Worldwide Service Development for Drive Systems and Predictive Maintenance

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1. Introduction

Fuji Electric's drive systems play an important role among electric machinery systems and have been delivered to a wide range of locations both in Japan and overseas locations. Technical innovation for these drive systems occurs at a swift rate, and new products rapidly become available. The service infrastructure, which consists of an after-sales service system and a parts supply system, must respond quickly and globally to rapid product changes.

Drive systems are configured in various combinations that range from high-voltage electrical equipment to electronic equipment, such as inverters and other driving devices, PLCs and rotary machines and have relatively long service lives. Accordingly, it is desired that the component parts in a drive system use the latest suitable predictive maintenance technology to help achieve stable operation.

This paper describes the latest trends and future outlook for service networks and predictive maintenance technology that address and support the needs and challenges, from a service perspective, of the global deployment of drive systems.

2. Worldwide Service Network

Drive systems play a crucial role at industrial facilities. In support of stable maintenance and management throughout the life cycle of a drive system, Fuji Electric has built a global service network for drive systems and provides detailed after-sales service. Figure 1 shows the main service network.

2.1 Overview of service network

The service system has a reception function for

Fig.1 Worldwide service network for drive systems

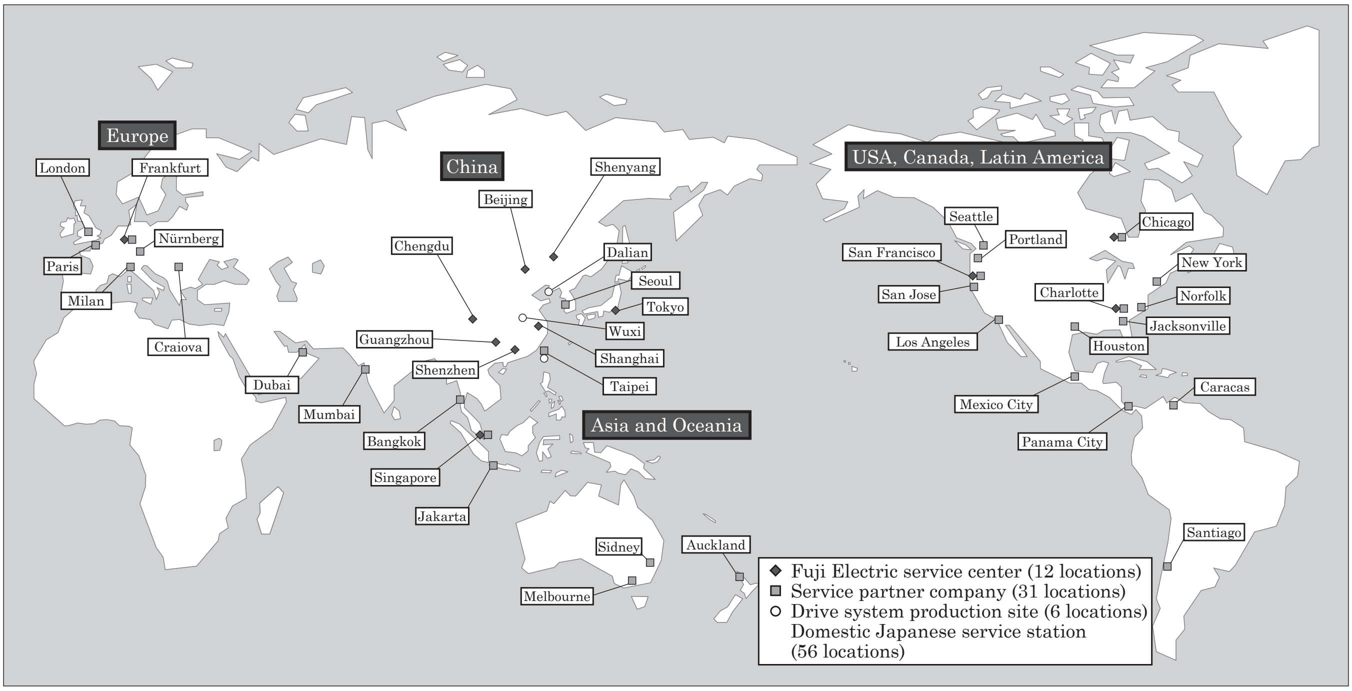

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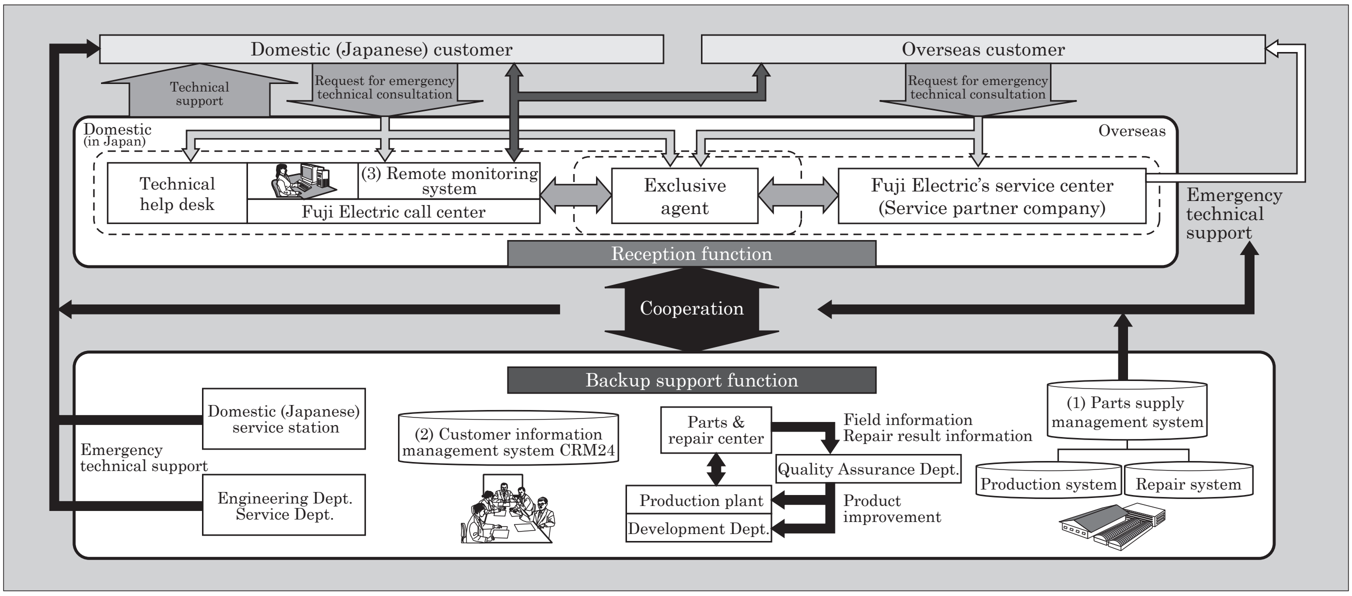
Fig.2 Functions and configuration of service system



handling emergency requests and technical consultations and a support function for supplying parts, performing repairs and providing technical support to customers and service personnel in order to facilitate a rapid recovery when a failure has occurred. Effective cooperation between the departments in charge of these functions enables the service system to respond quickly. Figure 2 shows the functions and configuration of the service system. These functions are supported by the following three service support systems, and a mechanism that enables the relevant departments to share information is configured.

(a) A "Parts supply management system" that is directly linked to a production plant and that supplies parts accurately
(b) A "Customer information management system (CRM24)" that implements centralized management of customer facility information
(c) A "Remote monitoring system" that realizes highly efficient maintenance and responds rapidly to failures

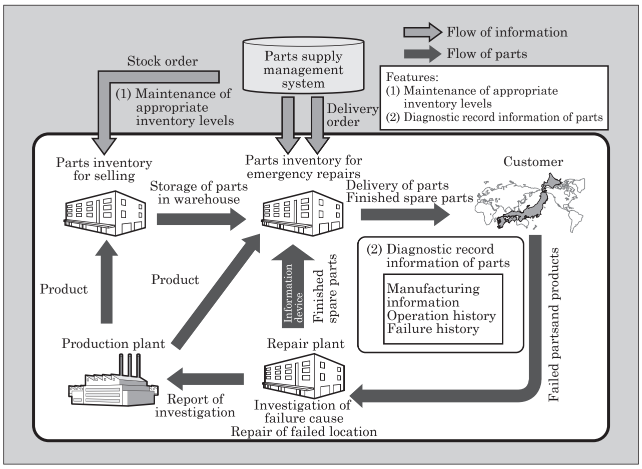
These three support systems are described in detail below.

2.2 Parts supply management system

When an emergency situation occurs at a customer's production facility, replacement parts and finished spare parts must be supplied rapidly. Fuji Electric deploys the parts supply management system shown in Fig. 3 as an infrastructure for managing the flow of parts from the stocking of inventory to the completion of repairs. As a result, parts can be supplied quickly when required, helping to maintain the stable operation of customers' facilities. Features of this system are described below.

(1) Rapid parts supply enabled by appropriate inventory levels

Fig.3 Parts supply management system and parts flow



The parts supply management system has a function for continuously maintaining an appropriate level of inventory. For example, if there is a shortage of inverter parts in the "inventory of parts for emergency repairs" unit, a delivery order is issued immediately to the "inventory of parts for sale" unit so that an appropriate level of inventory is maintained continuously. Thus, if a failure were to occur at a customer facility, parts can be supplied rapidly at all times.

(2) Utilization of diagnostic record information of parts

A function exists for reporting to customers the results of an investigation of the cause of failure and the repair status of failed inverter parts that have been collected, and for managing the diagnostic record information of each part. This information is feed-back via the quality department to the production plant and development department, and is reflected in product improvements and in successive products.

2.3 Customer information management system (CRM24)

(1) Call center reception function

To support the stable operation of equipment, a reception function capable of receiving calls at any time about the failure of customers’ equipment or handling technical inquiries is needed. Fuji Electric has established a reliable reception system by operating a 24-hour 365-day per year call center and a specialized technical help desk service for inverters.

(2) CRM24 (Customer Relationship Management 24) basic functions

The CRM24 shown in Fig. 4, the backbone system of the call center, performs detailed management of information concerning customers' facilities and equipment, provides the information necessary for facility operations and maintenance to Fuji Electric and to the customer, and provides rapid recovery support when a failure occurs.

(a) Customer information/equipment information management function

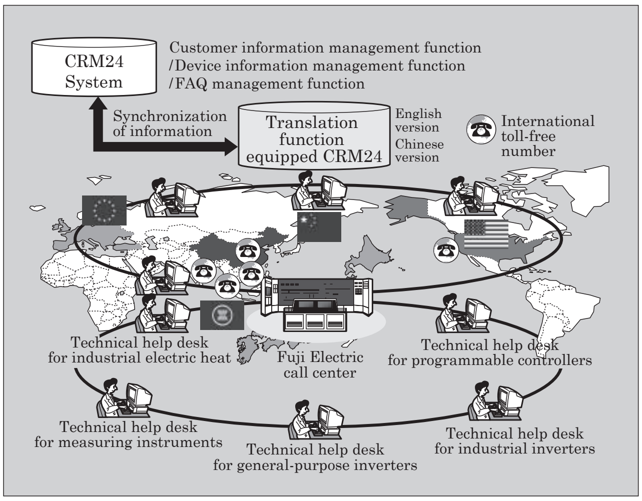
To support the stable operation of customers' equipment, this function is provided with a data structure capable of storing a list of delivered equipment, maintenance/failure information, drawings data, and emergency and maintenance support information, such as information about Fuji Electric's liaison structure. These information management functions enable equipment and facility information to be managed centrally, and are used for the stable operation of customers' facilities.

Moreover, precise support is provided through coordination with a specialized technical help desk.

(b) FAQ (Frequently Asked Questions) function

The FAQ function enables an operator to respond quickly to customer inquiries about the drive system, and a troubleshooting function and statistical function, based on incidents of failure and maintenance information, are also provided. Also, various statistical graphs can be generated easily and used as technical reference materials when responding to a received call, and at the same time, failure information and the like can be forwarded to the product development department.

Fig.4 Customer information management system (CRM24)



(3) CRM24 with translation function

Fuji Electric has constructed a CRM system equipped with a translation function for Chinese and English that uses template-formatted input to realize a 97% recognition rate of translated documents. Information can be shared between onsite Japanese engineers and foreign staff, as well as among staff in Japan, and Fuji Electric aims to provide support that is equivalent to onsite support in Japan for responding to various requests from overseas customers.

2.4 Remote monitoring system

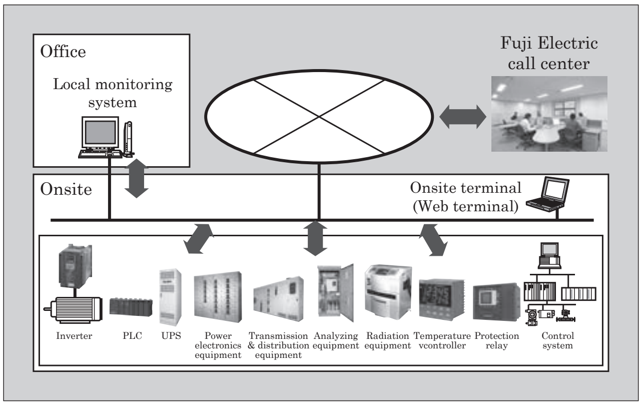
(1) Overview of the remote monitoring system

Fuji Electric supports remote monitoring throughout the entire equipment lifecycle, from delivery at a plant until renewal. In addition to enhanced abnormality identification and preventative maintenance functions based on device status assessment, a high-speed and real-time plant data acquisition function and a startup support function were developed as new functions. These functions contribute to improving the stability of plant abnormality identification and plant operation and help reduce the amount of time needed

Table 1 Main functions and effects of remote monitoring

	Function	Target	Description	Effect
Basic functions	Identification of device abnormality	Ascertainment of device status	○ Remote acquisition of data from which abnormal locations and causes of abnormalities of devices that configure a plant can be determined	○ Remote specialist provides detailed support and instructions for early recovery from abnormal states ○ Promotes higher efficiency since a specialist needs not always be present onsite
	Preventive maintenance		○ Acquisition and storage of data for detecting signs of abnormalities and for diagnosing degradation	○ Continuous stable operation as a result of being able to prevent failures ○ Diagnosis can be made without shutting down facility ○ Identification of plant trouble
New functions	Plant data acquisition	Ascertainment of plant status	○ Data acquisition and storage while plant is operating ○ Data acquisition during startup adjustment, and storage and adjustment of setting parameters	○ Reconsideration of settings and improvement of operation method for stable plant operation
	Startup support			○ Reduction of plant startup time

Fig.5 Configuration of remote monitoring system



for plant startup. Table 1 lists the main functions and effects of remote monitoring.

Fuji Electric's remote monitoring system configuration is compatible with the entire electrical equipment system, which extends from inverters and PLCs up to the control system, and enables information concerning electrical equipment and plants to be shared with call centers, local monitoring systems and onsite terminals (Web terminals). Moreover, in accordance with the communications environment and the security level, the method of communications between the onsite location and the call center can be freely selected as a VPN (Virtual Private Network), dial-up or Internet connection, or the like. Figure 5 shows the configuration of the remote monitoring system.

(2) Remote monitoring module functions

Fuji Electric has newly developed a remote monitoring module that functions to connect plant devices with a system for monitoring those devices, and is promoting the use of this module with all products supplied by Fuji Electric. This module is available in two varieties, a device-embedded type and an externally attached type. When installed on the various devices, the remote monitoring function acts as a platform and helps to achieve device miniaturization and higher quality of the monitoring function. Features of the remote monitoring module are described below. Also, Fig. 6 shows the structure of a remote monitoring module for inverters.

(a) Unified database (DB) and protocol

Device data is acquired and stored with tags in the unified DB of the remote monitoring module. Moreover, communication between the remote monitoring function and the exterior is implemented with a unified protocol that does not depend on a particular device.

(b) e-mail issuing function

If a device abnormality is detected, e-mail notification can be easily sent via the remote monitoring module to the related parties, enabling the rapid recognition of an abnormal state and sharing of relevant information.

(c) Web monitoring function

Fig.6 Structure of a remote monitoring module for inverters

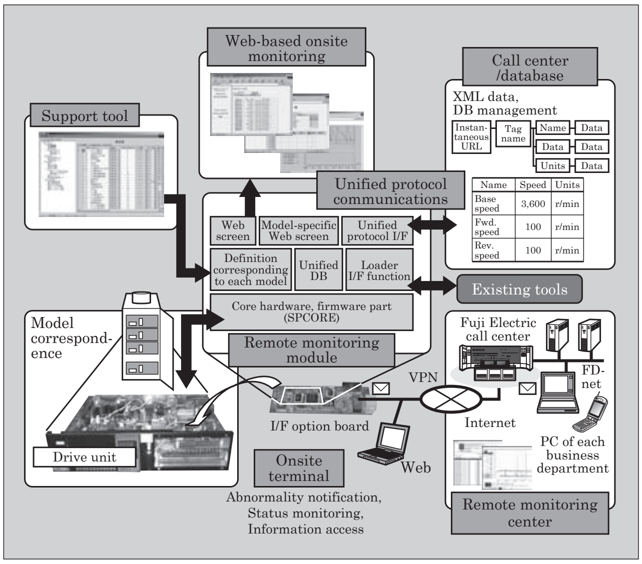
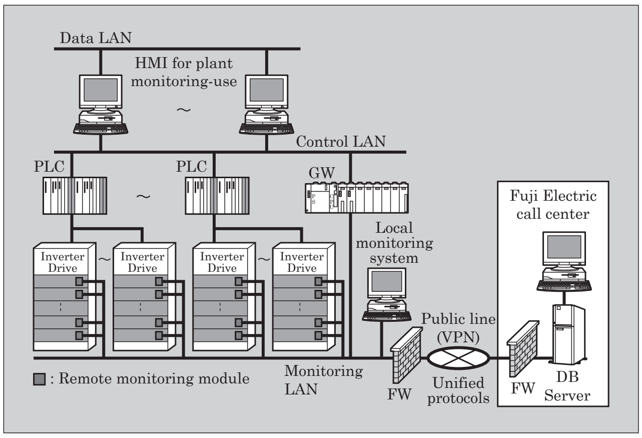


Fig.7 Example of a system that uses a remote monitoring module for an inverter



The remote monitoring module is provided with a Web server function. Devices can be monitored and adjusted remotely by connecting a Web browser-equipped PC to the network.

(3) Remote monitoring in a drive system

Figure 7 shows an example of a system for a plant that uses a remote monitoring module for an inverter.

Using a unified protocol, the inverter data acquired by the remote monitoring module is collected at a Fuji Electric call center and monitored. The inverter status can be checked from the Web screen of local monitoring equipment, and the provision of Fuji Electric's data acquisition and analysis support software package "f(s) NISDAS-x" enables high-speed real-time data acquisition and analysis.

2.5 Future efforts

In order to improve service capabilities not only in Japan, but also in China, North America, Europe and Southeast Asia, the parts supply system for emergency repairs and the centralized information management system (one stop channel) capable of responding to one-time inquiries from customers will be strengthened. Moreover, to further expand the application range for remote monitoring modules, Fuji Electric is planning to produce a series of remote monitoring modules equipped with an I/O function.

3. Predictive Maintenance Technology that Supports Drive Systems

3.1 Efforts involving predictive maintenance technology

The majority of equipment installed during the period of high economic growth of the 1970s is due for extensive renewal or replacement, and expectations are increasing for degradation diagnostic technology and remaining life assessment technology, which are crucial for equipment renewal and determining the renewal sequence. On the other hand, as it is becoming increasing difficult to shut down equipment in order to perform an inspection or diagnosis, expectations for live-line diagnostic technology are also increasing.

Therefore, with the goal of enabling electric equipment and facilities to operate smoothly throughout their entire lifecycle, Fuji Electric has continued to accumulate field data and pursue technical development, and has established many types of degradation diagnostic technologies, remaining life assessment technologies and live-line diagnostic technologies.

In the drive system sector, Fuji Electric is particularly involved in establishing predictive maintenance technology for drive systems and rotary machines, in which inverters are the component.

Representative examples of preventative maintenance technology for drive systems are listed in Table 2. To diagnose the degradation of electronic parts used in a drive system, tests such as opened testing of IC devices and sealed testing of thyristor devices have been performed. In recent years, diagnostic technologies that quantify the equipment environmental assessment have been developed. For general-purpose inverters that have been operating for a long time, Fuji Electric has developed a remaining life estimation system for parts needing regular replacement and this system does not require shutting down the facility or equipment.

As insulation degradation diagnostic technologies for rotary machines, remaining life estimation based on electric insulation diagnostic data and physicochemical degradation diagnosis of insulation material based on micro-sample collecting have been performed. As mechanical vibration diagnostic technologies for rotary machines, a vibration diagnostic system that uses wireless sensors has been newly developed and convenient, easy-to-use systems have begun to be provided.

3.2 Diagnostic technology for inverters

In addition to inverters for plant drives, general-purpose inverters are also key components used for driving equipment. These inverters are installed in relatively harsh environments, and a shift from breakdown maintenance to enhanced predictive maintenance based on degradation diagnostic technologies is highly anticipated.

(1) Overview of diagnostic technologies

Fuji Electric has developed various inverter diagnostic technologies as listed in Table 3.

Table 2 Drive system component devices and predictive maintenance technology

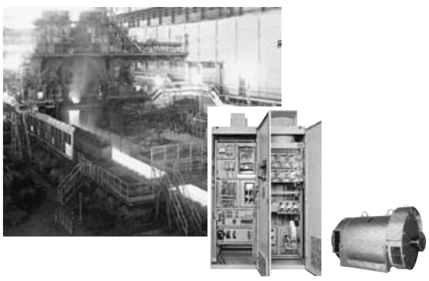
	Drive systems & rotary machines	Electronic control systems	Power supply equipment
Targeted equipment			
Typical degradation diagnosis/ remaining life assessment	Drive systems ○ Degradation diagnosis of power semiconductors ○ Degradation diagnosis of inverters Rotary machines ○ Remaining life assessment based on electric insulation data ○ Physicochemical degradation diagnosis ○ Mechanical vibration diagnosis	DCS, PLC ○ RAS analysis Battery ○ Short-duration discharge method	Oil-filled transformer ○ Gas-in-oil analysis ○ Structured neural remaining life assessment Molded transformer ○ Diagnosis of degradation due to reflected light High voltage switchboard ○ Infrared thermography ○ IV rays degradation diagnosis Breaker ○ Open/close characteristics ○ Degree of vacuum
Common	Printed circuit board ○ Installation environment diagnosis ○ Parts analysis and diagnosis	Common for all equipment ○ Insulation resistance ○ Partial discharge	

Table 3 List of inverter diagnostic technologies

Step	Diagnostic level	Diagnostic technology	Target of diagnosis	Main parts for diagnosis	Summary of diagnosis
1	Primary diagnosis	Degradation diagnosis by diagnostic specialist	General-purpose inverter Industrial-use inverter*	Rusting, discoloration, vibration of component devices and parts, status of discontinued and maintenance parts	A diagnostic specialist determines the degree of degradation based on a diagnostic evaluation chart. Also, the supply availability is adjusted for discontinued and maintenance parts.
		Simple diagnostic system for remaining life assessment	General-purpose inverter	Degradation diagnosis of parts needing regular replacement: main circuit electric capacitors, printed circuit board electrolytic capacitors, cooling fan etc.	Using a simple inverter diagnostic system, diagnosis is made based on usage status (operating time, temperature conditions) of parts needing regular replacement
2	Secondary diagnosis	Environment diagnosis	General-purpose inverter Industrial-use inverter*	Temperature, humidity, gas, dust, corrosion and the like of component devices and parts	Environmental measurements, dust adherence and corrosion on electric and electronic devices, rusting and the like are investigated, a determination of whether to implement preventative measures is made, and improvements are proposed. For further detail, a pull-up diagnosis is also performed.
		Diagnostic technology for degradation caused by environment	General-purpose inverter Industrial-use inverter*	Degradation of printed circuit board due to temperature, humidity, gas and dust	The degree of printed circuit board degradation due to operating conditions (temperature, humidity, gas and dust) and the remaining life are calculated.
		Device degradation diagnosis	Industrial-use inverter*	Sealed characteristics of power device based on leakage current	From the device leakage current value, degraded devices are identified and replaced with devices having matching characteristics to maintain the quality of the entire system.
3	Exact diagnosis	Electronic parts degradation diagnosis	Industrial-use inverter*	Characteristics of transistor, capacitor and IC	Using an electronic parts tester and electronic microscope, the amplification and abnormal indications such as internal corrosion, electrolytic corrosion and the like are detected early, and countermeasures are proposed.

* : Industrial-use inverters include Scherbius systems and Leonard systems.

Diagnostic technologies are categorized according to the diagnostic level as a primary diagnosis based on device observation and a diagnostic evaluation chart, a secondary diagnosis that involves measurement instruments and testing, and a detailed exact diagnosis. After a diagnosis has been made, an optimal maintenance plan incorporating a parts replacement period or renewal period is presented based on the findings of the diagnosis.

(2) Recent diagnostic technologies

Diagnostic technologies recently developed by Fuji Electric are introduced below.

(a) Simple remaining life assessment system for general-purpose inverters

This system uses a PC to assess the remaining life of electrolytic capacitors and cooling fans used in general-purpose inverters. The remaining life of electrolytic capacitors is calculated according to Arrhenius' law (which states that the life expectancy decreases by half when the temperature increases by 10 °C), and the remaining life for cooling fans is calculated according to a life curve based on wear of the bearings. The accuracy of both calculations has been improved by maintaining databases of test data and device data for each model type. The inverter models diagnosed are Fuji Electric general-purpose inverters that have been delivered more than 10 years ago.

Features of this remaining life assessment system are described below.

(i) A live-wire diagnosis can be performed onsite while the inverter is operating.

(ii) The diagnostic system stores prior model data and is able to make diagnoses instantaneously simply by inputting the inverter intake temperature, the utilization rate, the load rate, and the like.

(iii) Approximately 20 inverters can be diagnosed per day.

(b) Environmental degradation diagnostic technology

This system quantitatively evaluates degradation due to the installation environment and diagnoses the degradation and remaining life of printed circuit boards, which are a component of inverters. The diagnosis consists of a corrosion degradation diagnosis and a dust accumulation degradation diagnosis.

(i) Corrosion degradation diagnosis

Corrosive gas causes the wiring patterns (copper foil) on printed circuit boards, which are a component of inverters, to become thinner, and

Fig.8 Cross-section of corrosion in a copper fragment

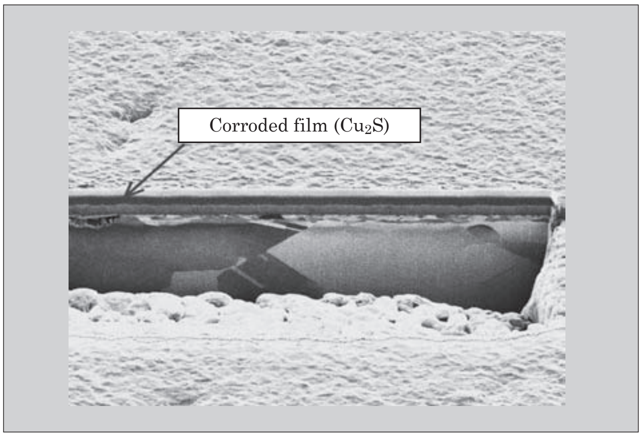
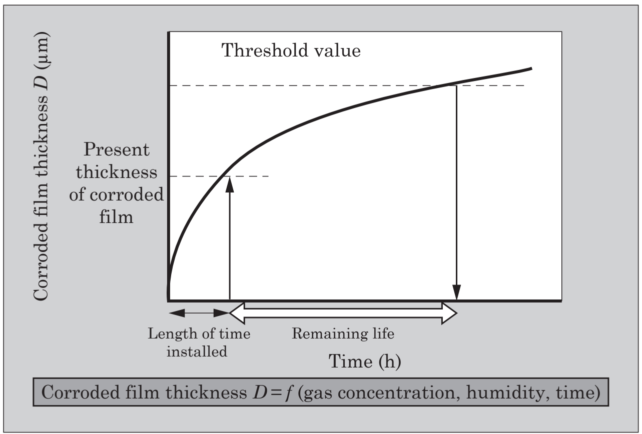


Fig.9 Example master curve of corrosion degradation diagnosis



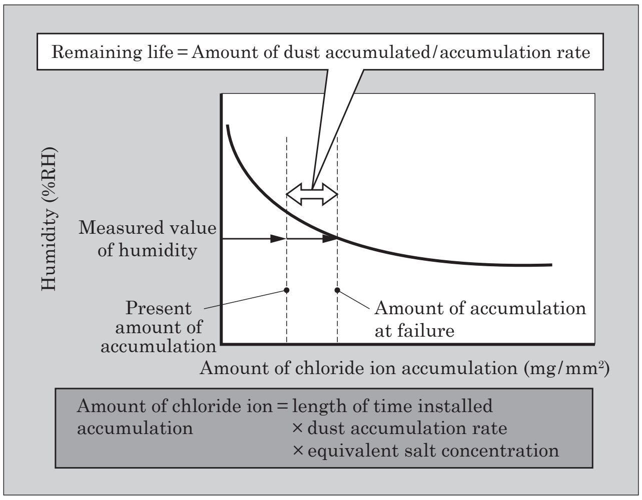
consequently the wire impedance increases and may result in electrical failure. To predict such problems, Fuji Electric has developed technology which, based on an assessment of the gas concentration, humidity, operating conditions and so on in the installation environment, estimates the time until the end of the lifespan is reached. Based on corrosion testing and evaluation of the corrosion film thickness, a master curve has been obtained for corrosion degradation diagnosis.

Figure 8 shows a cross-section of corrosion in a copper fragment, and Fig. 9 shows an example master curve of the corrosion degradation diagnosis.

(ii) Dust accumulation degradation diagnosis

Dust, including sea-salt particles and the like, accumulates on a printed circuit board, depending on the humidity and other conditions, may cause a decrease in the impedance between wires and lead to electrical malfunctions. In order to predict when such a problem might occur, Fuji Electric has developed technology for estimating the time until failure using operating condition data such as the equivalent salt

Fig.10 Example master curve of dust degradation diagnosis



concentration and humidity of the installation environment. A master curve for dust accumulation degradation diagnosis was obtained based on the relation between dust accumulation and humidity levels that lead to malfunction. Figure 10 shows an example master curve for the dust degradation diagnosis.

3.3 Rotary machine insulation diagnostic technology

Utilizing degradation diagnostic and remaining life assessment technology developed over many years for rotary machines, Fuji Electric has provided data for determining the timing of equipment overhaul or renewal.

Figure 11 shows a general association chart of the rotary machine diagnostic methods. Of the factors affecting degradation of a rotary machine, degradation of the winding insulation is the primary factor that determines the service life.

Two representative methods of winding insulation diagnosis are described below.

(1) Remaining life assessment using electrical diagnosis of insulation

This diagnosis targets the winding insulation of high-voltage rotary machines, and many successful diagnoses have been performed in the past. A degradation master curve was created based upon electrical insulation testing (DC absorption, AC absorption, tan δ, partial discharge) and disassembling investigation data of an aged rotary machine, and the remaining life was calculated with high accuracy (within approximately ±10%). Figure 12 shows the configuration of a remaining life assessment system using electrical insulation diagnosis.

(2) Physicochemical diagnosis of insulation degradation by heat

Physicochemical diagnosis is a diagnostic technique for quantifying property changes due to decreased mechanical strength, wear or excessive heat at winding locations that cannot be evaluated by the

Fig.11 General association chart of rotary machine diagnostic methods

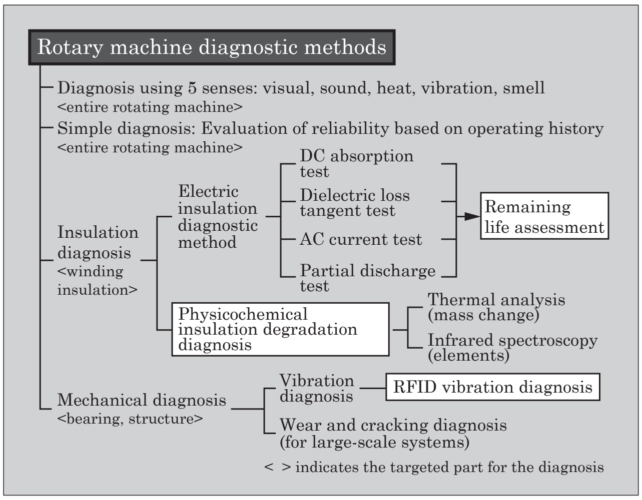
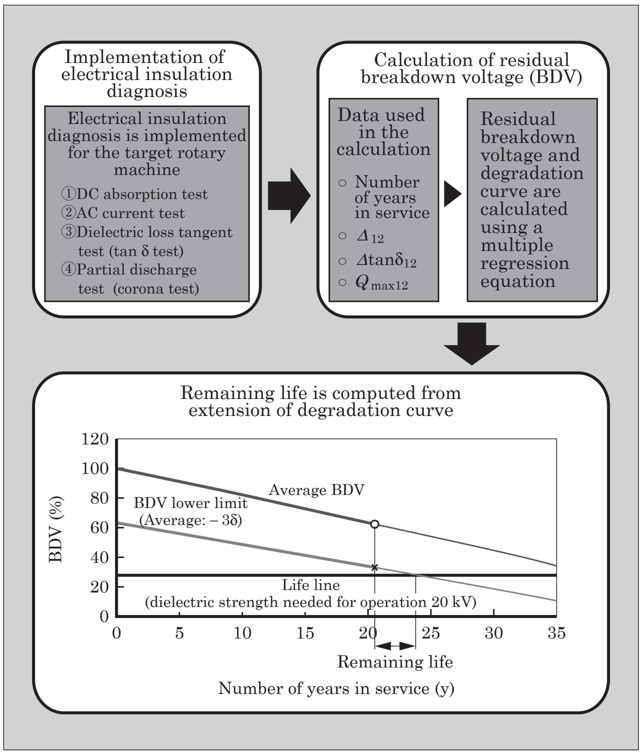


Fig.12 Configuration of remaining life assessment system using electrical insulation diagnosis

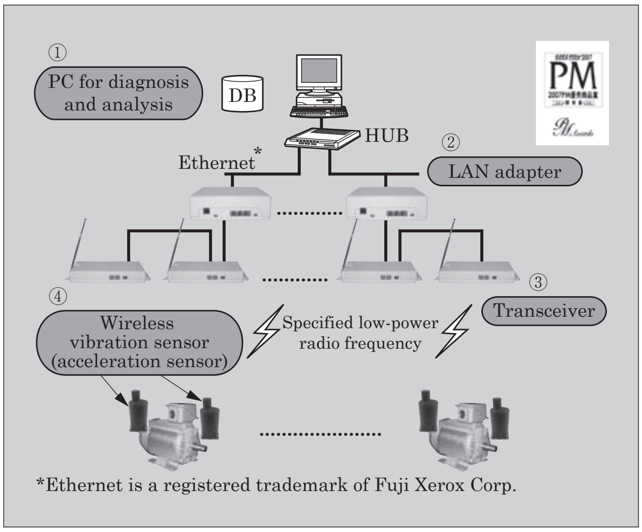


electrical insulation diagnostic method, and performs physicochemical analyses such as thermal analysis and infrared spectroscopy on minute samples taken from insulation materials such as reinforced members. The mechanical strength and heating loss of the insulation material are evaluated based on the analysis results, and the amount of remaining life can be determined incrementally.

3.4 RFID rotary machine vibration diagnostic system

(1) Present status of rotary machine vibration diagnostic technology

Fig.13 Overall configuration of RFID rotary machine vibration diagnosis system



The rotary machines of a drive system are used at many critical locations in a facility, and it is extremely important that abnormal conditions be ascertained, and that the facility operation be shut down according to plan before an abnormal condition occurs.

Vibration diagnosis is a typical mechanical diagnostic method for rotary machines. A portable-type manual diagnosis and an online diagnosis are performed. Issues with a manual diagnosis include the fact that measurements by maintenance personnel will depend upon an individual's skill level, the diagnostic work may be in a dangerous environment, and so on. At present, the online vibration diagnostic system is a wired system. Consequently, this system is expensive and its installation is limited to large-scale rotary machines. Because the system is wired, installation at an existing facility is expensive and the system has been limited in popularity.

To resolve these issues, Fuji Electric has combined its rotary machine diagnostic technology, wireless communications technology and MEMS (Micro Electro Mechanical Systems) technology to realize a rotary machine vibration diagnostic system that uses RFID (Radio Frequency Identification).

(2) System overview

With this system, an ultra low-power frequency is used to transmit vibration information from a wireless vibration sensor equipped with a built-in bidirectional acceleration sensor to a diagnostic analysis PC, and mechanical abnormalities due to low-frequency vibration and rolling bearing abnormalities due to high-frequency abnormalities are managed. The overall configuration of this system is shown in Fig. 13, and the diagnostic targets and system specifications are listed in Table 4. Furthermore, Fuji Electric received a PM Excellent Product Award (development award) for fiscal year 2007 from the Japan Plant Maintenance Institute.

Table 4 Diagnostic target and system specifications

	Frequency	Vibration measurement	Criteria for determination	Basis for determination
Diagnosis target	Low frequency (10 to 1,000 Hz)	VEL (velocity)	RMS value	Absolute value criterion based on vibration condition (ISO 10816)
		DISP (displacement)	Peak O/A (overall)	Relative value criterion based on time trends
			N/2N component (rotational speed component)	Relative value criterion based on time trends
			2f component (magnetic component)	Relative value criterion based on time trends
	High frequency (1 to 5 kHz)	ACC (acceleration)	RMS value	Relative value criterion based on time trends
			Q value (bearing diagnostic evaluation value)	Rolling bearing absolute value criterion based on Fuji Electric's own standards

	Item	Specification
System specifications	Diagnostic application range	Electric motor and generator (general rotary machine), rotational speed (600 to 3,600 r/min) Constant speed rotating device (partial determination not possible when changing speeds)
	Communication distance	20 m (max.) (depending upon installation environment)
	Frequency	314.88 MHz (Specified low power radio frequency (ARIB STD-T93)
	Measurement target	Low frequency (vertical/horizontal direction), high frequency
	Sensor/low frequency	10 to 1,000 Hz/No of sampling points: 4,096 points
	Sensor/high frequency	1 to 5 kHz/Number of sampling points: 4,096 points
	Dust-proof/waterproof structure	IP53 (outdoor simple countermeasure level)
	Method of attachment	Attached by screws (M5 screw holes)
	Battery life	Approximately 2 years (when sampling is performed once weekly)

(a) System configuration

The system is configured from a PC for diagnostic analysis and three other components.

(i) PC for diagnostic analysis

The PC transmits commands to acquire vibration data, and manages the collection and analysis of the vibration data. Up to 2,000 wireless sensors can be registered with the PC.

(ii) LAN adapter

Up to 30 transceivers can be connected.

(iii) Transceiver

A transceiver can communicate with up to 20 sensors.

(iv) Wireless vibration sensor

Equipped with a bidirectional (vertical, horizontal) acceleration sensor, the wireless vibration sensor measure vibrations and transmits the vibration data.

(b) Main functions

(i) Low frequency vibration diagnosis

Low frequency vibrations are diagnosed with a function for judging, based on ISO regulations (although individual user judgment criteria may also be set), mechanical abnormalities resulting from vibration conditions and a function capable of displaying measured information (peak value of displacement, frequency components, magnetic components, etc.) as a time series, performing trend control and providing a spectral display.

(ii) High frequency vibration diagnosis

High frequency vibrations are diagnosed with a function for judging abnormalities in rolling bearings as determined from the crest value and the RMS value of vibration acceleration, and a function capable of displaying RMS acceleration values as a time series, performing trend control and providing a spectral display.

(c) Features and effects of deployment

As a wireless small-size system, there is no need for wiring around devices as in a wired system, and the following effects are realized.

(i) Significant reduction in equipment cost and duration of construction

Cost can be reduced to one-third to one-half that of a conventional system.

(ii) Application to existing facilities, and changes and expansions are easy to realize.

(iii) Instead of periodic measurements by maintenance personnel, a facility or equipment can be diagnosed continuously online, thereby increasing the safety of the diagnosis, achieving further labor savings and improving the diagnostic accuracy.

3.5 Future efforts

For the remaining life assessment of a general-purpose inverter, Fuji Electric plans to expand the range of applicable models and to improve performance based on field results of corrosion degradation and dust accumulation degradation. For rotary machine vibration diagnosis, functional enhancements such as separating the sensor and antenna are planned.

4. Postscript

The deployment of a worldwide support service for drive systems and recent predictive maintenance technology have been described. After-sales service is a critical support operation for delivered products, and Fuji Electric intends to continue to expand its service network, to develop predictive maintenance technology, and to improve lifecycle service functions.