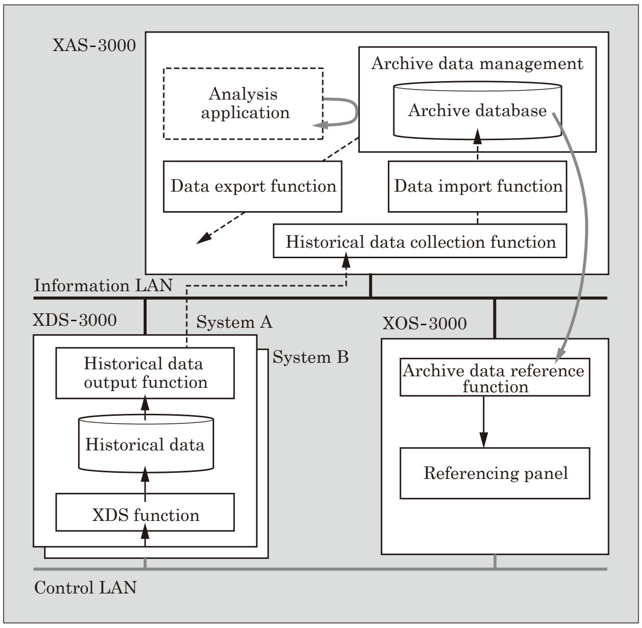


Fig.9 Configuration drawing of an archive station

stores historical data for a long period of time. The XAS-3000 can store historical data collected from the XDS-3000 for up to 10 years (see Fig. 9).

The historical data accumulated in the XAS-3000 can be viewed with the screen panel of the XOS-3000 in the same way as the data within the past one year. In addition, the data can be accessed through the use of open SQL (Structured Query Language) and be analyzed from various keys including data time, plant facility and information source (tag). Using this SQL access function enables quick customization such as incorporating an analysis engine specialized for the plant.

4.3 IoT-ready communication technologies

One of the important IoT technologies is communication technologies between systems, equipment or devices. There are currently several options for communication technologies applicable to IoT and they have been used in various ways depending on the purpose. OPC Unified Architecture (UA) has been gaining attention as an important option for communication technologies in the age of IoT. OPC UA is a successor technology to OPC Data Access (DA), which had grown as a communication technology for control systems. OPC UA is an open technology providing both performance and security.

Fuji Electric has quickly focused attention on this OPC UA and incorporated an OPC UA server function into the MICREX-VieW XX. Equipment and various systems with an OPC UA client function capable of connection to OPC UA can access the information of the plant managed by the MICREX-VieW XX while ensuring high security.

Studies have also been made on the configuration in which in the near future an IoT-ready higher-level system built on a cloud will collect the plant data retained by a monitoring and control system such as the MICREX-VieW XX (see Fig. 10). Also in such a configuration, the use of the OPC UA server function allows the configuration to be ready for IoT without any modification.

4.4 Security technologies

The international standards have been organized to meet control system security requirements, which encourages the development of an environment for applying security evaluation and certification based on common criteria. Fuji Electric has been participating in IEC/TC65/WG10, which is a domestic council of IEC 62443, and also involved as a joint enterprise in the Control System Security Center (CSSC) established in 2012 which is a corporation approved by Japanese Ministry of Economy, Trade and Industry. The aim of this is to improve Japan's international competitiveness in the control system market and to promote the creation of a security evaluation and certification scheme for control systems.

We also actively work on the latest technologies for security measures including intrusion detection and

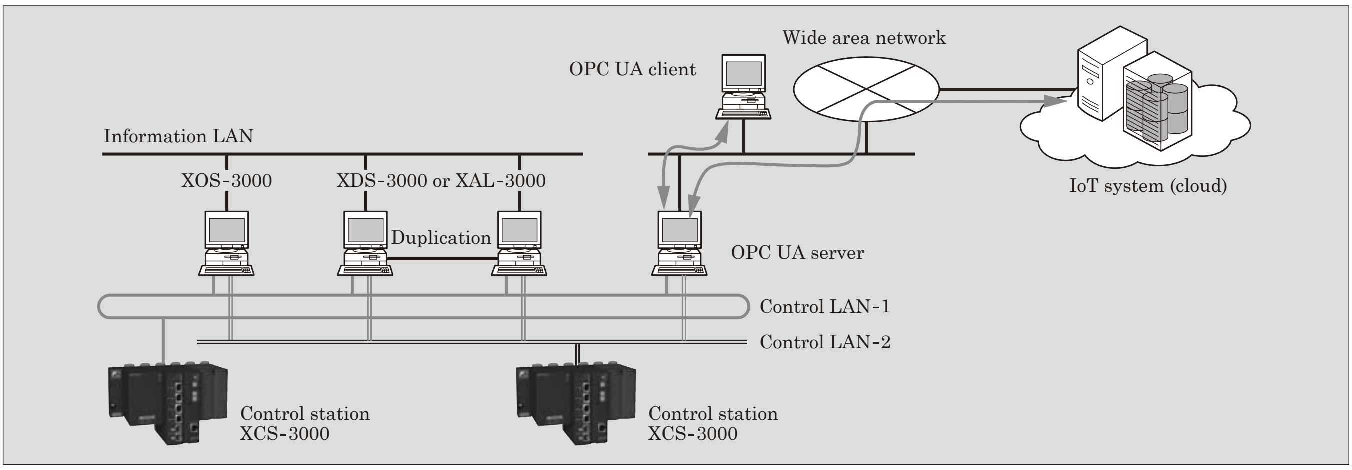


Fig.10 Conceptual drawing of the collaboration with IoT-ready systems when OPC UA server is used

operation monitoring as well as guidelines for building a secure system. We promote the building of secure systems covering areas from the component level to an entire system.

In view of the coming age of IoT, and in order to provide users with a safe and secure system to achieve stable plant operations, we have developed the MICREX-VieW XX by placing importance on security from the design stage to achieve systems with ensured security.

5. Postscript

This paper described the evolving of the monitoring and control system “MICREX-VieW XX.” The MICREX-VieW XX is sure to contribute to the manufacturing of high-quality products and stable and efficient operations required in various plants. We will commit to expanding the functions of our monitoring and control systems in order to solve the issues of our customers.

References

(1) Nishiwaki, T. et al. Small- and Medium-Scale Monitoring and Control System to Realize Inherence and Evolution of Customer Assets, “MICREX-VieW XX”. FUJI ELECTRIC REVIEW. 2014, vol.60, no.1, p.33-37.

(2) Sato, Y. et al. Latest Operaiton and Engineering Functions of Small- and Medium-Scale Monitoring and Control System, “MICREX-VieW XX”. FUJI ELECTRIC REVIEW. 2014, vol.60, no.1, p.38-42.

Equipment Monitoring System "MICREX-VieW PARTNER" Easily Cooperating with Integrated EMS

SUZUKI, Takehiro* HORIGUCHI, Hiroshi ‡ USUDA, Hiroshi ⁂

ABSTRACT

In conjunction with the expansion of the energy management system (EMS) market, an equipment monitoring system is capable of further growth as an infrastructure system that implements optimal operation and connects an EMS with actual equipment. Our recently developed equipment monitoring system "MICREX-VieW PARTNER" comes standard with engineering tools and functionality for cooperating with an integrated EMS. The system also makes it possible to minimize introduction cost and time when implementing the cooperation with the integrated EMS. In addition to its standard functionality, it also comes equipped with a schedule control function, demand monitoring function and customization function based on a simple language, thus making it compatible with various types of equipment.

1. Introduction

With the increasing demand for energy saving (energy conservation) in recent years, an optimal operation planning function has been attracting attention and its application is increasing(1)(2) as well as conventional energy management systems (EMSs). While EMSs are mainly designed to visualize energy, the optimal operation planning function is intended to make and control an operation plan for utility equipment based on energy supply (generation) prediction and demand prediction. In conjunction with the expansion of the EMS market described above, an equipment monitoring system is expected to grow further in the future as an infrastructure system that implements optimal operation and connects an EMS with actual equipment.

Fuji Electric has developed and provided an integrated EMS that integrate energy visualization and energy-saving controls in various business sectors including steel, general industry, store distribution, water treatment and regional communities to provide energy management functions(2). We also had been developing the "SIRIUS" and the "Partner IT" until 2009 and have been developing the "Partner Σ" since 2010 as equipment monitoring systems and offered them to our customers. Recently, however, there are increasing demands for ways to handle issues that are difficult to handle with Partner Σ, such as EMS cooperation.

This paper describes the equipment monitoring system "MICREX-VieW PARTNER" that can easily cooperate with the integrated EMS. This is a newly developed system based on enhancing Partner Σ. It inherits the screen operation and engineering procedures of the monitoring and control system "MICREX-VieW XX (Double X)" and supports the Internet of Things (IoT) and security to which increasing attention has been placed in recent years.

2. Development Background

In typical plants, independent equipment monitoring systems exist on the consumption side (demand side) and on the energy production and supply side (supply side) respectively. If these systems are optimized individually, losses are generated from the process of adjusting the balance between supply and demand. This often results in insufficient energy saving in the entire plant. On the other hand, when an integrated EMS is placed at a higher level and the equipment monitoring systems of the supply side and demand side are cooperated with the integrated EMS, an optimal balance is achieved between supply and demand, allowing maximum energy saving in the entire plant. This, however, requires significant labor and cost especially for implementing the cooperation between the integrated EMS and the equipment monitoring systems. This is because different communication methods and engineering environments are used for individual equipment monitoring systems so that every cooperation between an integrated EMS and an equipment monitoring system requires creation of a separate complete application in accordance with each case.

Against this background, Fuji Electric has developed the equipment monitoring system "MICREX-VieW PARTNER" that can easily cooperate with the integrated EMS (see Fig. 1). In addition to standard functionality such as monitoring, trend, reporting and alarm monitoring, it is equipped with a schedule con-

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

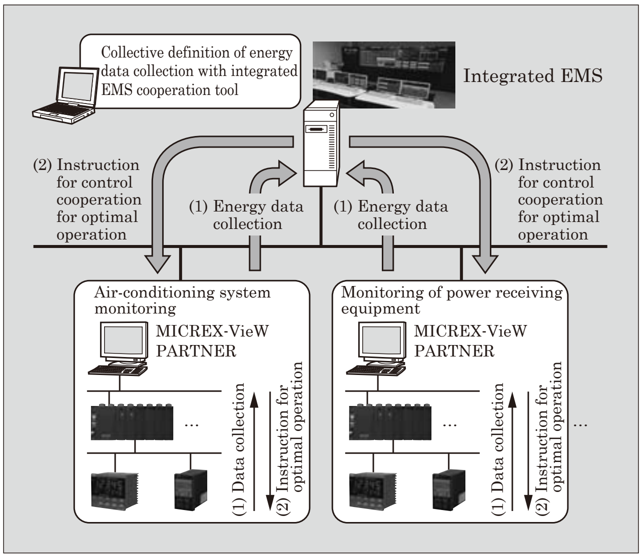


Fig.1 System cooperation between an integrated EMS and "MICREX-VieW PARTNER"

trol function, a demand monitoring function and a customization function based on a simple language, and can be used in common for various types of equipment.

3. Overview of "MICREX-VieW PARTNER"

Figure 2 shows the system configuration of MICREX-VieW PARTNER.

One server set can be installed within the system. In a duplicated configuration, one set consists of 2 servers. Moreover, a client function can be added to the server to use it as a standalone configuration.

Up to 14 computers can be installed in the system as clients. When a client function is added to each of the servers in a duplicated configuration, the maximum number of clients will be 16.

The controllers are connected to the server via a control LAN and up to 30 controllers can be installed.

The control LAN is an Ethernet*1 network connecting the servers and controllers. The inter-system LAN connecting System A server and System B server is an Ethernet network used for providing redundancy and equalizing data between the servers. The information LAN is an Ethernet network used for communicating between the servers and clients and for cooperation with other systems.

The major specifications of MICREX-VieW PARTNER are shown in Table 1 and its screen types and functions are shown in Table 2.

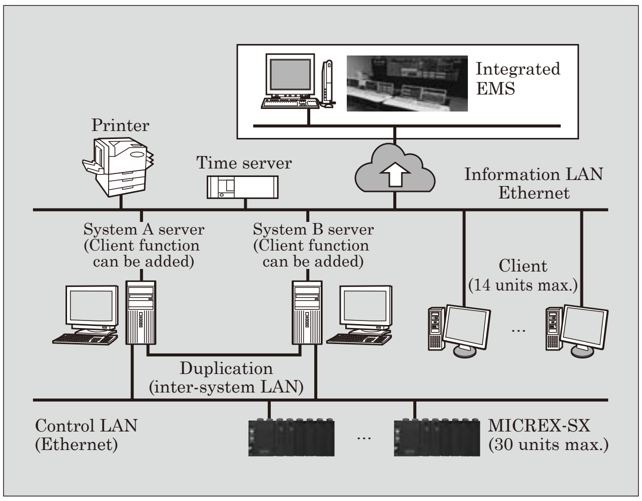


Fig.2 System configuration of "MICREX-VieW PARTNER"

Table 1 Major specifications of "MICREX-VieW PARTNER"

Item		Specification
Number of tags (quasi-instruments)		20,000
Message recording		365 days or 365,000 messages
Trend recording	Maximum number of recording*	○60-second cycle: 10,000 records ○5-second cycle: 5,000 records ○1-second cycle: 500 records
	Sampling frequency	○1 second to 1 hour
	Storage period	○3 years (60-second cycle) ○3 months (5-second cycle) ○7 days (1-second cycle)
Reporting	Maximum number of recording	○Daily report: 10,000 ○Monthly report: 10,000 ○Yearly report: 10,000
	Storage period	○Daily report: 10 years ○Monthly report: 10 years ○Yearly report: 10 years

* When status change of 60 records/30 seconds is continued

Table 2 Screen types and functions

Screen	Function
Group screen	○To list instrument graphics corresponding to the monitoring items in the controller. ○To arrange and edit instrument graphics displayed on the screen.
Tag menu screen	○To display one page of the group screen as one symbol and then display the integrated list of the statuses/values of the monitoring items on each page.
Loop screen	○To display the parameter settings and values of quasi-internal instruments corresponding to the monitoring items.
Integrated history screen	○To display a list of alarm messages and operation messages together.
Trend screen	○To display the trend of measurement data.
Annunciator screen	○To display a list of abnormalities occurring in the equipment.
Report screen	○To display and edit daily, monthly and yearly reports.
Plant screen	○To monitor and operate each equipment.
Schedule control screen	○To set the operation/shutdown schedule according to the seasons, the day of the week, or a specific day or period on the calendar.
Demand monitoring screen	○To set the value or schedule required for demand monitoring and perform monitoring.

*1: Ethernet: Trademark or registered trademark of Fuji Xerox

4. Features of “MICREX-VieW PARTNER”

(1) Easy cooperation with an integrated EMS

An integrated EMS conducts real-time energy-saving operations in accordance with the energy management and current operation condition of the entire plant. It thus needs to closely cooperate with multiple equipment monitoring systems installed inside the plant to manage operations. To implement such cooperation easily, MICREX-VieW PARTNER comes standard with engineering tools and functionality for cooperating with an integrated EMS.

The details of the cooperation with an integrated EMS are shown in Table 3. The conditions of all equipment managed by MICREX-VieW PARTNER are shared with and can be controlled by the integrated EMS in real time.

Users can use the engineering tools to notify the integrated EMS of aggregated data by just defining the energy collection cycle for each tag. As a result, the integrated EMS can easily build an energy-saving management system covering the entire plant.

(2) User-friendly design

The high-reliability, high-screen-operability including multi-window operation and universal design[3] of MICREX-VieW XX have achieved user-friendly operations.

(3) Use of quasi-internal instrument tags

In conventional equipment monitoring systems, tags are assigned to each of the monitoring and control points such as digital input (DI), digital output (DO), analog input (AI) and analog output (AO). Consequently, the association of AI with AO or the association of DI that manages control lock information with DO is established through engineering work.

For MICREX-VieW PARTNER, the collection of related DI, DO, AI and AO is represented as one quasi-internal instrument tag and implemented within the server as standard. The quasi-internal instrument tags consist of 6 types covering 90% or more of the tags used in the conventional equipment monitoring systems (see Table 4). This greatly improves the efficiency of engineering work. Tags that cannot be consolidated into any types can be used as independent ones in the same way as conventional tags.

Each monitoring and control point consolidated into the quasi-internal instrument tags is identified with a tag name concatenated with a period and an attribute name such as “Tag name. PV.” For example, you use the quasi-internal instrument tag DIO for starting a pump. Its internal attributes include pump start and stop state (PV), pump start and stop control (DO), controllability condition (OPC), operation lock state (LCK) and so on. In the quasi-internal instrument tag DIO, control conditions that had been incorporated individually have already been implemented, such as prohibiting the pump start and stop control in the state of operation lock.

The advantages of introducing the quasi-internal instrument tags are as follows:

(a) The number of tags has been reduced to less than half which makes management easier.

(b) Control conditions have already been incorporated into the quasi-internal instrument tags,

Table 3 Details of the cooperation with integrated EMS

Type of cooperation		Overview
Energy data cooperation		○The integrated EMS is notified of aggregated energy data in CSV format. ○The data aggregation cycle can be selected for each tag from 1, 5, 30 or 60 minutes.
Monitoring and control cooperation	Monitoring	○The integrated EMS is notified of the conditions of the equipment managed by MICREX-VieW PARTNER in real time. ○The cooperation cycle is one second for DI and 3 seconds for AI.
	Control	○The equipment is controlled based on the control order from the integrated EMS and the result is returned to the integrated EMS. ○The control record is also recorded in the integrated history of MICREX-VieW PARTNER.

Table 4 6 types of quasi-internal instrument tags

Instrument name	Instrument graphic	Function of the quasi-internal instrument tag
AIO (Analog I/O)		Analog input, analog output, industry value conversion, high/low input cut, upper/lower limit monitoring, disconnection monitoring, plate hanging, suspension, replacement and control lock
SUMM (DIO with operation monitoring)		Digital input, digital output, operation monitoring (operating time, number of operations), plate hanging, suspension, correction, preset and control lock
POWF (power factor)		Analog input, power factor conversion, upper limit monitoring, disconnection monitoring, plate hanging, suspension, replacement and control lock
SUMD (digital accumulation)		Counter value input, digital accumulation, input scaling, accumulation upper limit monitoring, suspension, reset, correction, preset and control lock
DIO (digital I/O)		Digital input, digital output, plate hanging, suspension and control lock
DIOTM (DIO with time measurement function)		Digital input, digital output, plate hanging, suspension, continuous operating time and control lock

which eliminates the work of preparing them.

(c) Since an instrument graphic has already been provided for each quasi-internal instrument tag, it is unnecessary to prepare it.

Incorporating the quasi-internal instrument tags within the server eliminates the need to have specific function blocks in the controller and allows engineering independent of the controller models. Furthermore, the controller is less affected by the addition or change of equipment so that expansion or modification can be made easier.

(4) Implementation of Schedule control function and demand monitoring function

MICREX-VieW PARTNER has implemented a schedule control function and demand monitoring function required for its application to public facilities as standard.

(a) Schedule control function

The schedule control function is used to control DO and AO according to a schedule composed of a combination of 3 seasons (summer, winter and other), a setting by the days of the week (see Fig. 3) and a setting on the calendar (see Fig. 4).

Two control methods are used: Fixed-time event method and range event method. The fixed-time event method provides only one control output (ON, OFF or analog setting value) on the preset time and does not check the operation for it. The range event method allows detailed scheduling of control outputs within a control period specified with start and stop.

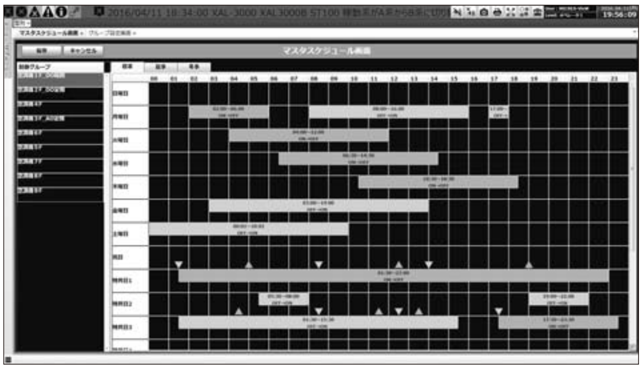


Fig.3 Example of master schedule screen

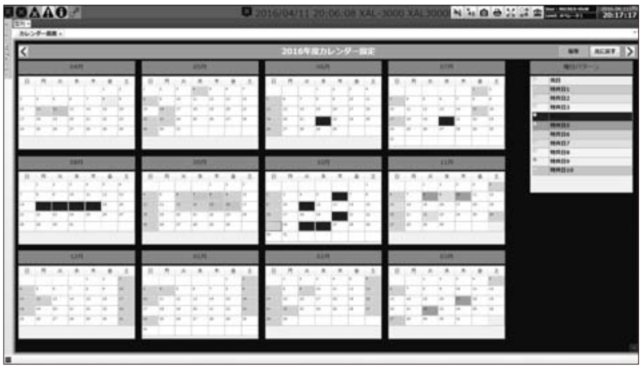


Fig.4 Example of calendar screen

The operation after a control is ordered is checked and if the specified state is not achieved within the specified period, the control order is output again. Furthermore, you can define multiple control suppression conditions required for the operation in accordance with the schedule such as the date and time of a planned blackout or room temperature setting. This makes it possible to recover operations considering the operation pattern and control sequence in the operating time slot; for example, during recovery from a blackout, setting the temperatures of air-conditioners after starting them depending on the facility. This results in efficient operation control which leads to further energy saving.

(b) Demand monitoring function

An example of the demand monitoring screen is shown in Fig. 5. The demand monitoring function is used to predict the usage of electric power or gas in the demand monitoring cycle (15, 30 or 60 minutes) and issue an 8-level alarm before the demand exceeds a preset demand monitoring value. Under the assumption of potential needs for detailed demand monitoring values due to electricity liberalization and diversified electricity contracts, MICREX-VieW PARTNER allows settings to be made by time slot to support a summer charge or time-slot-based charge. A preliminary line detection method has been adopted for demand alarm detection.

The demand monitoring value, alarm occurrence state and predicted demand values can be written to the controller anytime, and it is also possible to adjust the load from the controller.

(5) Simple language

There is a need to be able to easily change the color of the symbols and actually measured values shown on the plant screen based on various conditions or when more than one condition occurs simultaneously. There is another need for carrying out certain control when a specific condition is satisfied according to the state at that time. We have developed simple language to satisfy such complicated field needs that is unconventional. Figure 6 shows an example of description using the simple language for interlocking control logic.

This simple language includes an IF statement,

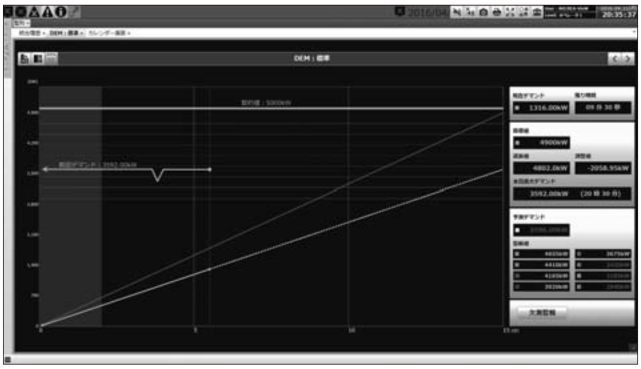


Fig.5 Example of demand monitoring screen

```
//
// 連動制御の例
//

//発生条件のチェック
If( #/TAG_001.PV.Value = 1 And #/TAG_002.PV.Value = 1)Then

    //制御出力 ( ON出力 )
    #/TAG_999.PV.Control( 1 )

EndIf

Return 0
```

Fig.6 Example of description using simple language for interlocking control

DO statement, WHILE statement, array and various functions (character string operation, time, arithmetic functions). It allows engineers who create plant screens to build judgment logics to satisfy field needs as desired. One of the major features that should be noted is the ability to write a name of a tag directly to read the value of the tag or provide control output. This makes it easy to create controller logics.

5. Postscript

This paper described the equipment monitoring system “MICREX-VieW PARTNER” that can be applied commonly to the monitoring of various types of equipment and that allows quick and comprehensive engineering from a higher-level EMS to implement cooperation easily.

From now on, we will aim to enhance the convenience of users and the scalability of customization including a further improvement of usability. We will also implement an Advanced application programming interface (API) that can flexibly respond to customer needs and handle a cooperation with existing systems. This will allow the “MICREX-VieW PARTNER” to optimally operate customers’ equipment as an equipment monitoring system that cooperates with EMSs capable of further growth.

References

(1) Kawamura, Y. et al. A Framework for Optimal Planning Systems on the EMS Platform. FUJI ELECTRIC REVIEW. 2013, vol.59, no.3, p.186-190.

(2) Horiguchi, H. et al. Integrated Energy Management System Platform. FUJI ELECTRIC REVIEW. 2011, vol.57, no.4, p.146-151.

(3) Sato, Y. et al. Latest Operaiton and Engineering Functions of Small- and Medium-Scale Monitoring and Control System, “MICREX-VieW XX”. FUJI ELECTRIC REVIEW. 2014, vol.60, no.1, p.38-42.

Mathematical Application Technology for IoT Solutions

MATSUI, Tetsuro* MURAKAMI, Kenya* TANGE, Yoshio*

ABSTRACT

As the Internet of Things (IoT) becomes increasingly widespread, devices which have conventionally not been connected to a network will become connected, and likewise, data which traditionally could not be measured will be collected and analyzed. It is very important that the wide variety of collected data should be used to discover and provide value. In order to achieve this, Fuji Electric has developed a mathematical application technology for data analysis and optimization. The latest mathematical application technologies are being applied to various types of products and systems. These technologies include anomaly diagnosis technology for batch processing, anomaly symptom detection based on ensemble prediction, and a technology for visualizing potential energy savings via formula manipulation optimization.

1. Introduction

The Internet of Things (IoT) is a concept of creating new value by having a connection between things and humans via a network. In the industrial sector, especially in the manufacturing industry, networks of various devices, such as industrial networks, have long been constructed in the business sites, which allows adequate monitoring and control of large plants. As the IoT becomes increasingly widespread, devices which have conventionally not been connected to a network will become connected, and likewise, data which traditionally could not be measured will be collected and analyzed. Once a wide variety of data have been collected, the point is how the data can be used to discover value and provide it to customers.

Fuji Electric has developed the following mathematical application technologies for data analysis, optimization and other applications and utilized data through products and systems to provide value[(1)(2)]:

(a) Proprietary neural network technology for contributing to efficient and stable operation of plants by high-accuracy prediction and anomaly diagnosis

(b) Meta-heuristic optimization technology suited for mathematical programming and nonlinear large-scale optimization problems to formulate optimum plant operation plans and minimize costs

(c) PID control technology and model predictive control technology for multi-variable systems as well as control performance monitoring technology for monitoring control performance degradation caused by characteristic change of the controlled object, all of which are used to enable stable plant control

This paper gives an overall picture of mathematical application technologies related to IoT solutions and presents the latest mathematical application technologies.

2. Overall Picture of Mathematical Application Technologies Related to IoT Solutions

Fuji Electric thinks of IoT solutions as ones that make use of data analysis and artificial intelligence technologies to deal with problems in industrial plant and social infrastructure fields for anomaly diagnosis, prediction and estimation and uses those results as the basis for optimization and creation of new value (see Fig. 1).

Anomaly diagnosis uses data analysis technology to very accurately diagnose what is occurring in a component or system and what is causing it. Up to now, for plant monitoring and control systems and various types of manufacturing equipment, the upper or lower threshold value that provides a criterion for an anomaly has been set for each measurement item to see if it is exceeded, so as to monitor plant conditions. In the future, detailed data in large volumes for the entire monitored object will become available for collection more than ever and monitoring the changes in those data on the whole is expected to be useful for prompt anomaly diagnosis.

For prediction and estimation, a model constructed by data analysis is utilized to predict the future conditions of the monitored object and estimate the values of variables not directly measured. In a large plant, for example, operating while predicting future changes allows the burden on the operators to be reduced and safer and securer operations to be realized.

For optimization and new value creation, what is

* Corporate R&D Headquarters, Fuji Electric Co., Ltd.

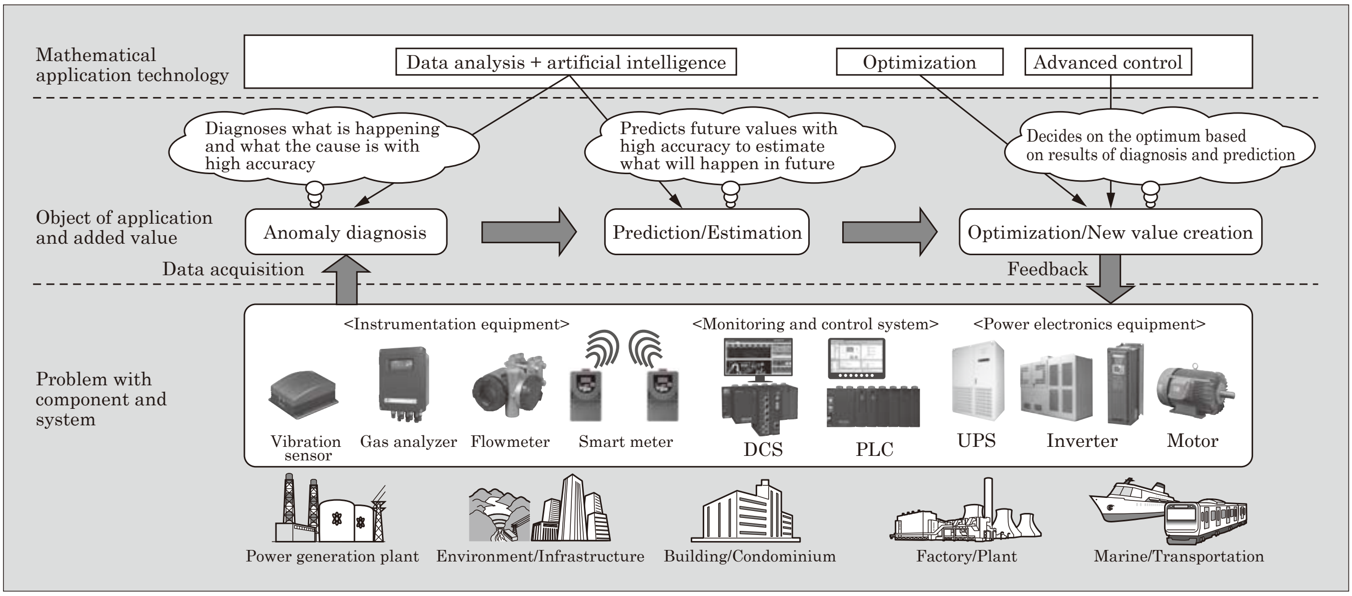


Fig.1 Overall picture of mathematical application technologies related to IoT solutions

Table 1 Representative mathematical application technologies

Classification	Technology	Outline
Data analysis technology	Anomaly diagnosis technology for continuous processing	Automatically detects abnormal states (states different from the usual) of plants by analyzing large volumes of data.
	Anomaly diagnosis technology for batch processing	Carries out anomaly diagnosis for batch processes, in which process values are not constant but the correlations between variables change in the middle.
	Quality prediction technology	Predicts quality indicators of end products based on the data measured during manufacturing and intermediate inspection results.
	Quality simulation technology	Uses trial manufacture or simulation to find the quality under the manufacturing conditions determined by design of experiments, models the manufacturing conditions and quality and searches the model to estimate the optimum manufacturing conditions.
	Soft sensing technology	Builds a mathematical model between data measurable online and data difficult to measure for estimation of data difficult to measure online.
	Event pattern extraction technology	Analyzes accumulated event log data to automatically extract patterns that appear frequently.
	Anomaly symptom detection based on ensemble prediction	Predicts learning data and input variables, which were conventionally determined by experts' close examination, by preparing multiple patterns according to simplified rules and placing emphasis on a model offering high accuracy for prediction.
	Abnormality avoidance operation presenting technology	Searches past event log data of plants to present as candidates operation procedures for abnormality avoidance carried out by operators.
	Structure health monitoring technology	Calculates the maximum acceleration and maximum story drift based on data measured by vibration sensors.
Optimization technology	Energy plant optimum operation technology	Automatically formulates the operation plans for energy supply plants that minimize the fuel costs while supplying energy to cover required demand in the proper quantity.
	Energy demand prediction technology	Predicts the maximum and minimum demand as well as demand at 24 points for every hour of the following day based on the calendar and such meteorological data as highest temperature and weather.
	Comprehensive store optimization technology for supermarkets and convenience stores	Optimizes operation (shutdown state and energy balance) of air conditioners and showcases in supermarkets and convenience stores to realize energy saving and reduction of environmental burden.
	Technology for visualizing potential energy savings via formula manipulation optimization	Applies the latest formula manipulation technology to analyze the optimization model for energy supply plants for visualizing the range of operation, thereby identify theoretical potential energy savings and limits.
	Delivery plan optimization technology	Determines the optimum route (allocation to individual vehicles and order of delivery) in delivery of packages from one delivery base to customers (destinations) by using multiple vehicles.
Advanced control technology	Control performance monitoring technology	Out of many control loops, efficiently finds those requiring improvement by using 4 indicators to quantify control performance for evaluating performance of a control system.
	Control parameter tuning technology	Identifies a plant model by using input and output data (MV and PV) of a plant to calculate PID parameters that satisfy the specification requirements (settling time, overshoot, etc.) of control.
	Model predictive control technology	Predicts future changes in a plant by using a model of the controlled objects and provide control while determining the optimum manipulated variables that keep the controlled target within the target value range.

the optimum is determined based on the results of diagnosis and prediction, which is fed back to problems in the real world. Such feedback is repeated for solving problems. Table 1 lists Fuji Electric's representative mathematical application technologies.

Of the results of the latest research and development, the following chapters present anomaly diagnosis technology for batch processing, anomaly symptom detection based on ensemble prediction and a technology for visualizing potential energy savings via formula manipulation optimization.

3. Anomaly Diagnosis Technology for Batch Processing

Recently, in the industrial and consumer fields, there are increasing demands for equipment maintenance and manufacturing quality management in the manufacturing process. A batch process, which is a type of manufacturing process, refers to one in which material feeding, processing or manufacturing, and delivery of products or partly-finished products are repeated using the same facility and equipment. In this paper, objects involving repeated similar handling by equipment and devices are generally referred to as batch processes. For example, they may indicate cooling equipment such as a refrigerated showcase to be described as an application example, in addition to a polymerization process in the chemical industry, semiconductor manufacturing process and injection molding process.

In batch processes, many sensors have come to be installed in various devices along with the progress of sensor technology to enable on-demand measurement of detailed state variables. Accordingly, Fuji Electric developed a high-accuracy anomaly diagnosis technology by multivariate statistical process control (MSPC) for batch processes. This raises great expectations for improvements in the management level to prevent the manufacture of defective products and to conduct preventive maintenance of equipment in the manufacturing process.

3.1 MSPC

Statistical process control refers to a technology that uses a statistical technique to monitor process operating conditions. The aim is to prevent the manufacture of products that do not meet the specifications in order to improve productivity. Univariate statistical process control (USPC), which has long been in wide use, is a technology to diagnose anomalies by setting the upper and lower limits of the control limit for process variables that have an influence on quality. However, it is prone to falsely detecting anomalies when the width between the upper and lower limits is too narrow and is not able to detect anomalies when the width is too wide.

Meanwhile, MSPC takes the correlations between

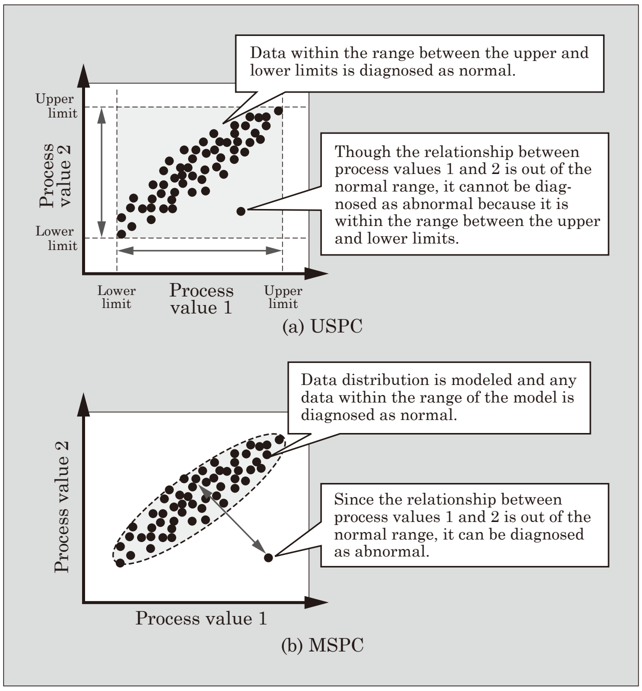


Fig.2 Difference between USPC and MSPC in anomaly diagnosis

variables into account for diagnosis, rather than judging anomalies by simply using upper and lower limits (see Fig. 2). First, the data in the normal range are modeled by using the principal component analysis technique. The model is then used to define the elliptic range shown in Fig. 2(b) as the normal range. For diagnosis, judgment is made based on the degree of deviation between the values of the variable to be diagnosed and this normal range. In this way, MSPC can accurately detect anomalies that cannot be detected by USPC.

3.2 MSPC for batch processes

Generally in a batch process, the process values are not constant but the correlations between variables change in the middle of the process. Accordingly, applying MSPC as it is may cause anomalies to be buried in larger changes of correlations between variables during the progress of the process, which makes detection of those anomalies difficult. To deal with this problem, we have developed MSPC for batch processes. It is capable of accurately detecting small anomalies in a batch process by subtracting the standard profile (average batch process change) from the raw data of the batch process as shown in Fig. 3.

3.3 Application example

This section describes an example of applying the MSPC for batch processes to a refrigerated showcase used for selling perishables in convenience stores and supermarkets. Refrigerated showcases may break down due to frost formation in the hot and humid period in summer. If a showcase fails, it causes sig-

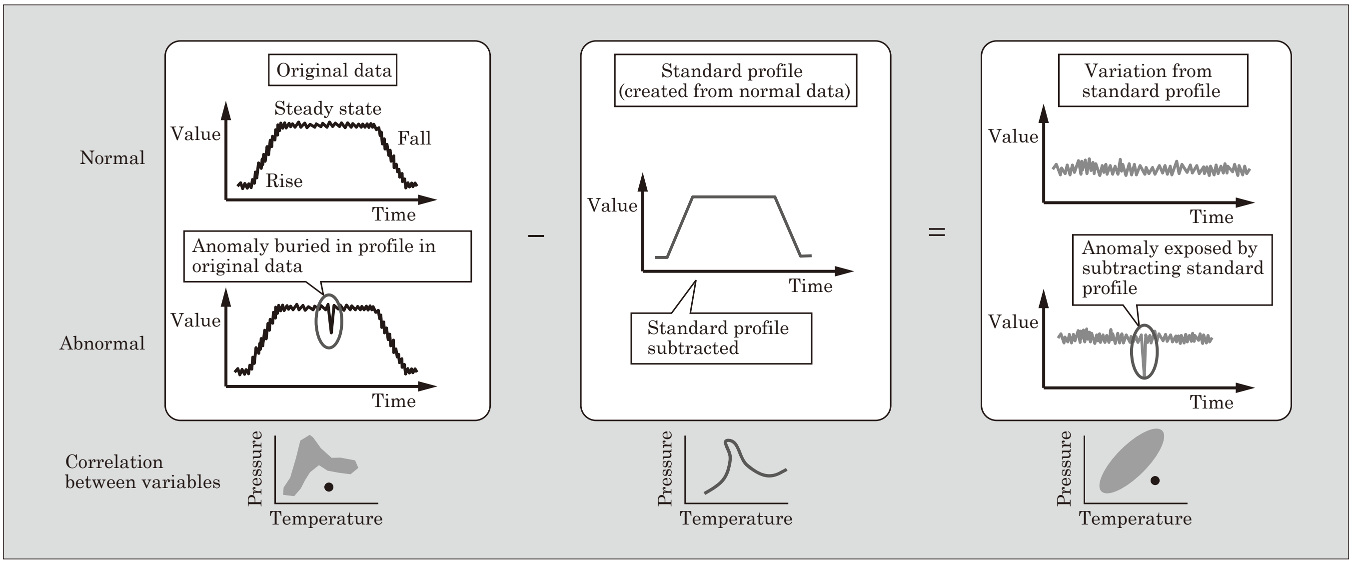


Fig.3 MSPC for batch processes

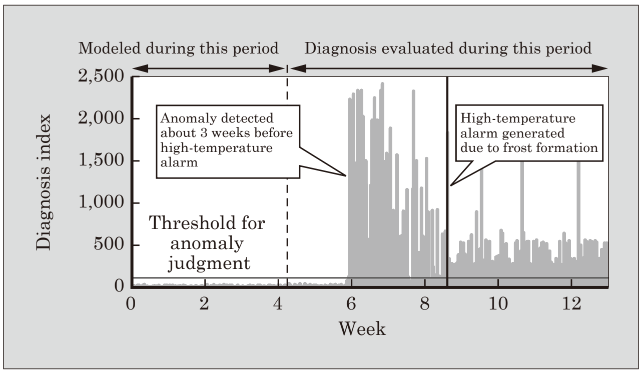


Fig.4 Example of application to refrigerated showcase

nificant losses to both the stores and consumers and needs to be predicted in advance so that measures can be taken. In refrigerated showcases, defrosting takes place at regular intervals and temperature and other data change periodically. This can be treated as a batch process.

Figure 4 shows an example of a refrigerated showcase in a real store. It was diagnosed by generating a high-temperature alarm caused by frost formation. Conventionally, frost could not be detected before an alarm was generated but, in this example, the diagnosis index rapidly increased about 3 weeks before the generation of the anomaly, which shows that a sign of an anomaly was clearly identified.

4. Anomaly Symptom Detection Based on Ensemble Prediction

Conventionally, for operating various plants, USPC is generally employed. In it, the upper and lower limits are set for the variable to be monitored to use as the basis for generating an alarm when any anomaly occurs. The operator runs the plant while predicting any anomaly in advance so that no alarm will be generated. For prediction, a common method is to check the trends of the variable to be monitored. Then, the upper and lower limits for the alarm are set in 2 stages, for the main alarm and pre-alarm as the preliminary stage, in order to monitor for a pre-alarm. For example, the upper limit can be set as the pre-alarm and the upper upper limit as the main alarm. This will configure operations to prevent the main alarm from being generated when the upper limit threshold value is exceeded, thereby ensuring safe operation of the plant. This method, however, had a problem that a pre-alarm did not necessarily guarantee the main alarm would be generated. It also had the problem that setting a low threshold value for the pre-alarm caused more cases of false detection.

In order to solve this problem, Fuji Electric has developed a technology for predicting anomaly generation by building a prediction model for the plant from the large volume of data accumulated. We are using it to predict changes in the monitored object. The main features are as follows:

(a) Capability of predicting changes in the monitored object after a pre-alarm
(b) A high detection rate maintained by prediction even with a higher pre-alarm threshold value
(c) A longer time margin allowed between the prediction and generation of the main alarm

4.1 Ensemble prediction

As techniques for building a prediction model from numerical data, statistical models and neural networks are often used. Statistical models include multiple regression and partial least squares models. With these models, the prediction accuracy greatly depends on the choice and preparation of the data used for creating a model, choice of variables used as the explanatory variables and the values of various parameters used when the model is created. Conventionally, a trial and error

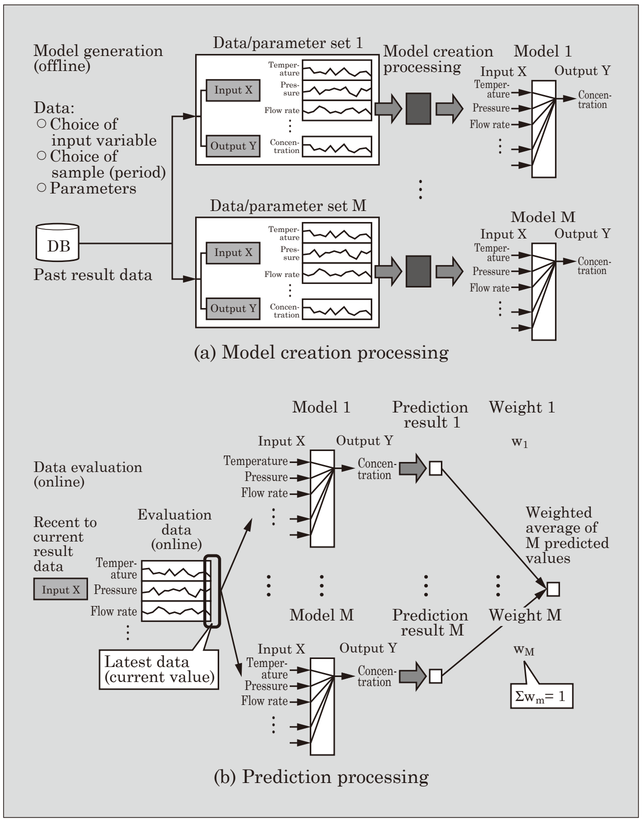


Fig.5 Outline of ensemble prediction

process was necessary to appropriately choose and set the conditions of model creation. In addition, the prediction accuracy greatly varied at times depending on the prediction model.

In order to deal with these problems, we have developed "ensemble prediction," in which the weighted average of outputs of multiple models with different learning data and parameters is used as the result of prediction (see Fig. 5). Ensemble prediction, which equalizes the prediction accuracy variation between the respective models, allows accurate prediction.

4.2 Application example

Figure 6 shows an example of predicting variables of the monitored object of a certain incineration plant.

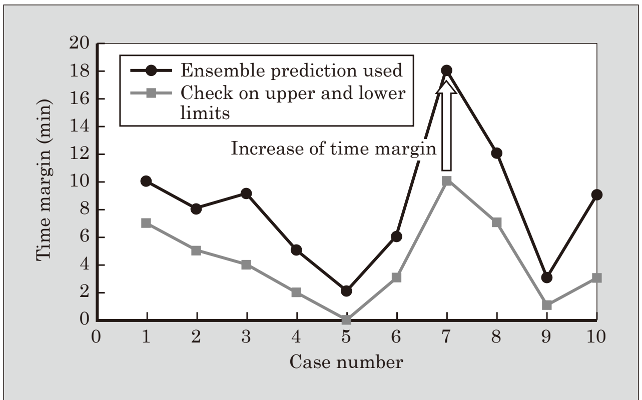


Fig.6 Example of application to incineration plant

The case number in the figure indicates that for an event with an actual anomaly generated. A time margin is a time period between detection of a sign of an anomaly and generation of the actual anomaly. In all cases of an anomaly generated, ensemble prediction shows a longer time margin, which indicates that the manager can deal with any anomaly generated with more time in advance.

5. Technology for Visualizing Potential Energy Savings via Formula Manipulation Optimization

Fuji Electric is working on popularizing energy management systems (EMSs) for measuring the amounts of energy consumption and supply of plants and offices to optimize equipment operation. The key to doing this is prior assessment including that of the energy-saving effect produced by introducing a system and payout time. Introduction of an EMS requires measuring equipment and related management systems, including systems for data management, monitoring, optimization, and the initial investment often becomes high. Accordingly, it is extremely important to make sure that energy reduction worth the initial investment cost is feasible, but accurately estimating it before the actual introduction is not easy.

To solve this problem, Fuji Electric has developed the world's first tool to visualize potential energy savings. It works by comparing the most energy-saving operable range of the equipment with the conventional operation based on the energy efficiency characteristic formula for the equipment.

5.1 Formula manipulation

Formula manipulation is a technology for automatically solving mathematical problems by using algorithms such as the quantifier elimination method. This is a method of transforming a polynomial with quantifiers expressed as a first-order predicate logical formula into an equivalent polynomial with all of the variables with quantifiers eliminated by repeating formula transformation and substitution. To visualize potential energy savings, the quantifier elimination method is used to transform a set of formulae, such as the characteristic formula and operation limiting conditions for the energy supply equipment, into a set of formulae only for the load and supply cost. This makes it possible to visualize the relationship between the load and supply cost.

5.2 Potential energy savings visualization tool

The potential energy savings visualization tool determines the operable range that satisfies the limiting conditions. It does this by using formula manipulation to solve the energy efficiency characteristics and operation limiting conditions such as the upper and lower limits of output for the intended energy supply equip-

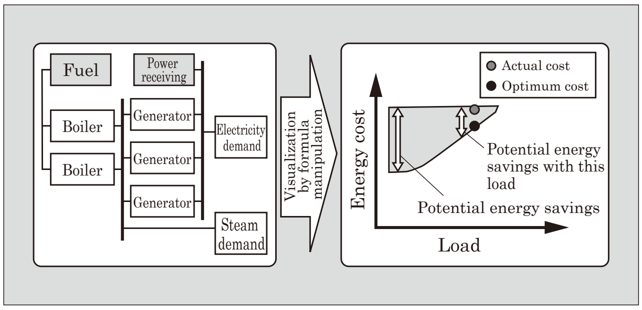


Fig.7 Outline of visualization of potential energy savings

ment. It then compares it with the conventional operation for visualizing the potential energy savings.

The operable range of the equipment here does not mean a simple total of the upper limits of the equipment capacity. It is the operable range that satisfies the limiting conditions of operation of the equipment including the upper and lower limits of output mentioned above and energy supply and demand balance. As shown in Fig. 7, the operable range can be plotted by the relationship between the load and cost of energy to supply to the load. The lowest side of the operable range indicates operation with the minimum cost and the potential energy savings can be easily grasped by looking at the difference from the actual operation.

5.3 Application example

Figure 8 shows an example of visualization by using formula manipulation for equipment that covers an air-conditioning load with 4 centrifugal chillers. As shown in Fig. 8(b), the 4 centrifugal chillers have different energy efficiency characteristics and upper and lower limits of output. Efficient operation is difficult with simple equalized output distribution or quantity control.

Figure 8(c) shows a result of visualization. The horizontal axis represents the overall air-conditioning load L and the vertical axis the total received power P and the filled in portions in the figure indicate operable ranges. Portions with a narrow width of the received power along the vertical axis against the load along the horizontal axis indicate that the degree of freedom of operation is small there. For example, with a 100 kW load, the operable ranges represented by 3 lines correspond to centrifugal chillers 1, 2 and 4 and, above all, centrifugal chiller 1 is shown to provide the highest efficiency and receives the lowest power. The figure shows that, in a portion with a wide width of the received power along the vertical axis against the load such as with a 400 kW load, multiple pieces of equipment are combined for operation and the received power may greatly vary depending on the output distribution of the respective pieces of equipment. The symbol ● indicates conventional operation and ▲ the state of optimum operation corresponding to conventional operation, and the difference between them is the potential energy saving. In an area with a larger

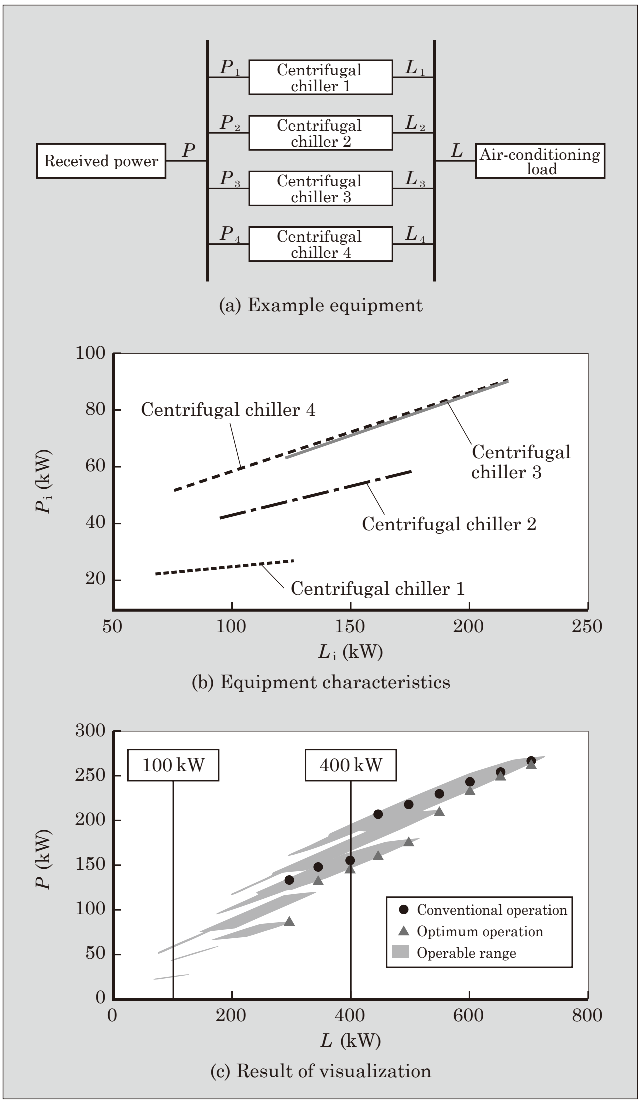


Fig.8 Example of application to centrifugal chiller equipment

difference between them, the energy-saving effect of optimization is larger.

In this way, the economic effect produced by introducing an EMS in various operating conditions can be grasped in advance by using the potential energy savings visualization tool. In addition, by applying this tool to an existing EMS, the optimality of the state of operation of the EMS can be checked and the certainty of the prior conditions including equipment characteristics can be verified. Furthermore, when replacement or addition of energy supply equipment is under consideration, the energy-saving effect of replacement or addition can be quantitatively understood in advance.

6. Postscript

This paper has given an overall picture of mathematical application technologies related to IoT solutions. It has also presented, as the latest mathematical application technologies, anomaly diagnosis technology for batch processing, anomaly symptom detection based on ensemble prediction and a technology for visualizing potential energy savings via formula manipulation optimization. In the future, we intend to continue to work on the establishment of technologies with a higher degree of perfection through application to real plants and create new customer value.

References

(1) Kurotani, K. et al. Current Status and Prospects of Measurement and Control Technologies. FUJI ELECTRIC REVIEW. 2012, vol.58, no.1, p.2-8.

(2) Matsui, T. et al. Data Analysis Technology in Plant Contrtol. FUJI ELECTRIC REVIEW. 2014, vol.60, no.1, p.21-26.

Supplemental Explanation

Supplemental explanation 1　SIL

p.142

SIL stands for Safety Integrity Level. It indicates the level of reliability required for safety functions of the system concerned. The reliability levels required for safety functions are classified into 4 levels from the lowest SIL 1 to the highest SIL 4. IEC 61508-1 defines as shown in Table 1 for low-demand operation and high-demand or continuous operation respectively.

Table 1　Definitions of safety integrity levels

SIL	Low-demand operation*1
4	10^{-5} or higher, lower than 10^{-4}
3	10^{-4} or higher, lower than 10^{-3}
2	10^{-3} or higher, lower than 10^{-2}
1	10^{-2} or higher, lower than 10^{-1}

SIL	High-demand operation or continuous mode*2
4	10^{-9} or higher, lower than 10^{-8}
3	10^{-8} or higher, lower than 10^{-7}
2	10^{-7} or higher, lower than 10^{-6}
1	10^{-6} or higher, lower than 10^{-5}

*1: Represents the average probability of failing to achieve the required function.
*2: Represents the probability of hazardous failure per unit time.

Product Line-Up of SiC Hybrid Modules (600 V, 1,200 V, 1,700 V)

USUI, Ryosuke *

In recent years, reduction of emissions of CO_2 and other greenhouse gases has been demanded for restraining the progress of global warming. In order to achieve this, energy-saving technology must advance further in a wide variety of fields. Energy saving of power electronics equipment such as inverters requires technological innovation in system components including power devices, circuits and control devices. It is an important mission for engineers to develop power devices that exhibit less power dissipation.

Insulated gate bipolar transistor (IGBT) modules, which are currently representative of power devices, use silicon (Si) IGBT chips and freewheeling diode (FWD) chips. However, the performance of these Si devices is approaching its theoretical limit based on physical properties, and significant reduction of power dissipation cannot be expected. Alternatively, the adoption of silicon carbide (SiC) devices, which have excellent characteristics including high heat resistance and high breakdown field resistance, can achieve low power dissipation that has been difficult for conventional Si devices. Inverters are expected to become more efficient and more compact through the mounting of SiC power devices.

Fuji Electric has completed the development of 600-V, 1,200-V and 1,700-V withstand voltage SiC Schottky barrier diode (SiC-SBD), and has commercialized SiC hybrid modules, which combines SiC-SBD and Si-IGBT in our conventional package (see Fig. 1).

1. Features

SiC hybrid modules utilize the same package as the conventional Si module to maintain compatibility. Fuji Electric SiC-SBD chips (withstand voltage: 600, 1,200, 1,700 V) are used as diodes, and 6th-generation "V Series" chips are used as IGBTs. It reduces loss by approximately 26% compared with conventional Si modules with a rating of 1,700 V and 400 A.

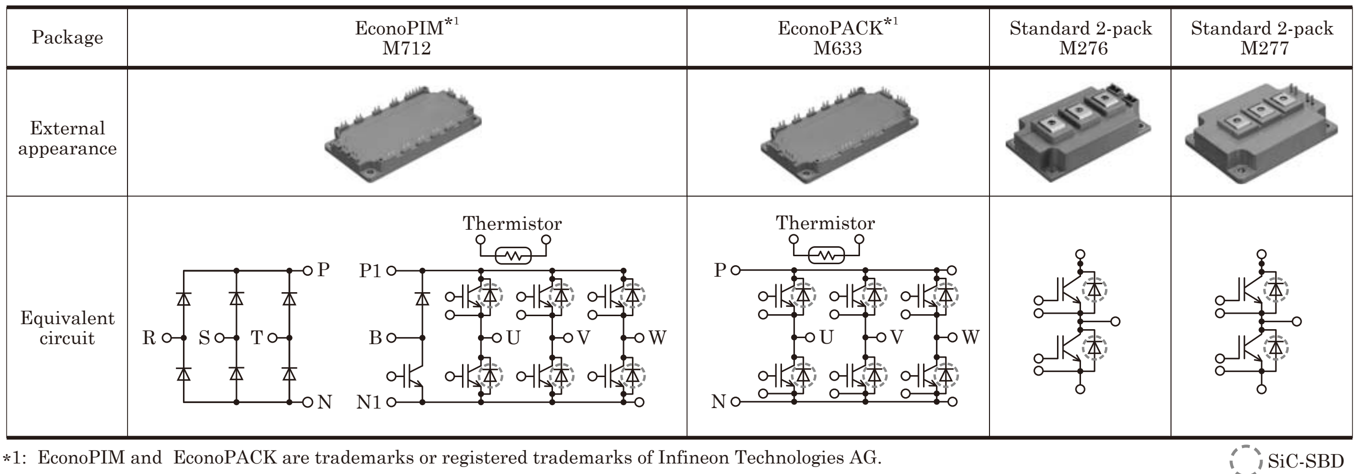
1.1 Product line-up

Table 1 shows the product line-up of the SiC hybrid modules. This time we have developed a power intelligent module (PIM) and modules having 6-in-1 and 2-in-1 circuit configurations. The PIM has built-in converter and brake components.

Table 1 Product line-up of SiC hybrid modules

Package	Circuit structure	Dimensions W × D (mm)	Rated voltage (V)	Rated current (A)
EconoPIM*1 M712	PIM	62 × 122	600	50, 75, 100
			1,200	35, 50
EconoPACK*1 M633	6-in-1	62 × 122	1,200	100
Standard 2-pack M276	2-in-1	62 × 108	1,200	300
Standard 2-pack M277		80 × 110	1,700	400

*1: EconoPIM and EconoPACK are trademarks or registered trademarks of Infineon Technologies AG.



*1: EconoPIM and EconoPACK are trademarks or registered trademarks of Infineon Technologies AG.

Fig.1 SiC hybrid module

* Electronic Devices Business Group, Fuji Electric Co., Ltd.

1.2 Inverter dissipation loss

In this section we will describe the dissipation loss of an inverter equipped with an M277 package device having a rating of 1,700 V, 400 A. Figure 2 shows the results of simulation of dissipation loss in the inverter. 2 kHz is the most commonly used carrier frequency f_C, and as such, the dissipation loss at this carrier frequency is approximately 26% lower for an inverter equipped with SiC hybrid modules than for an inverter equipped with Si modules. Furthermore, the reduction increases in proportion with the carrier frequency, and high-efficiency operation can thus be expected in the high-frequency operations of inverters.

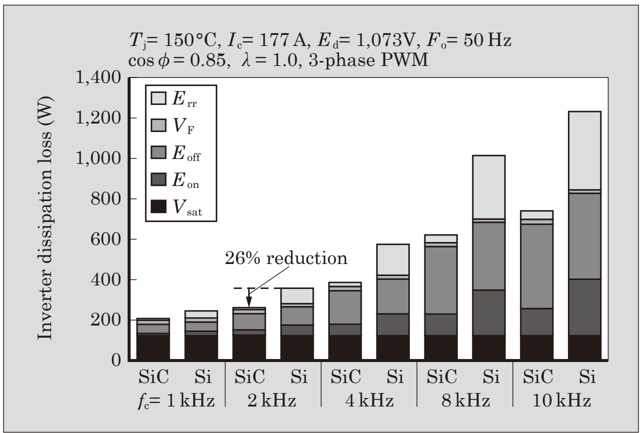


Fig.2 Results of simulation of dissipation loss in inverter

2. Characteristics

2.1 Reverse recovery loss reduction

Figure 3 compares the reverse recovery waveforms of the SiC hybrid and Si modules. The reverse recovery current peak value is quite small for the SiC hybrid module. This is because minority carrier injection does not occur in SiC-SBD, which is a unipolar device. The reverse recovery loss of a SiC hybrid module with a rating of 400 A is 99% lower than that of Si modules.

2.2 Turn-on loss reduction

The reverse recovery current peak value in FWD is reflected in the turn-on current peak value in an opposing arm IGBT. Since the turn-on current peak value decreases in proportion with the reverse recovery current peak value, turn-on loss can be reduced. Figure 4 shows a comparison of turn-on waveforms between a SiC hybrid module and Si module. Similar to reverse recovery waveforms, the turn-on current peak value is quite small. The turn-on loss of a SiC hybrid module with a rating of 400 A is 52% lower than that of a Si module.

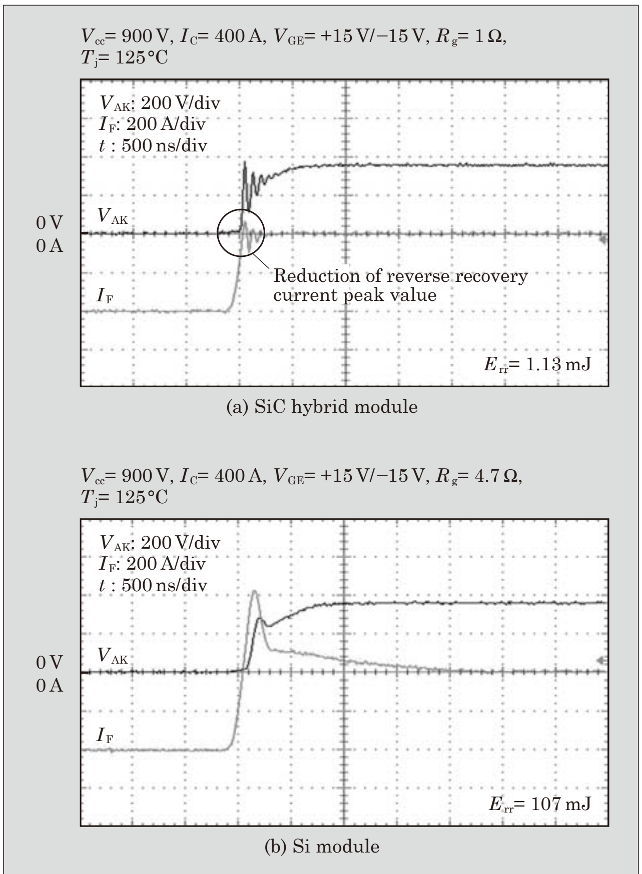


Fig.3 Reverse recovery waveforms

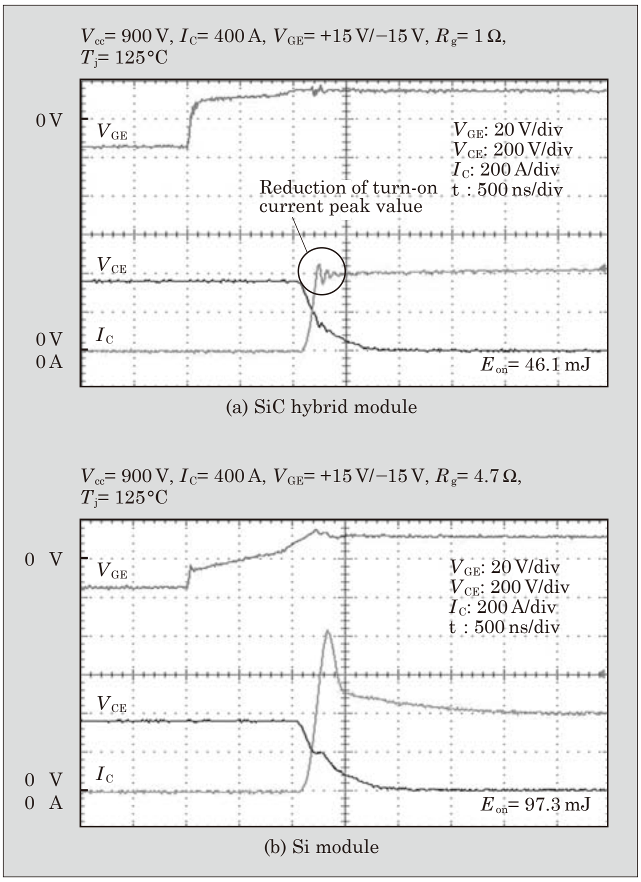


Fig.4 Turn-on waveforms

Launch time

Starting in June 2016

Product Inquiries

Sales Department I, Semiconductor Division, Sales Group, Fuji Electric Co., Ltd.
Tel: +81 (3) 5435-7152

Outdoor Digital Signage Vending Machine

KATSURAYAMA, Satoru* MATSUMOTO, Masahiro*

In recent years, both indoor- and outdoor-use vending machines are being increasingly required to adopt digital signage functionality as a new added-value feature. Fuji Electric introduced to the market the industry's first mass-produced digital signage vending machine in 2010.

In order to support the popularization of this digital signage vending machine, Fuji Electric has developed and released to the market the "FAE36M6RD6N4" digital signage vending machine as a popular model that could meet the specifications and cost requirements of the market. Outdoor installation is made possible by adopting misdetection prevention functionality for the touch panel and high-temperature countermeasures for the liquid crystal display (LCD) and the control circuit board. The external appearance is shown in Fig. 1, and the specifications are shown in Table 1.

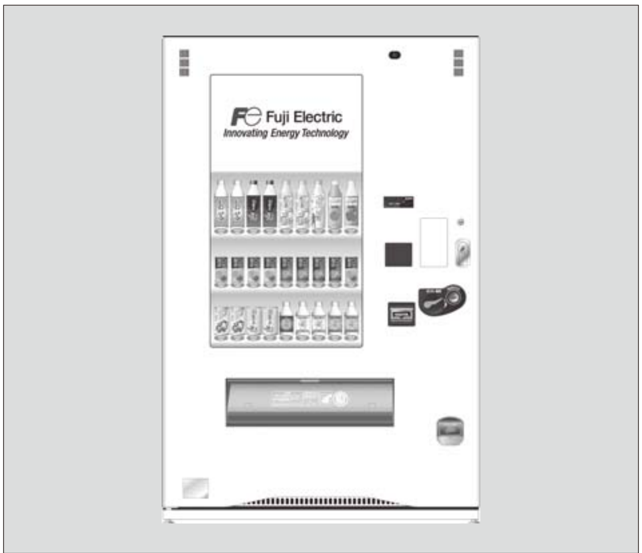


Fig.1 Digital signage vending machine

Table 1 Specifications of the digital signage vending machine

Item	Specification
Type	FAE36M6RD6N4
Dimensions	W 1,181 × D 720 × H 1,830 (mm)
Mass	291 kg
Product display	46-inch LCD (imaging)
Selection button	46-inch LCD (imaging)
Product selection method	Image sensor system touch panel
Products for sale	Small cans, medium cans, large cans, PET, bottle cans, etc.
Refrigerant	HF0-1234yf
Power consumption	1,500 kWh/y

* Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.

1. Touch Panel Misdetection Prevention

An image sensor system has been adopted as the detection system for the touch panel (see Fig. 2). This system achieves clear visibility without requiring the use of an electrode or conductive film for the surface of the glass.

The image sensor system suffers a disadvantage of misrecognizing direct sunlight or rain, and as a result, it was considered unsuitable for use outdoors. In this regard, we developed a proprietary algorithm for eliminating direct sunlight, rain and snow, as well as a drip-proof fan enclosure for preventing rainwater from adhering to the sensor. These enhancements enable the system to be installed for outdoor use.

(1) Proprietary algorithm

(a) When the number of touches per second exceeds the threshold value, it is judged as due to rain or snow, and not as a result of human operation. Accordingly, the relevant detection data is deleted, and prevention of misdetection due to rain

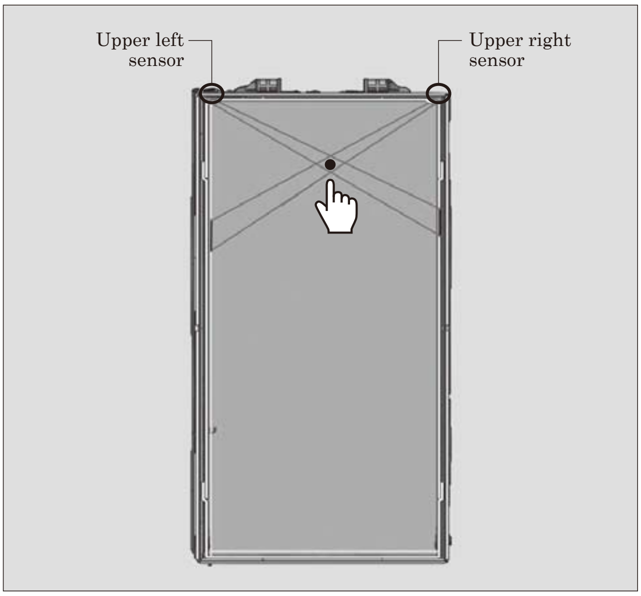


Fig.2 Detection of touch position via image sensors

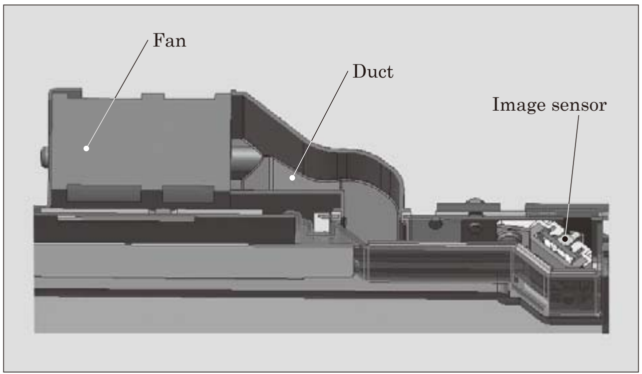


Fig.3 Drip-proof fan enclosure

or snow is achieved.

(b) For light-saturated images taken by the image sensor, comparison is made for the image depending on the existence of infrared. Accordingly, the relevant detection data is deleted as noise, and prevention of misdetection due to direct sunlight is achieved.

(c) The prevention of misdetection due to foreign objects is achieved by deleting the detection data of coordinates that continue to remain after a certain period of time.

(2) Drip-proof fan enclosure

When rainwater adheres to the image sensor, the images are distorted and human operation cannot be recognized. Therefore, the image sensor is equipped with a hood to prevent the penetration of rainwater during times of normal rain. Furthermore, even when rainwater adheres to the image sensor due to wind, the adoption of the drip-proof fan enclosure, which consists of a fan and duct, ensures detection of the touch position by maintaining an air flow strong enough to remove the rainwater that has adhered to the image sensor (see Fig. 3).

These operating conditions of the drip-proof fan apply the algorithm for preventing misdetection due to rain. When rain is detected, the drip-proof fan automatically starts operating and blows away the rainwater.

2. High-Temperature Countermeasures for LCD and Control Circuit Board

(1) LCD

The touch panel mounted to the door of the vending machine hotter than those installed indoors due to the influence of the ambient temperature and sunlight. As a function to lower the temperature of the touch panel, the unit comes equipped with a temperature control function for ensuring that the atmospheric temperature on the rear surface of the touch panel does not exceed a certain temperature via the use of a temperature-sensor connected air-cooling fan.

Furthermore, the LCD also becomes hot. A heat-resistant liquid crystal was adopted because a normal liquid crystal is susceptible to blackening due to summer temperatures. In addition, since the display becomes difficult to see under direct sunlight, we have developed and mounted a high-luminance type LCD for vending machines. The adoption of these measures enables the unit to be installed outdoors with an LCD.

(2) Vending machine control circuit board

The control circuit board for the vending machine comes equipped with a high-performance ARM (Cortex-A9)*1 microprocessor that utilizes Linux*2 as an OS. Since conventional digital signage vending machines came equipped with a commercially available PC, their usage was restricted to environments compatible with temperature and humidity criteria. However, such restrictions no longer apply since the control circuit board was designed based on the design criteria of the vending machine. The unit meets outdoor specifications that maintain reliability even under environmental conditions equal to those of conventional vending machines.

---

*1: ARM and Cortex are trademarks or registered trademarks of ARM Limited (or its subsidiaries) based in the EU and other countries.

*2: Linux is a trademark or registered trademark of Mr. Linus Torvalds in Japan and other countries.

Launch time

March 2016

Product Inquiries

Sales Department III, Sales Division, Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.
Tel: +81 (3) 5435-7077

2nd-Generation Low-Loss SJ-MOSFET “Super J MOS S2 Series” and “Super J MOS S2FD Series”

WATANABE, Sota*

Recently, renewable energy sources such as photovoltaic power generation and wind power generation have been becoming widespread against the background of the need to prevent global warming. However, energy consumption is increasing in the fields of social infrastructure, automobiles, industrial machinery, IT devices, consumer electronics, etc., and power conversion technology is gaining importance for even more efficient use of energy. There are requirements for power conversion devices such as high efficiency, high power density and low noise and semiconductor switching elements including power metal-oxide-semiconductor field-effect transistors (MOSFETs) used in their power conversion portions are required to offer a compact size, low loss and low noise.

In order to meet these requirements, Fuji Electric has released the 2nd-generation low-loss SJ-MOSFET “Super J MOS S2 Series” (S2 Series), a series of easy-to-use MOSFETs capable of improving the efficiency of power conversion equipment. This has been realized by improving the trade-off relationship between the withstand voltage BV_{DSS} and on-resistance of the element and suppressing the surge voltage at the time of turn-off switching. Fuji Electric has also released the “Super J MOS S2FD Series” (S2FD Series), which uses faster built-in diodes than those of the S2 Series. Tables 1 and 2 show the product line-ups and main characteristics of the respective series.

1. Features

The features of the Super J MOS S2 Series and Super J MOS S2FD Series are as follows.

(a) On-resistance per unit area $R_{on} \cdot A$ has been reduced by approximately 25% from conventional products.
(b) Reduction of the turn-off loss E_{off} and suppression of the surge voltage at the time of turn-off switching (V_{DS} surge) have been achieved at the same time. E_{off} at the V_{DS} surge of 480 V has been reduced by approximately 30 μJ.
(c) The loss generated by charging and discharging E_{oss} has been reduced by approximately 30% from conventional products.
(d) The total gate charge Q_G has been reduced by approximately 30% from conventional products.
(e) With the S2FD Series, the reverse recovery time t_{rr} of the built-in diodes has been reduced by ap-

Table 1 “Super J MOS S2 Series” product line-up and main features

V_{DS} (V)	$R_{DS\,(on)}$ max. (mΩ)	I_D (A)	Product line-up				
			TO-247 package 	TO-3P package 	TO-220 package 	TO-220F package 	TO-252 package 
600	25.4	95.5	FMW60N025S2	–	–	–	–
	40	66.2	FMW60N040S2	–	–	–	–
	55	49.9	FMW60N055S2	–	–	–	–
	70	39.4	FMW60N070S2	–	–	FMV60N070S2	–
	79	37.1	FMW60N079S2	–	FMP60N079S2	FMV60N079S2	–
	88	32.8	FMW60N088S2	–	FMP60N088S2	FMV60N088S2	–
	99	29.2	FMW60N099S2	–	FMP60N099S2	FMV60N099S2	–
	125	22.7	FMW60N125S2	–	FMP60N125S2	FMV60N125S2	–
	160	17.9	FMW60N160S2	–	FMP60N160S2	FMV60N160S2	–
	190	15.5	FMW60N190S2	FMH60N190S2	FMP60N190S2	FMV60N190S2	–
	280	10.4	–	FMH60N280S2	FMP60N280S2	FMV60N280S2	FMD60N280S2
	380	8.1	–	–	FMP60N380S2	FMV60N380S2	FMD60N380S2

* Electronic Devices Business Group, Fuji Electric Co., Ltd.

Table 2 “Super J MOS S2FD Series” product line-up and main features

V_{DS} (V)	$R_{DS\,(on)}$ max. (mΩ)	I_D (A)	Product line-up		
			TO-247 package 	TO-220 package 	TO-220F package 
600	27	95.5	FMW60N027S2FD	–	–
	43	66.2	FMW60N043S2FD	–	–
	59	49.9	FMW60N059S2FD	–	–
	75	39.4	FMW60N075S2FD	–	FMV60N075S2FD
	84	37.1	FMW60N084S2FD	FMP60N084S2FD	FMV60N084S2FD
	94	32.8	FMW60N094S2FD	FMP60N094S2FD	FMV60N094S2FD
	105	29.2	FMW60N105S2FD	FMP60N105S2FD	FMV60N105S2FD
	133	22.7	FMW60N133S2FD	FMP60N133S2FD	FMV60N133S2FD
	170	17.9	FMW60N170S2FD	FMP60N170S2FD	FMV60N170S2FD

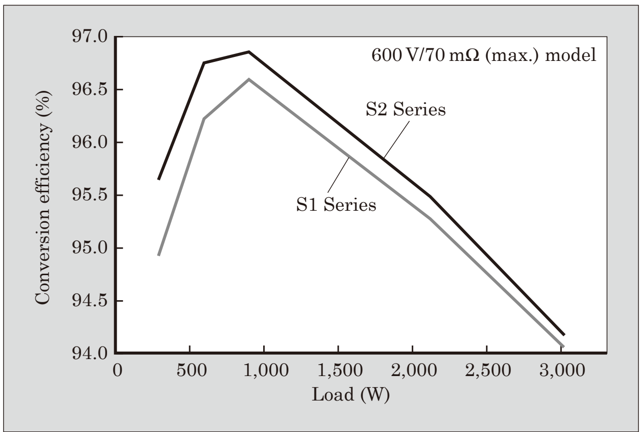


Fig.1 Conversion efficiency characteristics

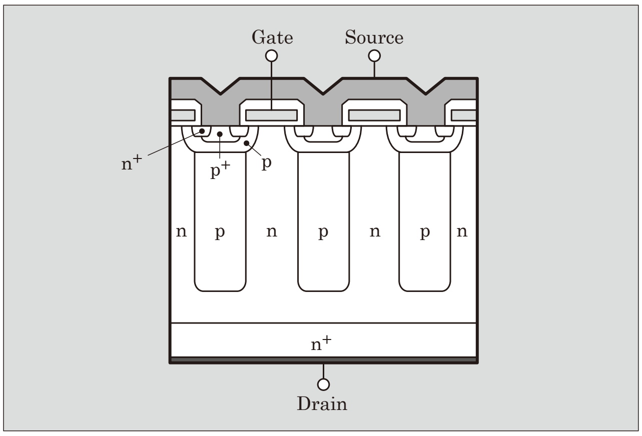


Fig.2 SJ-MOSFET superjunction structure

proximately 50% from those of the S2 Series.

2. Application Example

We have conducted a comparative evaluation using the FB-LLC current resonant circuit of a power supply equipped with the 600-V/70-mΩ (max.) model of the S2 Series and the conventional “Super J MOS S1 Series” (S1 Series) (see Fig. 1). The input and output conditions used are the input voltage at 230 V, output voltage at 53.5 V and the resistance of the external resistor R_G at 5.1 Ω.

The S2 Series has suppressed false activation due to gate vibration and improved the trade-off characteristic between E_{off} and V_{DS} surge to successfully reduce Q_G and E_{oss}. This shows that the S2 Series provides higher efficiency than the S1 Series in all load regions and is capable of realizing higher-efficiency and higher-reliability power supply.

3. Background Technologies

3.1 Reduction of on-resistance

For reducing the conduction loss of a power MOSFET, the on-resistance during conduction must be reduced but the size of a chip that can be mounted in a package is limited, and thus the reduction needs to be achieved without increasing the chip size. For that purpose, technology for reducing $R_{on}{\cdot}A$ such as a superjunction structure as shown in Fig. 2 is essential. With the S2 Series, the impurity diffusion process has been improved for maintaining a high impurity concentration of the n-type regions and reduced the resistance value. This has reduced $R_{on}{\cdot}A$ from 20 mΩ·cm^2 with the S1 Series to 15 mΩ·cm^2 with the S2 Series, a 25% reduction.

3.2 E_{off} reduction and V_{DS} surge suppression

Figure 3 shows the trade-off characteristic between E_{off} and V_{DS} surge. For suppressing V_{DS} surge and false activation of the gate, $V_{GS(th)}$ and internal resistance R_g have been optimized, which has enabled the

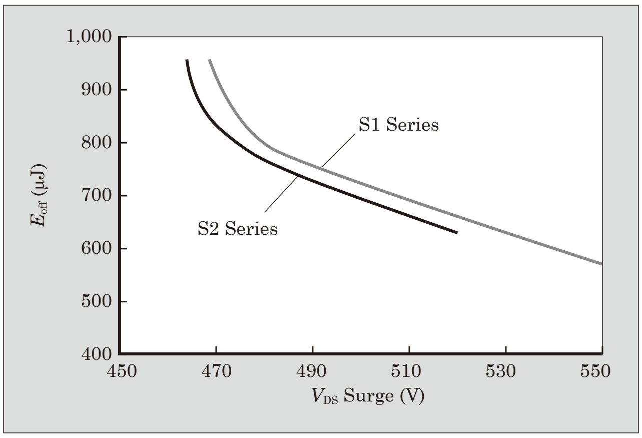


Fig.3 E_{off}-V_{DS} surge trade-off characteristics

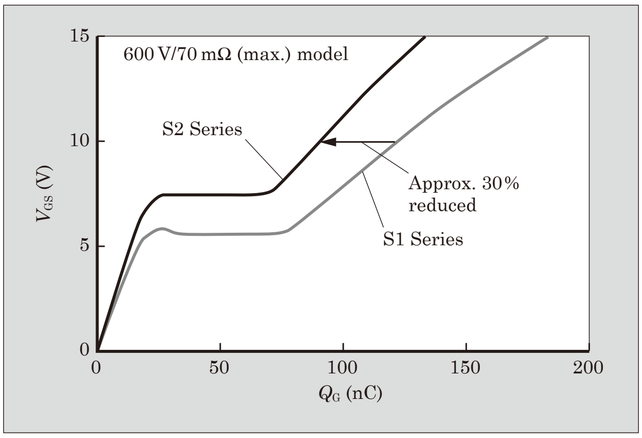


Fig.4 Q_G characteristics

S2 Series to achieve smaller E_{off} than that of the S1 Series at the same V_{DS} surge and improved the trade-off characteristic between E_{off} and V_{DS} surge.

3.3 Reduction of loss with light load

When the power supply is running with a light load, the current that flows into the MOSFET is small

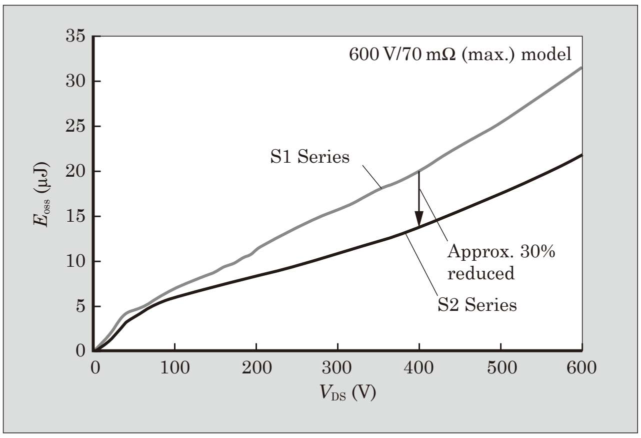


Fig.5 E_{oss} characteristics

and the percentage of the conduction loss out of the entire loss is smaller, which increases the percentage of the drive loss and E_{oss}. One example is the operation with a load of 600 W or smaller in the characteristic in Fig. 1. Accordingly, as shown in the Q_G characteristic in Fig. 4, the surface structure has been optimized to reduce Q_G, which is an indicator of drive loss, by approximately 30% compared to the S1 Series with V_{GS} at 10 V. As shown in the E_{oss} characteristic in Fig. 5, E_{oss} with V_{DS} at 400 V has been reduced by approximately 30%. This has led to a 0.73% improvement of the conversion efficiency with a light load of 300 W.

Launch time

March 2016

Product inquiries

Sales Department III, Sales Division, Electronic Device Business Group, Fuji Electric Co., Ltd.
Tel: +81 (3) 5435-7156

High-Speed Discrete IGBT "High-Speed W Series"

HARA, Yukihito*

As the demand for energy in the world has been steadily increasing, there has become a greater need for energy-saving solutions. It is against this backdrop that very high expectations have been placed upon power electronics technology for delivering high-efficiency power conversion and miniaturization of electric equipment.

For example, the inverter welding machines used at construction sites are required to be smaller and lightweight to facilitate greater portability. As a result, uninterruptible power systems (UPSs), power conditioning sub-systems (PCSs) and the devices that make use of them need to be able to perform high-speed switching, while achieving low power dissipation.

When it comes to improving performance conversion efficiency as one of the performance factors of these devices, there is a strong requirement for low power dissipation in the switching device, and in particular, devices that operate at 20 kHz or higher are being required to achieve low power dissipation characteristics during high-speed switching so as to make reactor miniaturization possible.

Fuji Electric has developed and released to the market the high-speed discrete insulated gate bipolar transistor (IGBT) "High-Speed W Series" as a unit capable of improving the on-voltage and switching characteristic trade-off, while achieving miniaturization for the inverter welding machine and enhanced efficiency for the UPS and PCS (see Fig. 1).

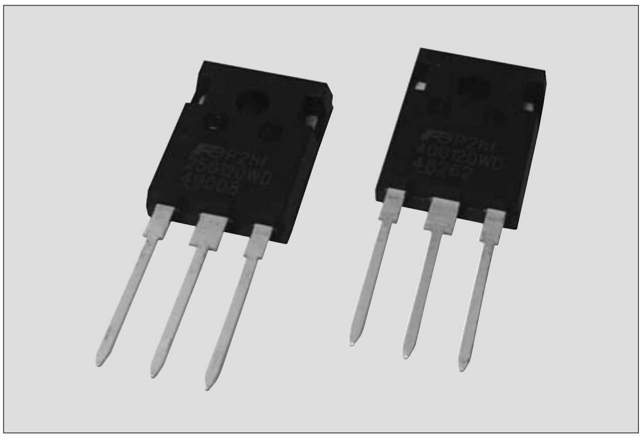


Fig.1 "High-Speed W Series"

* Electronic Device Business Group, Fuji Electric Co., Ltd.

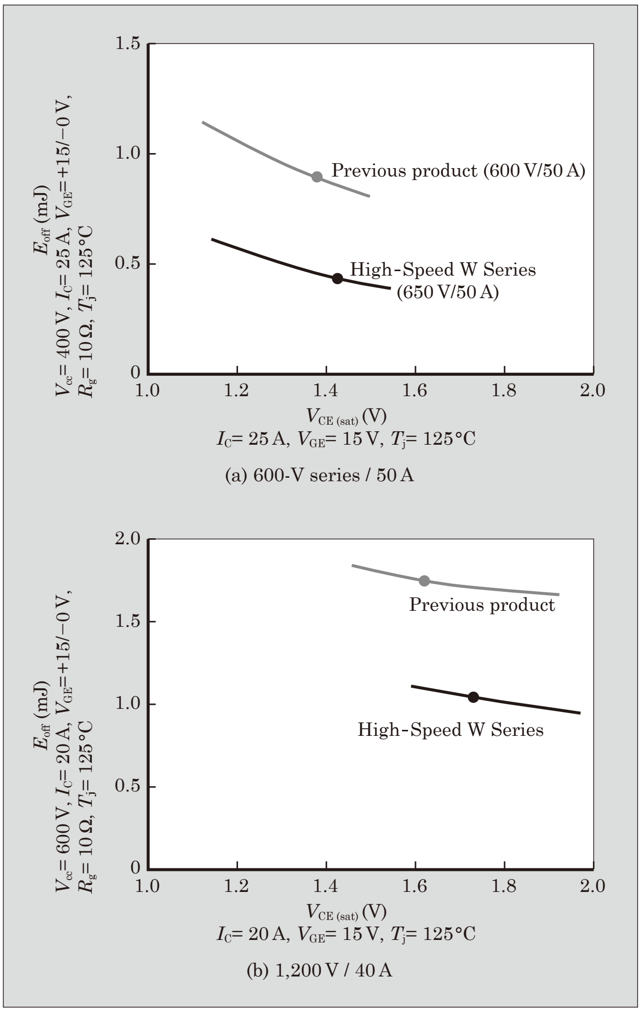


Fig.2 $V_{CE\,(sat)}$-E_{off} characteristic

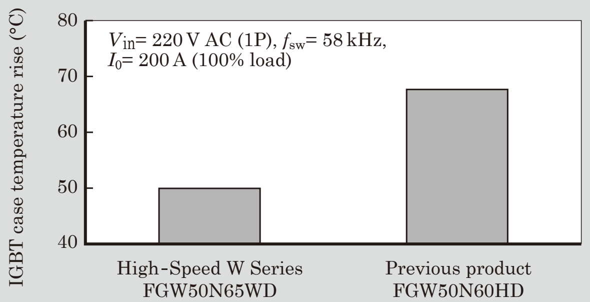
1. Features

The High-Speed W Series has the following features:

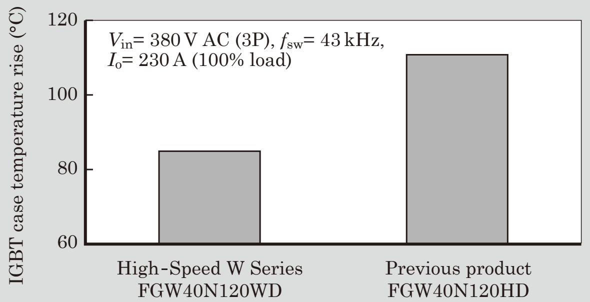
(a) Applicable to high-frequency drive (20 to 100 kHz)
(b) Approx. 40% reduction in turn-off loss (compared with conventional product) (see Fig. 2)
(c) Rated 650 V / 40 to 75 A, 1,200 V / 25, 40 A (see Table 1)
(d) Package: TO-247 (all lead-free solder)

Table 1 "High-Speed W Series"

V_{CE}	Package	I_C (T_C = 100 °C)					Internal diode
		25 A	40 A	50 A	60 A	75 A	
650 V	TO-247	–	FGW40N65WD	FGW50N65WD	FGW60N65WD	–	Yes (Rated I_F = Rated $I_C \cdot 1/2$)
		–	FGW40N65WE	FGW50N65WE	FGW60N65WE	FGW75N65WE	Yes (Rated I_F = Rated I_C)
		–	FGW40N65W	FGW50N65W	FGW60N65W	FGW75N65W	No
1,200 V	TO-247	FGW25N120WD	FGW40N120WD	–	–	–	Yes (Rated I_F = Rated $I_C \cdot 1/2$)
		FGW25N120WE	FGW40N120WE	–	–	–	Yes (Rated I_F = Rated I_C)
		FGW25N120W	FGW40N120W	–	–	–	No



(a) Single-phase model (200-A model)



(b) 3-phase model (230-A model)

Fig.3 Inverter welding machine evaluation results

2. Application Example

In this section, we will describe an application example for the inverter welding machine. Inverter welding machines require the use of devices that take a long time before activating overheat protection, and as such, great importance is placed on the ability to suppress rising temperatures of the case of the devices so as to ensure a low temperature. Figure 3 shows the evaluation results for the temperature rise of the case of the IGBT while operating the inverter welding machine at a load of 100%. Conventional inverter welding machines have mostly operated at a switching frequency of approximately 20 kHz, but the inverter welding machine described in this paper comes in a single-phase 58-kHz model and a 3-phase 43-kHz model. By applying the High-Speed W Series we were able to suppress the temperature rise in the case of the IGBT by approximately 30% compared with the conventional "High-Speed V Series."

3. Supporting Technologies

There has been an increasing trend in recent years to raise the switching frequency for inverter welding machines. Furthermore, many UPS and PCS operate at a switching frequency between 20 and 40 kHz. Therefore, we designed the discrete IGBT so as to enable high-speed switching operation, while also achieving low power dissipation characteristics.

3.1 IGBT chip

As shown in Fig. 4, the High-Speed W-Series has improved the $V_{CE\ (sat)}$-E_{off} trade-off by introducing an active structure for significantly reducing parasitic capacitance when compared with the previous product, while also optimizing the field stop layer, incorporating a collector layer that suppresses hole injection and thinning the substrate. Furthermore, design is implemented with emphasis placed on achieving a low E_{off} characteristic so as to further increase the drive frequency.

In addition, IGBT of the 600-V series have been designed with a rated voltage of 650 V to meet the strong demand for high voltages capable of securing voltage

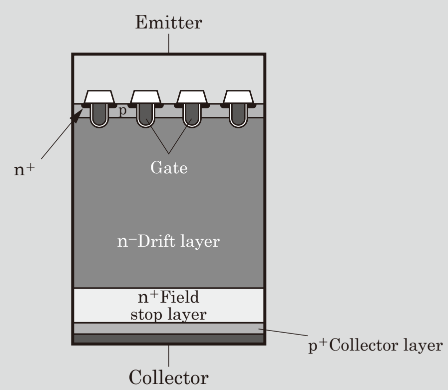


Fig.4 IGBT chip cross sectional structure

New Products

margin.

3.2 FWD chip

Design emphasis is placed on switching loss, just as it is with the IGBT. Moreover, the free wheeling diode (FWD) guarantees a capacity of 650 V, while also maintaining low recovery loss characteristics through the optimization of the thickness of the drift layer based on the previous FWD.

Meanwhile, the FWD for 1,200 V is the same FWD as the previous product, which maintains low recovery loss characteristics.

3.3 Package

The industrial standard compliant TO-247 package has been adopted, just as it was for the previous product. Lead-free solder has been utilized for the solder below the chip, and it is compliant with the RoHS Directive (EU2011/65/EU). Furthermore, high reliability has been secured in heat and power cycles.

Launch time

1,200-V rated product: September 2015
650-V rated product: December 2015

Product inquiries

Sales Department III, Sales Division, Electronic Device Business Group, Fuji Electric Co., Ltd.
Tel: +81 (3) 5435-7161

Overseas Subsidiaries

* Non-consolidated subsidiaries

America

Fuji Electric Corp. of America
Sales of electrical machinery and equipment, semiconductor devices, drive control equipment, and devices
Tel +1-732-560-9410
URL http://www.americas.fujielectric.com/

Fuji Electric Brazil-Equipamentos de Energia Ltda *
Sales of inverters, semiconductors, and power distribution
Tel +55-11-2283-5991
URL http://americas.fujielectric.com/pt-br/

Reliable Turbine Services LLC
Repair and maintenance of steam turbines, generators, and peripheral equipment
Tel +1-573-468-4045

Fuji SEMEC Inc.*
Manufacture and sales of door opening and closing systems
Tel +1-450-641-4811

Asia

Fuji Electric Asia Pacific Pte. Ltd.
Sales of electrical distribution and control equipment, drive control equipment, and semiconductor devices
Tel +65-6533-0014
URL http://www.sg.fujielectric.com/

Fuji SMBE Pte. Ltd. *
Manufacture, sales, and services relating to low-voltage power distribution board(switchgear, control equipment)
Tel +65-6756-0988
URL http://smbe.fujielectric.com/

Fuji Electric (Thailand) Co., Ltd. *
Sales and engineering of electric substation equipment, control panels, and other electric equipment
Tel +66-2-210-0615
http://www.th.fujielectric.com/

Fuji Electric Manufacturing (Thailand) Co., Ltd.
Manufacture and sales of inverters (LV/MV), power systems (UPS, PCS, switching power supply systems), electric substation equipment (GIS) and vending machines
Tel +66-2-5292178

Fuji Tusco Co., Ltd. *
Manufacture and sales of Power Transformers, Distribution Transformers and Cast Resin Transformers
Tel +66-2324-0100
URL http://www.ftu.fujielectric.com/

Fuji Electric Vietnam Co.,Ltd. *
Sales of electrical distribution and control equipment and drive control equipment
Tel +84-4-3935-1593

Fuji Furukawa E&C (Vietnam) Co., Ltd. *
Engineering and construction of mechanics and electrical works
Tel +84-4-3755-5067

PT. Fuji Electric Indonesia *
Sales of inverters, servos, UPS, tools, and other component products
Tel +62 21 398-43211
URL http://www.id.fujielectric.com/

Fuji Electric India Pvt. Ltd. *
Sales of drive control equipment and semiconductor devices
Tel +91-22-4010 4870
URL http://www.fujielectric.co.in

Fuji Electric Philippines, Inc.
Manufacture of semiconductor devices
Tel +63-2-844-6183

Fuji Electric (Malaysia) Sdn. Bhd.
Manufacture of magnetic disk and aluminum substrate for magnetic disk
Tel +60-4-403-1111
URL http://www.fujielectric.com.my/

Fuji Furukawa E&C (Malaysia) Sdn. Bhd. *
Engineering and construction of mechanics and electrical works
Tel +60-3-4297-5322

Fuji Electric Taiwan Co., Ltd.
Sales of semiconductor devices, electrical distribution and control equipment, and drive control equipment
Tel +886-2-2511-1820

Fuji Electric Korea Co., Ltd.
Sales of power distribution and control equipment, drive control equipment, rotators, high-voltage inverters, electronic control panels, medium- and large-sized UPS, and measurement equipment
Tel +82-2-780-5011
URL http://www.fujielectric.co.kr/

Fuji Electric Co.,Ltd. (Middle East Branch Office)
Promotion of electrical products for the electrical utilities and the industrial plants
Tel +973-17 564 569

Fuji Electric Co., Ltd. (Myanmar Branch Office)
Providing research, feasibility studies, Liaison services
Tel +95-1-382714

Representative office of Fujielectric Co., Ltd. (Cambodia)
Providing research, feasibility studies, Liaison services
Tel +855-(0)23-964-070

Europe

Fuji Electric Europe GmbH
Sales of electrical/electronic machinery and components
Tel +49-69-6690290
URL http://www.fujielectric-europe.com/

Fuji Electric France S.A.S
Manufacture and sales of measurement and control devices
Tel +33-4-73-98-26-98
URL http://www.fujielectric.fr/

Fuji N2telligence GmbH *
Sales and engineering of fuel cells and peripheral equipment
Tel +49 (0) 3841 758 4500

China

Fuji Electric (China) Co., Ltd.
Sales of locally manufactured or imported products in China, and export of locally manufactured products
Tel +86-21-5496-1177
URL http://www.fujielectric.com.cn/

Shanghai Electric Fuji Electric Power Technology (Wuxi) Co., Ltd.
Research and development for, design and manufacture of , and provision of consulting and services for electric drive products, equipment for industrial automation control systems, control facilities for wind power generation and photovoltaic power generation, uninterruptible power systems, and power electronics products
Tel +86-510-8815-9229

Wuxi Fuji Electric FA Co., Ltd.
Manufacture and sales of low/high-voltage inverters, temperature controllers, gas analyzers, and UPS
Tel +86-510-8815-2088

Fuji Electric (Changshu) Co., Ltd.
Manufacture and sales of electromagnetic contactors and thermal relays
Tel +86-512-5284-5642
URL http://www.fujielectric.com.cn/csfe/

Fuji Electric (Zhuhai) Co., Ltd.
Manufacture and sales of industrial electric heating devices
Tel +86-756-7267-861
http://www.fujielectric.com.cn/fez/

Fuji Electric (Shenzhen) Co., Ltd.
Manufacture and sales of photoconductors, semiconductor devices and currency handling equipment
Tel +86-755-2734-2910
URL http://www.szfujielectric.com.cn/

Fuji Electric Dalian Co., Ltd.
Manufacture of low-voltage circuit breakers
Tel +86-411-8762-2000

Fuji Electric Motor (Dalian) Co., Ltd.
Manufacture of industrial motors
Tel +86-411-8763-6555

Dailan Fuji Bingshan Vending Machine Co.,Ltd.
Development, manufacture, sales, servicing, overhauling, and installation of vending machines, and related consulting
Tel +86-411-8754-5798

Fuji Electric (Hangzhou) Software Co., Ltd.
Development of vending machine-related control software and development of management software
Tel +86-571-8821-1661
URL http://www.fujielectric.com.cn/fhs/cn/

Fuji Electric FA (Asia) Co., Ltd.
Sales of electrical distribution and control equipments
Tel +852-2311-8282
URL http://www.fea.hk/

Fuji Electric Hong Kong Co., Ltd.
Sales of semiconductor devices and photoconductors
Tel +852-2664-8699
URL http://www.hk.fujielectric.com/

Hoei Hong Kong Co., Ltd.
Sales of electrical/electronic components
Tel +852-2369-8186
URL http://www.hoei.com.hk/

Printed on recycled paper