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Present Condition of JFE-SCADA System and Future Prospects†

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Abstract:

Since the 2000s, the development of the communication technology has changed the architecture of remote monitoring system from specialized equipment to general-purpose computers. JFE Engineering has developed the remote monitoring system for pipelines since the 1980s, and has been tackling development of JFE-SCADA of original specifications which is suitable for remote monitoring. In recent years, in addition to the pipeline applications, JFE Engineering enlarged the SCADA system to solar power plants as a package. This paper outlines achievements and future prospects in these activities.

1. Introduction

High reliability is required in remote pipeline monitoring systems, as these systems are critical equipment for performing monitoring of the status of transport/supply of fluids and smooth operation of the transport/supply equipment, and also for taking quick and accurate action during emergencies and disasters. Since the objects of monitoring/operation are interspersed at numerous points in remote areas along the pipeline route, the information (data) necessary in remote monitoring are normally collected via the telecommunications infrastructure.

In the design and implementation of remote monitoring systems and so-called SCADA (Supervisory Control And Data Acquisition) systems with objects of monitoring/operation located in remote areas, it is necessary to consider network equipment utilizing the telecommunications infrastructure. As issues, economy, including the economy of the telecommunications infrastructure, improvement of telecommunications performance, and reliability may be mentioned.

JFE Engineering has an extensive record of pipeline construction, ranging from city gas/industrial pipelines to pipelines for thermal power plants, and has also designed and delivered many SCADA systems for pipelines. In recent years, JFE Engineering has also grappled with the development of SCADA systems based on the "pipeline operation know-how" and "system implementation know-how" acquired as a result of that experience.

2. Configuration of Remote Monitoring Systems

2.1 Three Elements of Remote Monitoring Systems

The configuration of a remote monitoring system can be broadly divided into three elements (**Fig. 1**).

(1) Master Terminal Unit

The master terminal unit is installed in the central monitoring base and comprises a database server for collection and storage of process data from the object of monitoring/operation, and human machine interface (HMI) for central monitoring of the process as a whole.

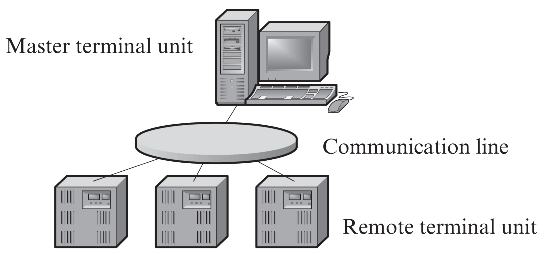

Fig. 1 SCADA System structure

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The database server stores trend data and report data for operational management as well as other log data. The HMI displays the process status, warning information, etc. on a graphic screen. When controlling the process, commands are transmitted to the object of monitoring/operation by automatic control or operation by the operator.

(2) Telecommunications Network Equipment

Telecommunications network equipment comprises the communication medium, which connects the master terminal unit and the remote terminal unit and is used to transmit data, and the communication control unit.

As communication media, in addition to the leased lines of a telecommunications carrier, satellite communication lines, etc. and privately-owned lines using optical cable or microwave communication are also used. The communication control unit is selected depending on the classification (Performance, Interface specification) of the communication medium.

(3) Remote Terminal Unit (RTU)

Remote terminal units (RTU) are installed at the objects of monitoring/operation in remote locations.

The RTU comprises an input/output unit which is connected with the various types of sensors and actuators installed in the process and performs digital input/output and analog/digital (or digital/analog) conversion, control units for process control and data processing, and touch panel displays, display lamps, operation switches, etc. as user interface.

2.2 Gas Pipeline Remote Monitoring System

Station equipment, which is the object of monitoring/operation of pipeline facilities that transport natural gas, includes a valve station with an emergency shutdown valve to shut down the pipeline during emergencies, a pressure reducing station with heating and pressure reducing equipment and a supply station with gas metering equipment. In the remote monitoring systems of large-scale pipelines, the number of RTUs exceeds 100.

Because gas pipeline equipment is a critical lifeline, real-time centralized monitoring 24 hours a day, 365 days a year is required in the remote monitoring system in order to ensure stable gas transportation operation and secure safety. In addition, high reliability as a tool for securing safety/shutdown of the pipeline during emergencies and disasters is also required.

(1) Master Terminal Unit

As hardware for the database, equipment with resistance to temperature changes, vibration, voltage fluctuations, etc. is used. Redundant hard disks and equipment are also provided to secure reliability and stability by reducing the system failure rate.

Malfunction of the master terminal unit can cause serious damage to pipeline operation. Therefore, a master terminal unit itself is provided at multiple locations in consideration of earthquakes and other wide-area disasters, and in many cases, a master terminal unit is also installed at a separate site as backup in case of abnormalities.

(2) Telecommunications Network Equipment

Redundancy systems for communication lines include duplex systems which use a different class of communication line (wire line and wireless link, etc.) and systems in which the object of monitoring/operation is connected to a loop.

In duplex communication lines, land lines such as optical fiber, etc. which support high speed, large volume communication are frequently used in the main communication line, while satellite communication lines, which have the drawbacks of low speed and limited capacity, are selected for backup lines because satellite communication offers particularly high resistance to wide-area disasters. Backup lines are used as communication lines during abnormal conditions (when the main line is out of service, during disasters). In some cases, backup lines are installed only for objects of monitoring/operation with a high degree of importance.

(3) Remote Terminal Unit (RTU)

Redundancy equipment is adopted for hardware such as the central processing unit (CPU) of RTU control units, power supply circuits, input/output devices, etc.

3. Background of Development of Remote Monitoring Systems

3.1 Trends in Remote Monitoring Systems

In the remote monitoring systems of the 1980s, minicomputers and distributed control system (DCS) were adopted as the master terminal unit, and communication lines were basically leased lines by 1-to-1 connection. Therefore, as shown in **Fig. 2**(a), the topology of the network between the master terminal unit and the RTUs took the form of a tree network by one-to-many connection.

At that time, leased lines were slow and had small

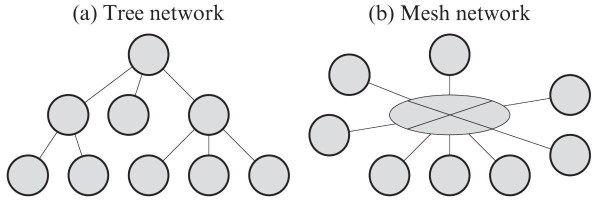

Fig. 2 Network topology

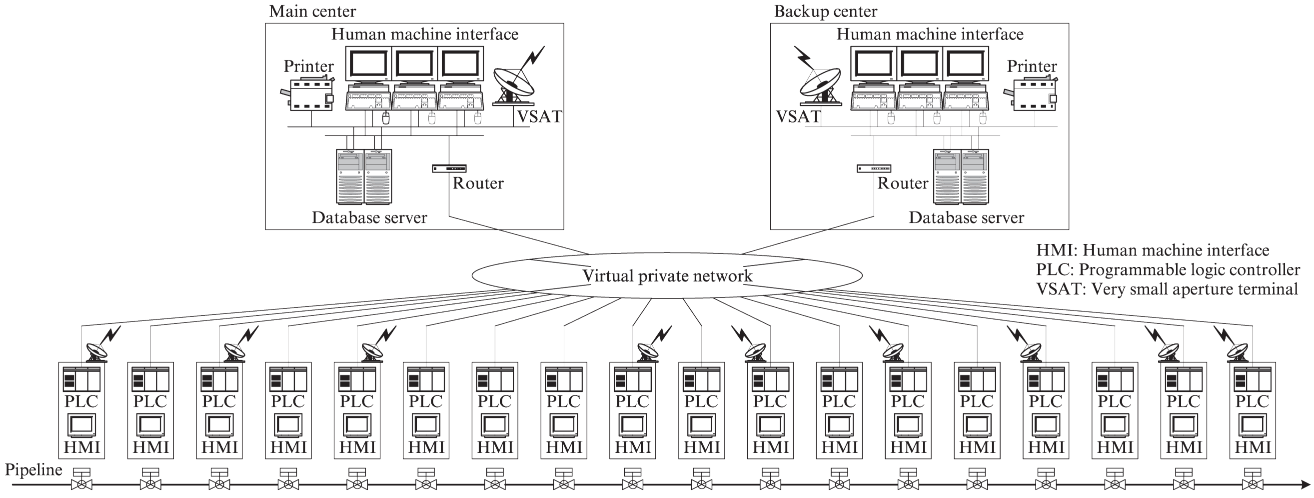

Fig. 3 SCADA System configuration

capacities, and circuit quality was inferior in comparison with the present. To compensate for poor circuit performance and quality, data communications were performed by high-level data link control (HDLC) or a dedicated protocol by way of a dedicated communication control unit (telemeter device).

For this reason, remote monitoring systems were configured using a combination of specialized hardware/software produced by the equipment manufacturers.

In the 1990s, transmission control protocol/internet protocol (TCP/IP) came into wide use as a general telecommunications protocol, and there was a shift from makers'specialized master terminal units to open systems based on general-purpose operating systems such as UNIX*1 and Windows*2. As Windows gained de facto standard status, general-purpose SCADA package software that ran on Windows appeared, and personal computers were applied/introduced in master terminal units.

In the services used from the beginning of the 2000 decade, virtual leased lines were constructed by virtual private network (VPN) using the IP networks of telecommunications services companies. This change was a response to an expansion of the applicable range thanks to improvement of security by encryption, encapsulation, etc. and reduction of delay by high speed telecommunications.

In VPN services, TCP/IP is used for connections between the master terminal unit in the remote monitoring system and the RTUs, which are widely distributed and located in remote areas. This approach enables a mesh-type network configuration (Fig. 2(b)) with diverse connections and ample extensibility. In addition, since the master terminal unit is not routed through a maker's specialized communication control unit (telemeter device) in the telecommunications interface by TCP/IP, direct telecommunication connection to programmable logic controllers (PLCs), which are the control units in the RTUs, is possible.

The spread of VPN services accelerated the changeover of remote monitoring systems from specialized hardware produced by manufacturers to general-purpose hardware ((personal computer) + (general-purpose software) in the master terminal unit, router + PLC in the RTUs).

3.2 History of System Development

In the remote monitoring system for the oil transport pipeline for Narita International Airport, which JFE Engineering completed in the first half of the 1980s, a telemetering system and computer system were adopted, and a privately-owned metal cable was used as the communication line. In the remote monitoring system for the high pressure gas line between Sodegaura and Anegasaki for Tokyo Electric Power Company, Inc., which was completed in 1984, a communication line using a privately-owned optical cable was adopted in a pipeline facility for the first time in Japan. In 1996, JFE Engineering also delivered remote monitoring systems in which satellite communication lines were applied for the first time in Japan for the Yufutsu-Sapporo gas pipeline for Japan Petroleum Exploration Co., Ltd. and the Sapporo main line construction project for Hokkaido Gas Co., Ltd.

Virtual private network (VPN) service was adopted in a communication line for the first time in Japan in the remote monitoring and control equipment modernization project (completed in FY2003) in the Niigata pipeline network for Japan Petroleum Exploration Co., Ltd., and the largest-scale system using general-purpose SCADA software in Japan (5 Master terminal units, 47 RTUs)

*1 UNIX is a registered trademark of The Open Group in the United States and other countries.
*2 Windows is a trademark of Microsoft Corporation in the United States and other countries.

was constructed[4].

Thereafter, accompanying the transition to general-purpose hardware and software related to remote monitoring systems, JFE Engineering also began development of SCADA system software, and now supplies integrated services from basic planning and detailed design of systems and creation of software to maintenance and inspection.

Initially, a general-purpose SCADA platform was used in the development of remote monitoring systems, but due to limitations on its performance, JFE Engineering developed its own original SCADA software (JFE-SCADA), which is suitable for monitoring and control of pipelines and solves the problems discussed below.

In 2011, JFE Engineering introduced an actual remote monitoring system using JFE-SCADA, and since that time, system implementation by the company has been based on JFE-SCADA (**Fig. 3**).

4. Features of JFE-SCADA

This chapter presents the features and standard functions of JFE-SCADA, which was developed based on the "pipeline operation know-how" and "system implementation know-how" cultivated by JFE Engineering in projects to date.

4.1 Standby Redundancy System for Database Server

The database of the master terminal unit uses a standby redundancy system consisting of a primary (operating system) server and secondary (standby system) server.

Under normal conditions, only the primary server performs data collection by way of the communication line, and the data collection function of the secondary server is in the standby state. Data collection by the secondary server is performed through the primary server without using the communication line. If the data collection function of the primary server is stopped, data is collected by the secondary server via the communication line.

In standby redundancy systems, data collection is performed by one server. This means the communication load (communication data volume) is reduced by one-half in comparison with parallel redundancy systems, in which data collection is performed individually by both servers. Thus, in addition to securing the necessary reliability by the standby redundancy system for the database server, communication costs (running costs) can also be reduced.

4.2 Database Equalization Process

Under normal conditions, database equalization between the primary server and the secondary server is performed by the server standby redundancy system. In case of malfunction of the primary server (data collection function stop), data collection is continued by the secondary server, but the database of the primary server is deficient from the time of the malfunction (stop) until restart.

The equalization process is a function for completely duplexing the data between the servers by making up the deficient data. The deficient data during a function stop of the primary server is made up from the secondary server by the equalization process after recovery/startup of the primary server.

The equalization process between servers improves operability by ensuring complete consistency between the databases (trend data, report data, log data) of the two servers and preventing omissions of data.

Because the databases perform data collection and updating on a structured query language (SQL) base by a general-purpose relational database management system (RDBMS), it is easy to access data from other systems and move stored data. As a result, use of stored data as big data is possible.

4.3 Standby Redundancy System for Communication Lines

Communication lines take a network configuration with standby redundancy by a main network and a backup network.

Under normal conditions, communication is performed via the main network, which has a high order of priority. The data collection function by the backup network is in the standby state, and only line diagnosis signals for disconnection detection are transmitted.

In case communication by the main network is interrupted by disconnection, equipment malfunction, etc., data collection switches to the backup network. When the condition of communication by the main network is restored, the system automatically returns to data collection by the main network, which has a high order of priority. Because switching of the main network and

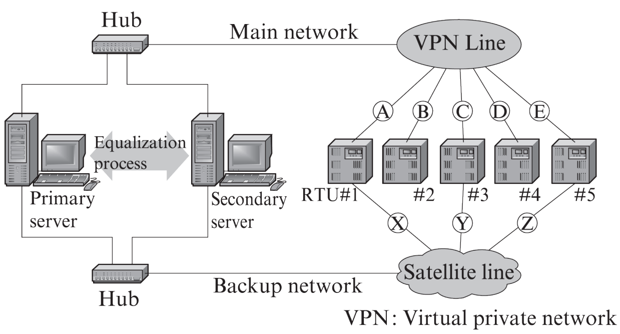

Fig. 4 Redundant system by duplex server and duplex line

backup network is executed in RTU units, the main network can be used with maximum effectiveness.

In **Fig. 4**, data collection is performed by lines A to E under normal conditions, but when line A is disconnected, only RTU#1 switches to satellite line X. With restoration of line A, the system automatically returns to data collection by line A.

Since standby redundancy of the communication network reduces the communication load on the backup network, it is superior from the viewpoints of use of low speed, small capacity satellite lines, and also use of measured rate type lines (system in which charges are based on the actual data volume).

4.4 Asymmetric Redundancy of Communication Lines

Because backup lines are used as communication lines when the main line is affected by a disaster, etc., satellite communication lines are frequently used as backup lines. However, the communication speed of satellite lines is slow, their communication capacity is small, and delay is large in comparison with main lines. Therefore, if the collected data capacity and collection cycle of the master terminal unit are matched to the speed and capacity of main communication line, the possibility of data deficiency when the backup line is used is a concern. To avoid this kind of data deficiency, it is necessary to match data collection to the speed and capacity of the backup communication line, but as a result, the main line could not demonstrate its full performance.

To solve this problem, in JFE-SCADA, it is possible to change the data collection parameter setting flexibly in the individual communication lines of all the RTUs. Thus, in Fig. 4, the data collection parameters of lines A–E and lines X–Z can be set individually, matched to the respective line capacities.

Adoption of asymmetric redundancy, which makes it possible to change the data collection parameters of each monitoring/operation point and each line, realized a SCADA system in which the respective communication performances of all lines can be utilized optimally and effectively in systems consisting of a mixture of different types of communication lines.

4.5 Measures to Improve Control Signal Reliability

In pipelines, which are lifeline facilities, emergency shutdown devices are provided in order to shut down the pipeline on an emergency basis to prevent the spread of a disaster in case the pipeline itself is damaged by a disaster, etc. However, in the unlikely event that an emergency shutdown device is shut down by mistake, supply problems may occur in the lifeline. To improve reliability by maintaining the pipeline supply, the following measures have been implemented to prevent erroneous shutdowns.

(1) Coding of Control Commands (Shutdown Commands to Emergency Shutdown Valves)

Control commands are signals which are coded using multiple bits, and signals are output to the process (emergency shutdown valve) only in case the control command transmitted from the master terminal unit is in complete agreement with the code of the receiving-end RTU.

(2) Redundancy of Signal Output

To prevent erroneous signal output due to a hardware malfunction of an RTU, the PLC output module and relay line are duplexed, and signal output to the process (emergency shutdown valve) is performed under an AND condition.

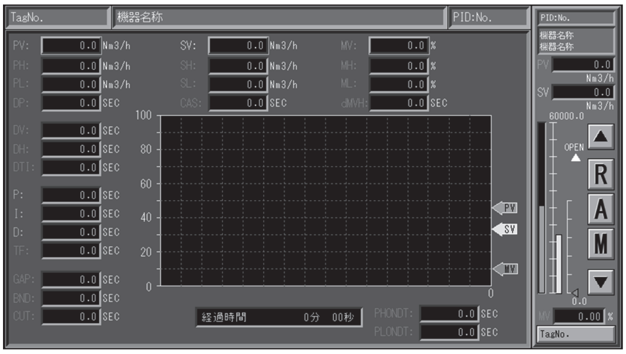

Fig. 5 Example of the adjustment panel for process control

4.6 Continuous Loop Control Monitor

An adjustment panel for process control is mounted in the system to support monitoring of the control status of the continuous process loop which controls the RTU and adjustments of the control parameters. This function also makes it possible to use JFE-SCADA as a medium-to-small scale control unit by combining JFE-SCADA and instrumentation PLC (**Fig. 5**).

4.7 Interface with Other Systems

In addition to use as communication drivers with PLC of various companies, a wide variety of interface functions can also be implemented in JFE-SCADA, for example, OPC[*3] (OLE for process control), FTP (file transfer protocol) server/client, etc. for connection with other systems.

This function makes it possible to construct advanced monitoring and control systems linked to other systems.

[*3] OPC is a standard interface specification of Microsoft Corporation.

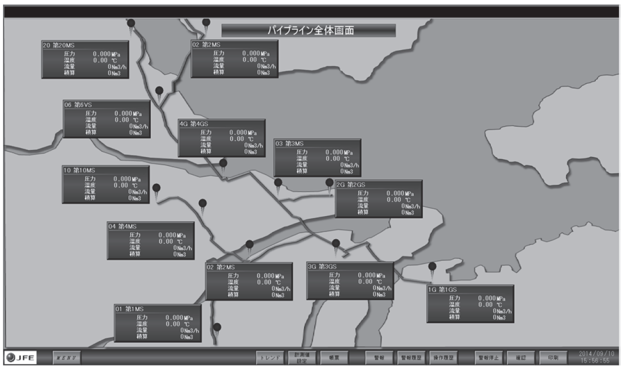

Fig. 6 Example of the pipeline overview display

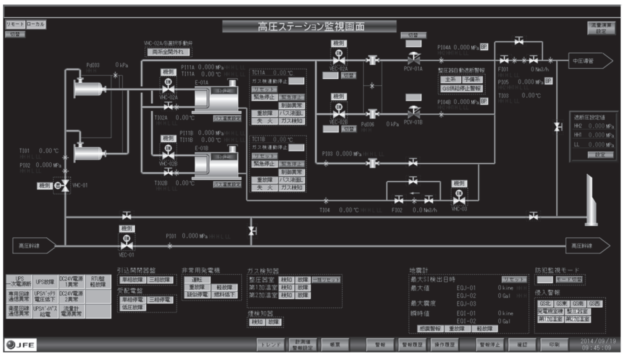

Fig. 7 Example of the station monitoring display

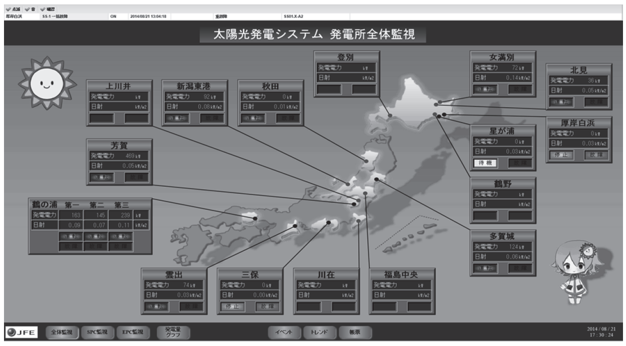

Fig. 8 Solar power system overview display

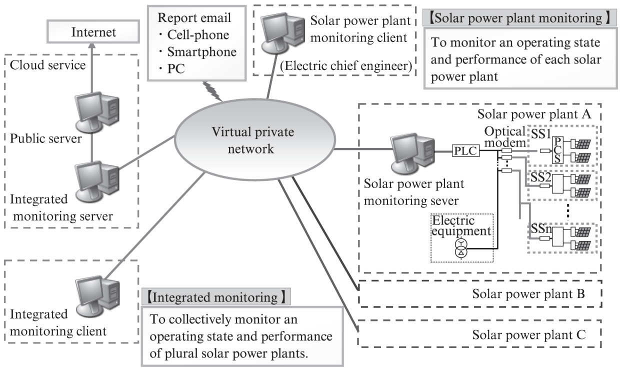

Fig. 9 Image of integrated system

5. Examples of Deliveries of JFE-SCADA

The following introduces examples of deliveries of remote monitoring systems using JFE-SCADA (**Figs. 6**, **7**).

5.1 Pipeline SCADA System

In the remote monitoring system for the Okayama pipeline (completed in June 2011) for Mizushima LNG Co., Ltd., JFE Engineering developed and delivered the first actual JFE-SCADA with redundancy by duplex servers and duplex communication lines.

The remote monitoring system in the Hachinohe pipeline for JX Nippon Oil & Energy Corporation was completed in March 2015. Considering expansion of gas supply destinations, this system provides system extensibility for more than 30 monitoring/operation points.

5.2 SCADA System for Solar Power Plants

In addition to pipelines, JFE-SCADA is also packaged as a dedicated remote monitoring system for solar power plants, and was introduced at JFE Solar Power Tsu (Kumozu Solar Power, completed in July 2013).

A total of 18 power plants (11 in FY 2013, 7 in FY 2014) are in operation.

Because unmanned operation is normally used at solar power plant sites, these systems are equipped with a function which automatically transmits messages (malfunction information) to registered members by the email information function of the monitoring server. With this email information function, message transmission to multiple registered members on set days/time periods is possible by schedule management.

For centralized monitoring of the equipment condition and operational results of multiple power plants by JFE Engineering's Yokohama Head Office, an integrated monitoring server based on cloud technology was constructed for integrated management of the SCADA of all power plants. Remote integrated monitoring of all power plants at any desired location can be performed by using a mobile terminal such as a laptop personal computer (PC) or smartphone (**Figs. 8**, **9**).

6. Future Outlook

Accompanying the transition of remote monitoring systems to general-purpose computers, JFE Engineering grappled with the development of a proprietary JFE-SCADA system. Thanks to a system configuration with high customizability, it is possible to respond quickly and flexibly to increased functions and customer requests.

In addition to application of JFE-SCADA to remote monitoring systems for pipeline facilities, the authors hope to expand the range of applications of this technology in the future, for example, responding to the need for packaging of systems for geothermal binary power plants, ship ballast water management systems, etc. Moreover, in system modernization and system integration for existing pipelines, the system modernization procedure or system integration method will be planned, based on JFE Engineering's wealth of pipeline operation know-how and system implementation know-how, so as to minimize the effect on equipment operation during the transition period, thereby ensuring a smooth transition to JFE-SCADA.

The authors are also planning an operator training function based on linkage of JFE-SCADA with JFE Engineering's Win GAIA™ [6] (Gas pipeline Analysis by Integrated Application: Gas pipeline network non-steady transport simulation system) and expansion of the functions of the SCADA system by utilizing open data such as weather reports, earthquake disaster information, etc.

In FY 2015, JFE Engineering began operation of a big data server for integrated storage of operational data for all types of plants owned by the company. This server enables long-term storage of the data collected by JFE-SCADA. JFE Engineering is planning to apply this system to equipment diagnosis (maintenance support) and operation analysis, and an expansion of functions based on analysis and effective use of the collected and stored information.

7. Conclusion

The development and results of the JFE Engineering JFE-SCADA remote monitoring system and the outlook for the future were introduced.

In the future, JFE Engineering will continue its efforts to propose and supply systems which meet the needs of customers based on its leading-edge technical capabilities and accumulation of know-how, so as to make an even greater contribution to the stable operation of customers' facilities than in the past.

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