Recently Developed Diagnostic and Maintenance Technology for Substations

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1. Introduction

Our advanced information society, as well as factory- and household-automation, has increasingly needed stable, high quality electric power. In this regard, it is crucial to sustain and improve maintenance technology in the field of electric power. In addition, it is necessary to make maintenance more effective, due to the increase in equipment per maintenance person and to the wide range of maintenance activities for the large-scale, advanced-functioned and aged equipment.

Predictive maintenance technology for early malfunction detection and diagnosis has recently been developed. Equipment monitoring systems using various sensors have been put into use, primarily in new installations. Further, the maintenance support system has begun to effectively process, manage and aid in the management of various maintenance related information including those of sensors. Further, the maintenance support system, recently developed and partially applied, has been combined with controllers and protection device to synthetically process the relevant data.

Fuji Electric has developed and delivered this equipment monitoring and maintenance support system for gas-insulated switchgears (GIS) and transformers. Long term field-tested and introduced at Fuji's own factory, these systems integrate sensor, predictive maintenance, AI and system control technology. In addition, a fault location device for the GIS and a quick fault recovery system using automatic restoration devices have also been developed.

In this paper, the authors will describe Fuji's diagnostic and maintenance technology used in substations and their associated maintenance support systems.

2. Features of Substation Equipment in View of Diagnosis and Maintenance

Major substation equipment include the GISs, transformers (oil-filled or gas-insulated), metal-enclosed cubicles (air-, gas- or solid-insulated) and reactive power control equipment (static condensers or shunt reactors), which are usually installed outdoors.

The features of this equipment are summarized in **Fig. 1** from the standpoint of diagnosis and maintenance. Also shown is that there is a limit to the amount of work that can be accomplished by our five senses. In the next section, important technology and systems needed to upgrade on-site diagnosis and simplify and reduce maintenance will be introduced.

Fig. 1 Features of substation equipment in view of maintenance and diagnosis

Equipment	Features
GIS	- Parts are installed and concealed in an enclosure. - Moving parts (switching mechanism) operate infrequently and intermittently. - Troubles are likely to occur by operation. - Many parts are gas-tight sealed.
Transformer	- Major parts are installed and concealed in a tank. - Auxiliary equipment like LTC and hot-line oil filter operate frequently - Troubles in auxiliary equipment and oil leakage are likely to occur.
Enclosed cubicle	- Major parts are nearly installed and concealed in an enclosure. - It is composed of relatively small devices. - Moving parts (switching mechanism) operate infrequently and intermittently. - Troubles are likely to occur by operation.

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Features in view of maintenance and diagnosis
- It takes much time to maintain and diagnose the equipments, due to large number of their units. (GIS, enclosed cubicle) - It is difficult to inspect the main circuit from outside. (It is impossible to inspect the inside in running) - Troubles in control or auxiliary equipment may adversely affect the main performance. (It is impossible to check it by trial operation in running) - Reading and recording data from measuring instruments are laborious. (Some instruments are located on higher place) - Finding out an abnormal symptom is difficult. - Some abnormalities discovered on inspection are too much spreading. - Some cases will cause difficulties in making a judgement.

Table 1 Sensor application for GIS

GIS equipment	Monitoring and measuring item	Sensor	Diagnostic item					Inspection support	Fault location
			Insulation	Current carrying	Switching	Gas-tightness	Deterioration and consumption		
GCB	Number of switching operations	Position sensor					○	○	
	Time of switching operation	CT for measuring DC			○				
	Number of oil pressure pump operations	–					○		
	Accumulated operation time of oil-pressure pump	–					○		
	Continuous operation time of oil-pressure pump	–				○			
DS/ES	Number of switching operations	Position sensor					○	○	
	Time of switching operation	Position sensor			○				
LA	Number of discharges	Electromagnetic counter						○	
	Resistive leakage current	CT	○						
Common	Partial discharge	Internal antenna	○						
	Tank surface temperature	Thermocouple		○					
	Flash in tank	Optical fiber							○
	Gas pressure	Pressure sensor				○		○	○
		Sudden pressure relay							○

3. Equipment Monitoring Technology Using Sensors

There are various physical parameters either logged on site during routine inspections or not yet measured at all (or measured only during periodical maintenance). If some of these parameters useful in diagnosing equipment abnormality are continuously monitored and automatically diagnosed, it is possible to upgrade as well as effectively perform maintenance.

Sensors, comprised of detector and a transducer which converts detected signal to a standard level signal, are required for automatic monitoring and diagnosis.

3.1 Reducing maintenance with the use of sensors

Abnormality of insulation or the current carrying capacity through the substation equipment leads to internal malfunction. Defect of the driving mechanism of a circuit breaker or a transformer load tap-changer causes breaking malfunction or faulty voltage regulation. If such abnormalities or defects can be detected at an early stage, fault can be prevented. Form the viewpoint of predictive maintenance, it is necessary to monitor insulation, current, and switching as well as gas leakage. It is also necessary to predict the contact consumption that occurs in the switchgear contacts, date inspections and automatically log inspection records. Once a fault has occurred, it is also necessary to locate the fault in order to restore operation as soon as possible and thus prevent the fault from spreading. Therefore, sensors which monitor insulation, current carrying switching, and gas-tightness, in addition to recommending spection, automatically log inspection records and locate faults are indispensable.

3.2 Requirements for using sensors

Special attention must be paid to the detection level and environmental conditions, etc. of the sensors applied to the substation equipment.

(1) The possibility of taking measurements using the sensors during operation to detect the phenomena which lead to malfunction.
(2) The sensors should not reduce equipment reliability.
(3) The sensors should withstand environmental conditions. (temperature, humidity, noise, surge, etc.)
(4) Although not laborious to maintain and inspect the sensor itself, the possibility of providing and automatic monitor for saving manpower in maintenance.
(5) The sensors should be applicable to both new and existing equipment.
(6) The sensor system should be economical.

3.3 Examples of sensor application

Major examples of sensors, which Fuji Electric has developed and applied up to now, are shown in **Table 1** (for the GISs) and in **Table 2** (for the transformers).

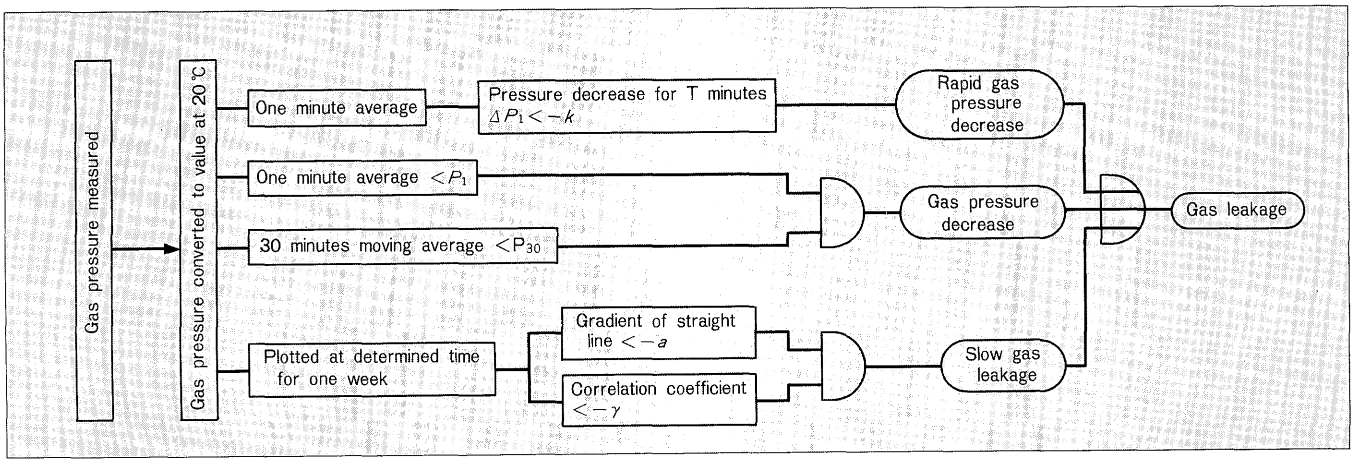
4. Diagnosis and Judgement

In order to diagnose equipment abnormality and to

Table 2 Sensor application for transformer

Transformer	Monitoring and measuring item	Sensor	Diagnostic item: Insulation	Current carrying	Switching	Gas-tightness	Deterioration and consumption	Inspection support
Transformer main body	In-oil-dissolved gas	Gas chromatograph	○	○			○	
		Combustible gas sensor						
	Partial discharge	Supersonic sensor	○					
		High frequency CT						
		Internal antenna (Gas-insulated transformer)						
	Oil temperature	Potentiometer		○				○
		Thermistor						
	Oil level	Potentiometer				○		○
	Oil leakage	Capacitance sensor				○		○
	Gas pressure (Gas-insulated transformer)	Pressure sensor				○		○
	Gas temperature (Gas-insulated transformer)	Potentiometer		○				○
		Thermistor						
LTC	Number of tap changing	Rotary encoder					○	○
		Position sensor						
	Time of tap changing operation	Rotary encoder			○			
		CT						
	Motor current	CT			○			
	Driving torque	Torque sensor			○			
	Tap position	Rotary encoder						○
	Hot-line oil filter pressure	Pressure sensor					○	○

Fig. 2 Algorithm for monitoring gas leakage



predict life expectancy, it is important to process the sensor's signals and to determine the criteria concerned. In signal processing, it is necessary to reduce noise with respect to signal level, thereby increasing the SN ratio. Measures both in hardware (shield, grounding, filter) and in software are taken against noise in the substation. Measures in software are mainly operational processing, which calculate mean, root-mean-square, moving average or maximum, minimum, median, and mode value; but in some cases, can conduct fixed time processing. The processing method is usually selected by the monitored object.

In order to determine the judgement criteria, it is necessary to know the sensor's signal output level which accompanies the fault progression in the equipment. This output level can be determined in the design stage of the equipment or in the simulated fault test using the actual equipment.

In the decision making process, it is general that one decision is made per observation. The diagnosis method based on the "EXPERT SYSTEM" has recently come into use. Using this system, multiple results (the possibility of several abnormalities) are made from multiple observations.

An example of the algorithm used in the GIS for monitoring gas leakage is shown in **Fig. 2**. Gas leakage is classified into three patterns and ensures continuous and detailed diagnosis as compared with that of the maintenance personnel.

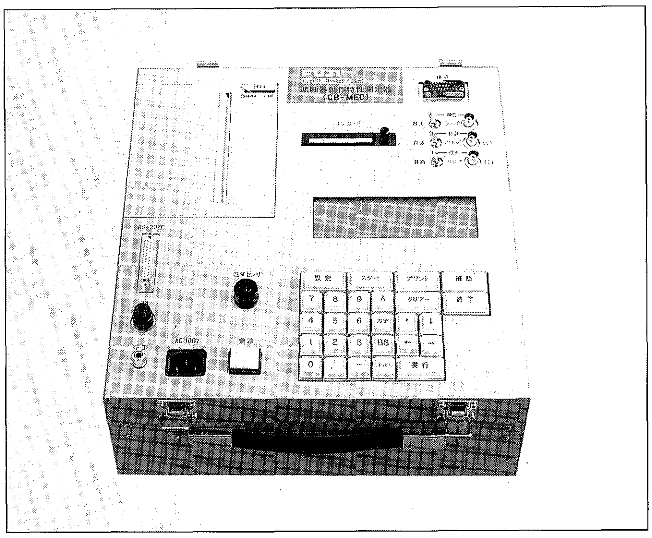
5. Maintenance Support System

As for the maintenance support system for substation equipment, two approaches are utilized. One is portable measuring devices used especially for maintenance and inspection tools, and the other is an on-line system with sensing devices mounted on the equipment.

As a typical example of the former, a portable performance measuring device for the circuit breaker shown in **Fig. 3** automatically measures and logs the control current, stroke, time to switch off and irregularities in its three-phase operating time.

Using the technology which processes and edits various sensor information, the equipment monitoring system and the maintenance support system have recently been put into operation. The basic composition of these systems is shown in **Fig. 4**. Signals from the sensors mounted on the substation equipment are inputted to the signal transducers in the local stations located nearby. The signal transducers convert the sensor signals into a level which a computer can process. Programmable controllers are generally used because of their high processing capability for large quantity of analog and digital signals.

Fig. 3 View of performance measuring device for circuit breaker



Measurement and diagnostic judgement are made in the local stations, and the relevant data are transmitted to the higher level station. In some cases, these data are briefly indicated in the local station.

The composition of the local station unit differs in the scale of the substation, the number of sensors, configuration of the substation equipment, areas of maintenance (the unit of the equipment, the type of equipment, circuit, bank, etc.).

One monitor station (data manager equipment) is usually installed per substation, collecting and processing data from each local station. It indicates countermeasures in response to some abnormalities. Data transmission from each local station to the data manager equipment is an N:1 type. The optical LAN system is often adopted to reduce noise as well as the quantity of cable in the substation yard.

To improve man-machine interface, a CRT display is used in the data manager equipment. Technical data of the data manager equipment delivered to a distribution substation are featured below.

Composition and view of the system are given in **Fig. 5**.

(1) System specifications

Substation outline

84 kV GIS:	10 units
20 MVA gas-insulated transformer:	2 banks
6 kV gas-insulated cubicle:	16 feeders
Local station in optical LAN network:	13 cubicles
Telemeter number:	Approx. 500
Supervising point number:	Approx. 1,000 points

Processor features

CPU: 32 bit microprocessor

Main memory : 16 MB

External memory: 2 drives for 3.5 inch diskettes
Hard disk 100 MB + 170 MB
Magnetic-optical disk 512 MB

Operation: JIS keybord and mouse

CRT: 15 inch color, 1,120 x 750 dots

Printer: Kanji (Chinese characters) printer and color video printer

Software: OS/2 + logger software (general use) + dedicated software

Fig. 4 Basic composition of maintenance support system

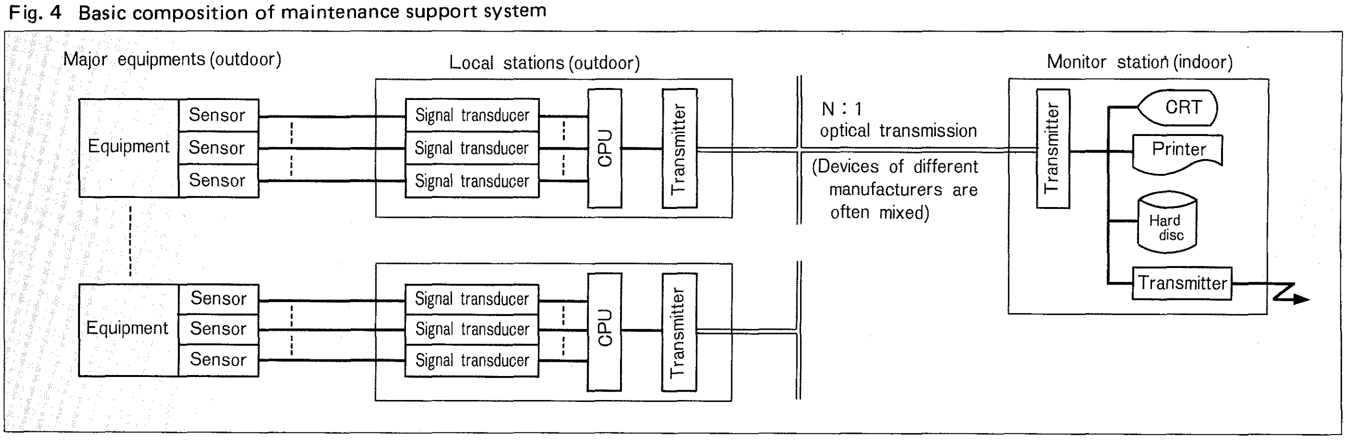


Fig. 5 Detailed composition of maintenance support system and view of local and monitor station

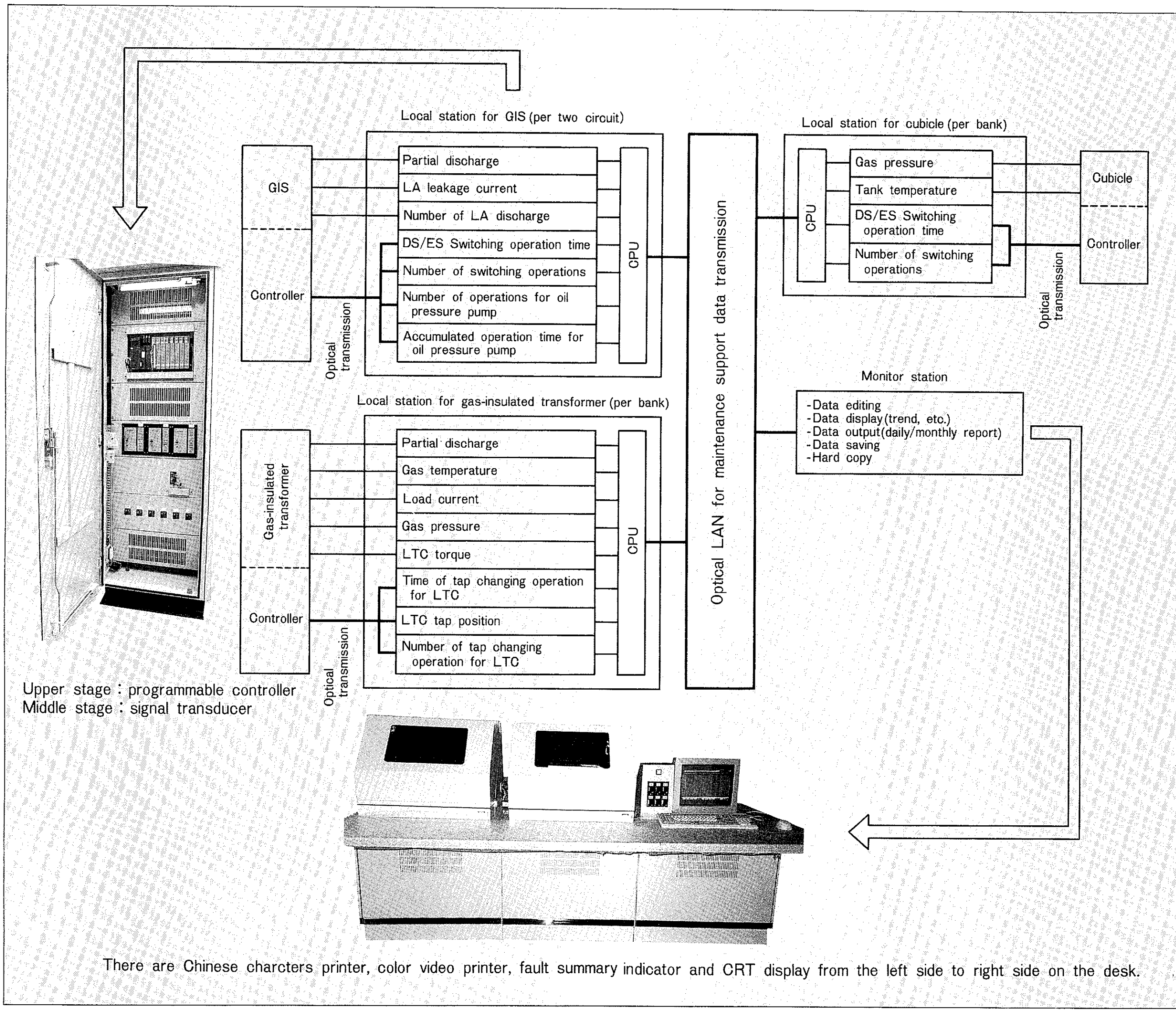


Fig. 6 Trend graph sample of transformer characteristics

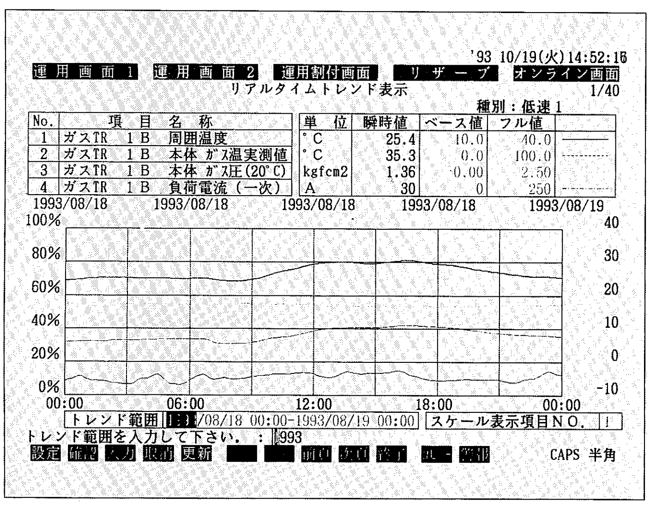
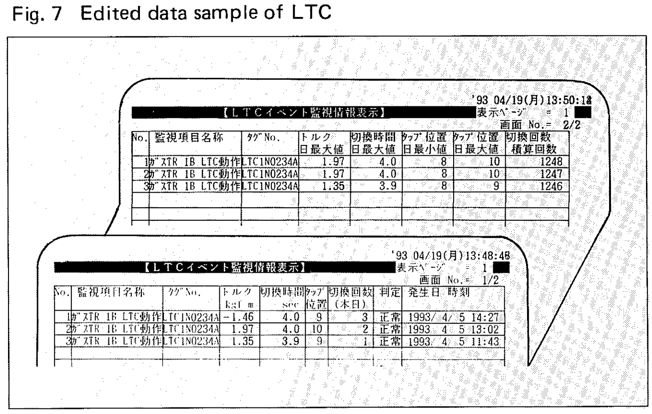


Fig. 7 Edited data sample of LTC



Layers of display: 2 - 3 layers

Turn off automatically with non-operation counter

(3) Data format

Display of current value

Daily log (manual output)

(2) Operation of CRT display

Menu selection method

Monthly log (automatic or manual output)
History information table of abnormalities (generation and recovery)
Trend graph (designated term): A sample for a transformer is shown in **Fig. 6**.
Equipment operation record: A sample for LTC data is shown in **Fig. 7**.
Color hard copy
Data correction (For example, the counter for accumulated operation number is corrected after system interruption)
(4) Saving of data
One year in hard disk
Manually copies to magnetic-optical disk

6. Conclusion

Recent maintenance and diagnostic technology for substation equipment and its associated systems have been described in this paper.

Following the future trend of the control device and the operation support system, the substation system itself will also have to be totally optimized, streamlined and upgraded.

The user's know-how and field data collected during operation and maintenance will help to further develop the associated system technology. The authors will be grateful for the user's future guidance and support in this matter.