Monitoring Equipment for the Gas-Insulated Power Apparatus

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1. Introduction

The gas-insulated power appratus, filled with a highly insulating SF_6 gas, has high reliability without being directly affected by changes in environmental factors such as humidity, salt, and dust. The apparatus, however, cannot be visually inspected for internal operation. A preventive maintenance system is being developed which will continuously monitor equipment operation to detect any sign of malfunction at an early stage so that corrective actions can be taken.

In this paper, the outline and actual applications of monitored parameters, sensors, transducers, detection methods, and electrical performance of preventive maintenance and the fault locator for the gas-insulated appratus will be introduced.

2. Preventive Maintenance System

The preventive maintenance system consists of sensors which convert physical quantities produced from the equipment into transmittable signals, transducers which change sensor signals into electrically controllable signals, and a processor which analyzes transducer outputs according to a preset algorithm to determine if the equipment is operating correctly. In this section, we look at the hardware (sensors and transducers) of the preventive maintenance system used in actual applications. The sensor is a critical part of the system; it is built into the monitored equipment and should be able to function as long as the equipment is in operation. It should also be able to withstand noise and surge.

2.1 Monitored parameters and applicable sensors

Table 1 shows the major monitored parameters, detection methods, and types of applicable sensors for the gas-insulated power apparatus.

The monitored parameters should be kept to a minimum, in the interest of equipment reliability and ease of sensor maintenance. The selection of monitored parameters

Table 1 Monitored parameters and applicable sensors

Monitored parameters		Detection method	Sensor	Location	Determine error signals
Insulator degradation	Partial discharge	Detects radiation current	Antenna	Inside the tank	If the detected level of partial discharge exceeds a preset value over a certain period of time, the processor assumes a malfunction, indicating caution or warning depending on the degree of deviation.
	LA leakage current	Detects resistance shunt leakage current	High sensitivity CT	LA earthing wire	Detected level of resistance shunt leakage current is averaged at certain intervals. If the average current value continues to exceed a preset value over a certain period of time, the processor assumes a malfunction.
Machine fault	CB switching characteristics	Measures make/break time, during which the coil remains energized	Hall-effect CT	Control panel circuit	While the equipment is running, the operation time is automatically measured. Any deviation from the standard value is assumed a malfunction.
	Frequency of operation	Counts the total number of position sensor actuations	Optical location sensor	Operating mechanism	The frequency of operations is recorded cumulatively. When the service life reaches a certain level, an alert is issued.
Leakage in the airtight chamber	Gas pressure	Diaphragm	Distortion gauge, using thermal resistor for temperature adjustment	Gas pipings	Detected pressure values are normalized to their thermally equivalent values at 20°C and averaged at certain intervals. If the average pressure is below a preset value, the processor assumes a malfunction.
Vacuum leakage	Partial discharge	Detects pulse current	Electrostatic capacitance shunt electrode	Inside the tank	If the detected pulse current value continues to exceed a preset value over a certain period of time, the processor assumes a malfunction.

Fig. 1 Partial discharge monitor

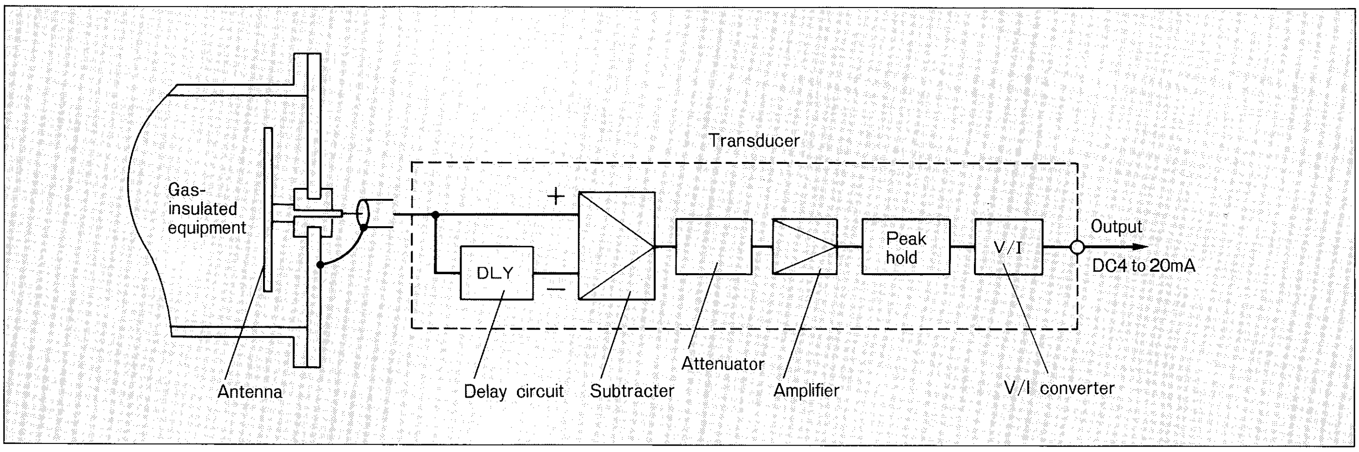

Fig. 2 Transducer used for partial discharge detection

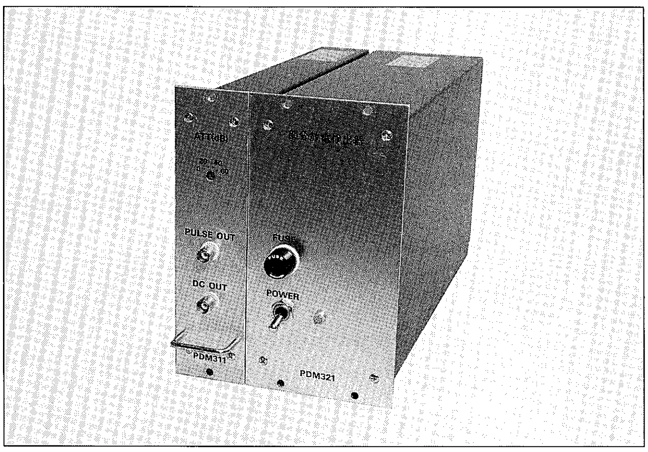

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Table 2 Causes of defective insulation and discharged electric charges

Causes of defective insulation	Approximate range of discharged electric charges (pC)
Floating electrode	500 to 10,000
Internal foreign substance	50 to 1,000
Cracked insulator	50 to 1,000
Interrupted conductivity	10,000 to 100,000

requires careful consideration of items that require routine inspection, the history of equipment malfunctions and failures, and preventive actions for possible problems.

Various detection technologies are available for practical applications. For the type of sensors to be used, appropriate detection methods should be evaluated according to its intended purpose and requirements for specific applications, and particularly important, cost-per-performance analysis.

2.2 Requirements for applicable sensors

When selecting sensors, the following basic requirements should be taken into accout:

(1) The sensor should not affect the reliability of the entire system.
(2) The sensor can be inspected without shutting down the equipment.
(3) The sensor should be usable over a wide range of models, economical, and easy to operate.
(4) The sensor should have a built-in self-diagnostic capability for fool-proof operation.

2.3 Equipment configuration

This section covers equipment configuration for the monitored parameters, complete with detection principles and electrical performance.

(1) Partial discharge monitor

Figure 1 shows the equipment configuration. Inside the SF_6 gas apparatus, partial discharge occurs in the form of several nonosecond-wide electromagnetic pulses; subsequently emitted electromagnetic pulses are detected by electrodes inside the equipment. Noise coming from outside the system through a conductor is a relatively flat pulse approximately ten to a hundred times wider than the inside discharge waveform. This noise is eliminated through delay and subtraction circuits to detect high-frequency (50MHz or more) pulse segments. **Figure 2** shows the transducer. A measuring range of approximately 200pC covers most of the insulation defects given in **Table 2**.

(2) Leakage current monitor for metal oxide surge arrester (hereinafter referred to as LA)

This device detects unbalanced shunt current resulting from incremental resistor shunt current-an indicator of the degradation of zinc oxide. It employs a three-phase vector-cancel system comprised of three-phase leakage currents in the earthing wire, using a high-sensitivity current transformer (hereinafter referred to as CT), and cancels capacitance shunt current. **Figure 3** shows the high sensitivity CT sensor which detects leakage current.

Safely separated from the primary circuit, the CT has excellent capabilities to withstand noise and surges. **Figure 4** shows a noise waveform that appears on a waveform monitor in the transducer when an 8/20μs, 20kA lightning surge current is drawn into a earthing wire that goes through the CT. In this case, 0.5 Vp (equivalent to 0.2mA) noise is produced. Performance characteristics do not change, however, before and after power application, indicating excellent noise resistance. This simple device is capable of detecting approximately 10μAp leakage current in field applications.

(3) Circuit breaker (CB) switching characteristics monitor

If malfunction occurs in the mechanical drive part of the CB, its actuation time, during which the control current energizes trip and closing coils, changes. This device detects the control current using a "through-type" Hall-effect CT to measure changes in duration that the coils are energized. **Figure 5** shows the equipment configuration. Insulation amplifiers are used at the input section of the transducer for protection against noise and surges from the Hall CT installed in the control circuit. A preferential circuit allows the switching characteristics to be monitored for both tripping and closing, monitoring time in increments of one ms.

(4) Vacuum leakage monitor for the vacuum interrupter

A hermetically-sealed vacuum interrupter, highly degassed and evacuated, is an excellent insulator and arc supressor. With its maintenance-free and long service

Fig. 3 High-sensitivity CT for LA leakage current transformer

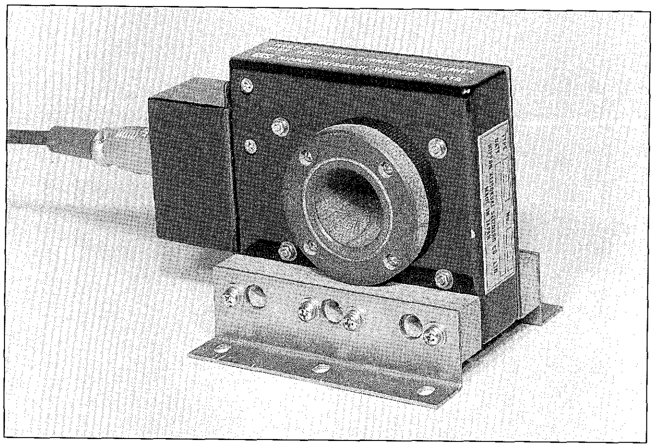

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Fig. 4 Noise waveform

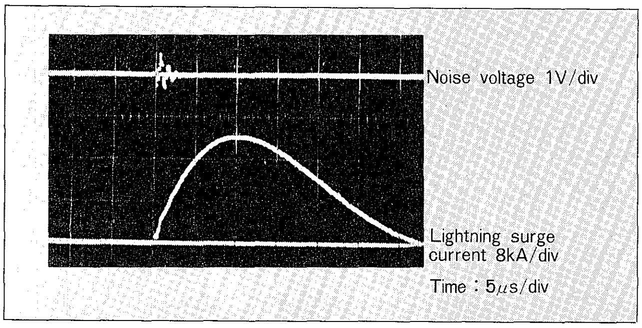


Fig. 5 Switching characteristics monitor

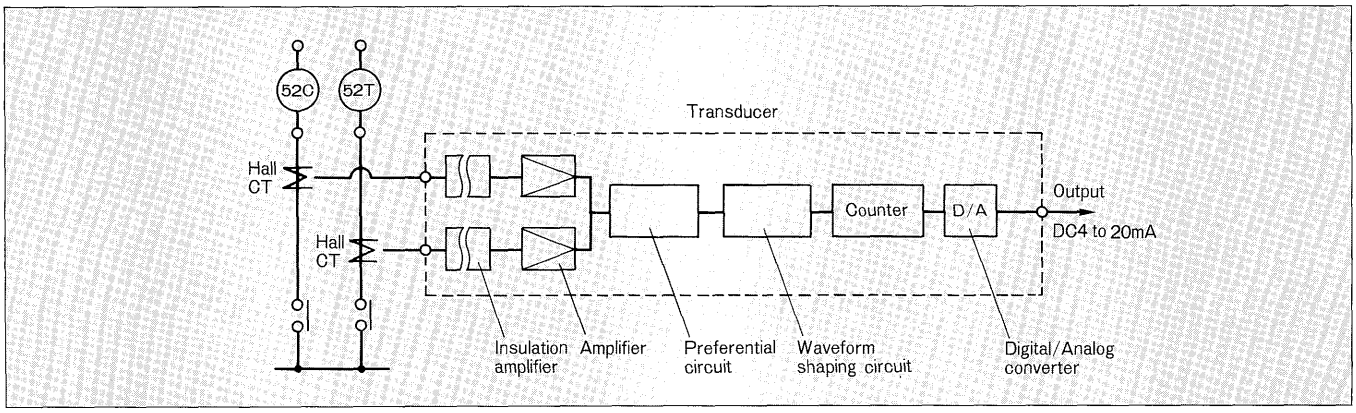
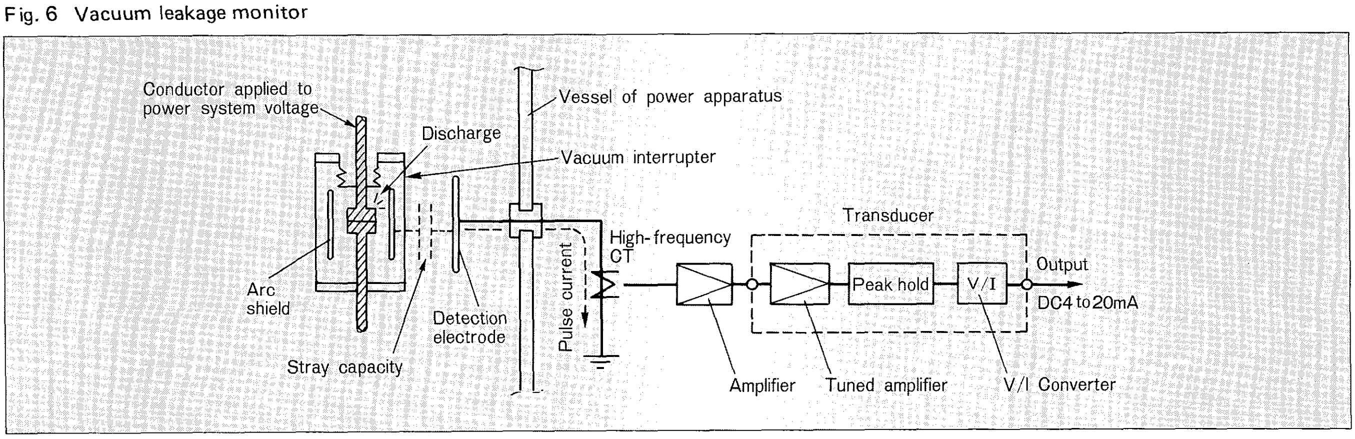


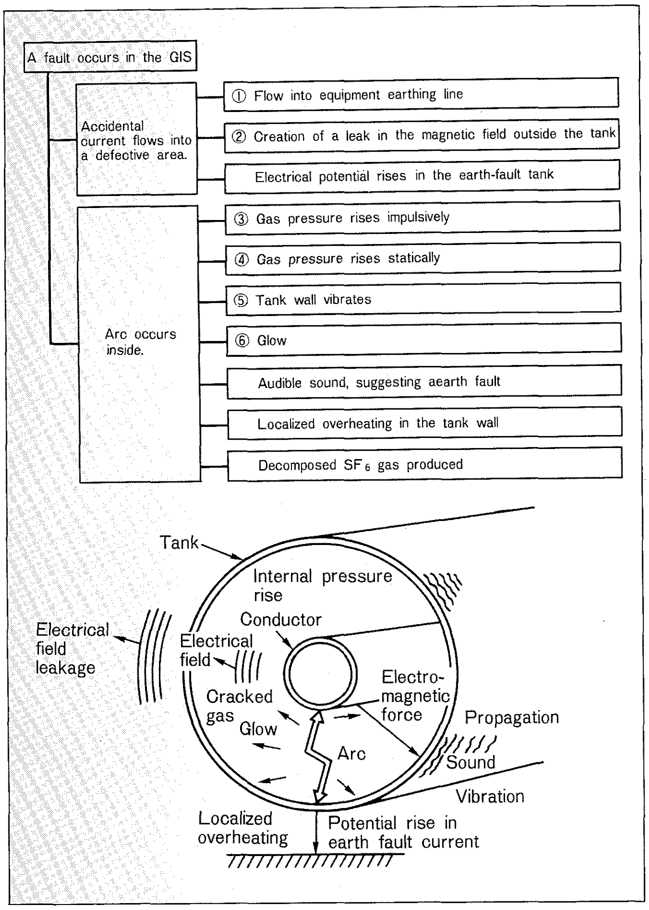
Fig. 6 Vacuum leakage monitor



life advantages, a vacuum circuit breaker (VCB) is being used as part of the SF_6 gas apparatus. When the degree of vacuum drops, however, a vacuum interrupter does not work as an insulator or arc suppressor. A practical vacuum monitor system is required for better maintanability of the equipment. Fuji Electric has developed a vacuum monitor based on discharge pulse current detection.

Figure 6 shows the configuration of the vacuum monitor. To continuously monitor the degree of vacuum, the unit must be sensitive to any loss of vacuum, whether the CB is on or off. A detection electrode is located just opposite the interrupter to enhance the gradient of charge potential inside the interrupter for positive pickup. When the degree of vacuum drops, discharge occurs in the interrupter and a subsequent pulse current tracks to earth via the stray capacity between the interrupter and electrode. The current is detected by the CT. The interrupter-to-electrode gap should be determined depending on the system voltage and types of interrupter used for individual applications.

Fig. 7 Fault symptoms in the GIS



3. Fault Locator

If an earth fault or short circuit occurs in the tank of the gas-insulated power appratus, the fault locator immediately locates the defective point, allowing for corrective action. Once the faulty gas section is localized, the operation is quickly switched over to a faultless system in order to recover a normal run with minimum downtime.

In this section, we will discuss fault symptoms, detection methods, results of actual applications, and the surge values of the sensors and detectors.

3.1 Fault symptom and detection

Figure 7 shows two categories of fault symptoms. One is due to accidental current, and the other is induced by arc. **Table 3** lists detection methods and causes for each fault. Faults can be detected more positively and accurately by checking for one or more of these symptoms. The magnitude of detectable faults varies with ① the type of fault (short circuit or a single-phase earth fault), ② system earthing method, ③ equipment earthing method, and ④ equipment configuration. It is important to decide on the best possible detection method, allowing for economy.

Table 3 Fault detection methods

Detection method	Cause	Applicable sensor	Actual usage	Features and requirements
①Earthing wire current	Current shorting from a defective tank to earth	Current transformer (CT, photosensor, search coil, and magnetic field sensor)	Available	Each container is earthed at one point, and insulated individually.
②Magnetic field around the tank	A magnetic field induced by accidental current around the tank	Magnetic field sensor (search coil and photosensor for magnetic field)	Available	Variation of induction field magnitude should be eliminated. Fault isolation algorithm is complex.
③Impulsive gas pressure	A transient pressure rise due to accidental arc current	Pressure sensor (pressure relay)	Available	Difficult to identify a single-phase earth fault due to invalid earthing. CB and DS arc detection need to be considered.
④Static gas pressure	Pressure rise in a faulty tank	Pressure sensor (distortion gauge)	Available	Difficult to identiry a single-phase earth fault due to invalid earthing. CB and DS arc detection need to be considered.
⑤Vibrating acceleration	Tank vibration due to accidental arc current discharge	Acceleration sensor (piezoelectric element)	Available	Difficult to identify a single-phase earth fault due to invalid earthing. CB and DS operation need to be considered.
⑥Arc glow	Accidental arc glow	Photosensor (photodiode)	Available	CB and DS are detection need to be considered.

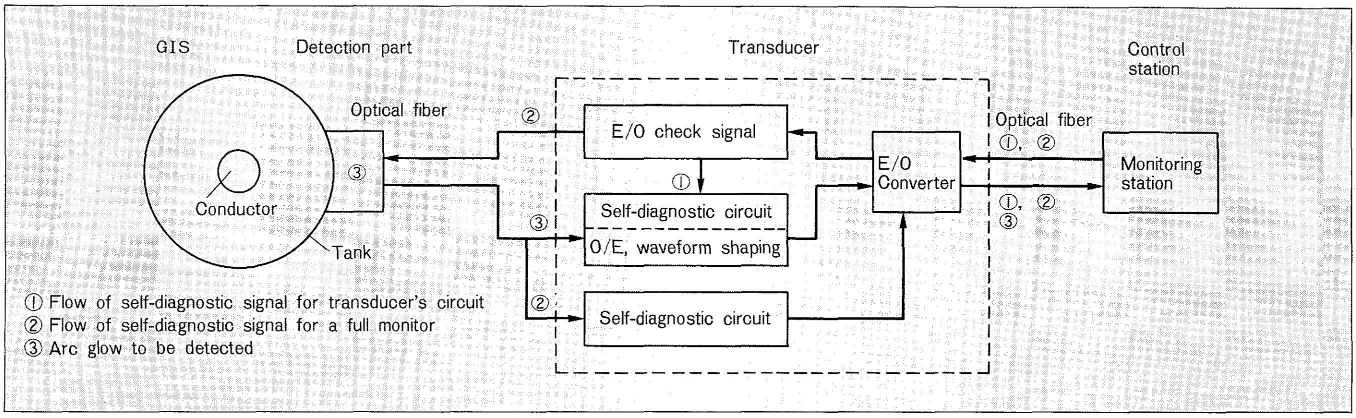


Fig. 8 Arc glow monitor

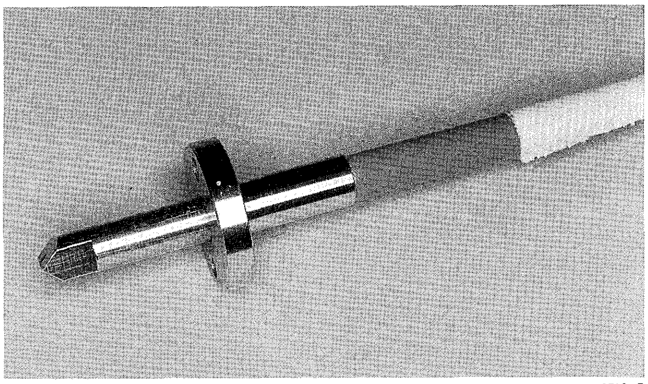


Fig. 9 The tip of a sensor

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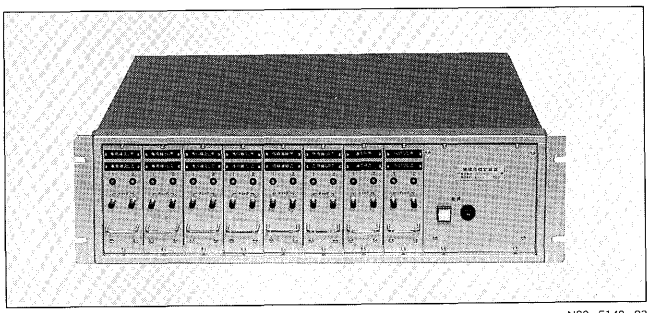
Fig. 10 Transducer used for arc glow detection

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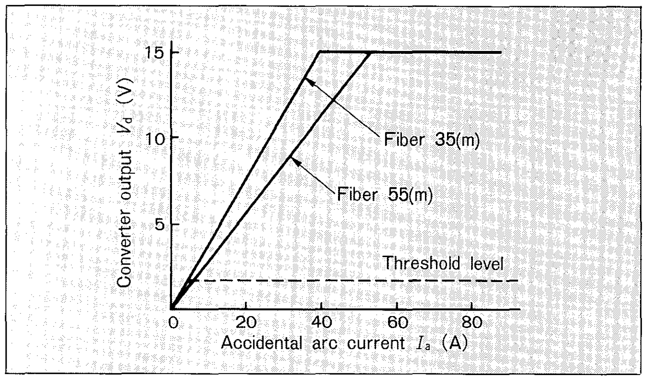

Fig. 11 Detection characteristics of accidental arc glow

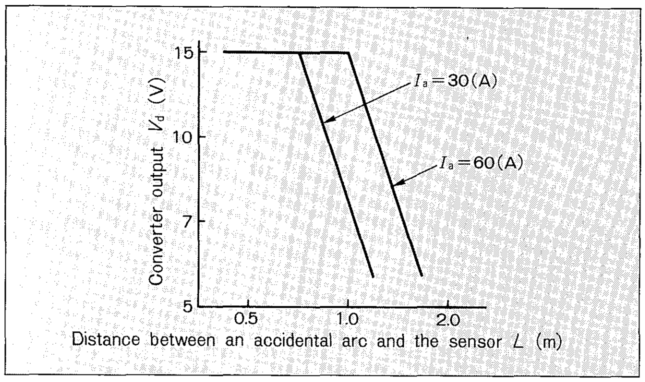

Fig. 12 Decay characteristics of accidental arc glow

3.2 Arc glow detection

A faulty gas section can be located using a simple algorithm by detecting gas pressure, earthing wire current (section-by-section isolation), or arc glow. This section deals with actual applications.

(1) System configuration

Figure 8 shows the configuration of the entire system. An arc glow detector is installed in the tank of the gas-insulated apparatus in such a way that a sensor can be removed without having to degas the tank. A built-in self-diagnostic is always checking the system in two ways. One is a quick check of the transducer's electric circuits (**Fig. 8** ①), and the other is a complete check of the entire system, including fiber optics (**Fig. 8** ②). The latter contains optical fibers that transmit a beam of light for detection. The system can accept additional data from the delay timer and protective relay circuits that categorize fault symptoms into those due to an accidental arc and those due to an arc occurring upon the opening of a circuit breaker or disconnecting switch (hereinafter referred to as DS). **Figure 9** shows the tip of a sensor, and **Fig. 10** shows a transducer.

(2) Light reception characteristics

Figure 11 shows the detection characteristics of this system with respect to the length of the optical fiber between the detector and transducer, and **Figure 12** shows the decay characteristics of receiving sensitivity with

Table 4 System verification of practical applications

Areas of verification	Factors to be verified against
Input power	Incorrect operation upon a momentary voltage drop or shut-off Voltage fluctuation tolerance
Surge resistance	Radio wave, square wave, damping oscillation noise
Dielectric strength	AC, impulse voltage
Thermal performance	High and low temperatures, heat cycle
Shock and vibration	Oscillation frequency, amplitude, and acceleration

respect to distance. The detection characteristics are inversely proportional to the length of the optical fiber, and the decay characteristics are roughly proportional to the square root of the distance. These factors should be considered when determining the number and location of the sensors.

(3) System verification of practical applications

Sensors and transducers are subjected to surges that are produced upon the opening or closing of the CB and DS. To overcome the effects of surges and to ensure reliable performance, dielectric strength is increased between the power source and the earth, and between signal lines and the earth. **Table 4** shows what has been done to achieve satisfactory performance in actual applications. A signal-delay circuit function has also been confirmed in an experiment where a large 31.5kA current arc was received.

4. Conclusion

In this paper, monitored parameters, sensors and transducers of the preventive maintenance system and the fault locator, including its detection methods and electrical characteristics, were introduced.

Recently, advanced functions of the equipment and maintenance system require a more advanced monitoring system as well as the introduction of knowledge engineering (AI) into power equipment. For development and utilization of the system, it is essential to have experience in and know-how of operation and maintenance of the equipment, and cooperation with the user of the equipment is desirable.