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DIAGNOSTIC TECHNIQUES FOR SUBSTATION EQUIPMENT

Mitsuru Tanimoto
Hideo Kaneko
Masaru Isozaki

1 INTRODUCTION

In recent years, in order to cope with the superannuation of installations and increase in number of unattended substations, it is expected to improve the reliability of installations through application of preventive and predictable maintenance technology as well as further enhancement of patrol inspection techniques.

Gas-insulated switchgears (GIS) and transformers are the main stream of the substation equipment and they are gas- or oil-filled highly safe and highly reliable equipment aiming at freedom from maintenance, being widely adopted at site, in particular, adoption of GIS is increasing every year. However, they have their own short-comings, that is, they are invisible from outside.

It is by this reason that it is expected to establish a "predictable maintenance" techniques by which symptoms of anomalies of the equipment are diagnosed from outside, if it is possible under the operating conditions of the equipment in order to forecast the event that is bound to come across, this permitting to carry out maintenance work as necessary. In response to such demand, an on-line system that would supervise the status of equipment automatically is under project to be produced by combining organically the sensing technology and data processing technology that have made a remarkable progress in recent years, and in fact, in some sectors, these are already put into practice and started being widely adopted for effective use.

The present report introduces the outline of external diagnosis equipment on the substation equipment, as well as an example of projects for the substation equipment supervising system, developed by Fuji Electric.

2 EXTERNAL DIAGNOSIS EQUIPMENT ON SUBSTATION EQUIPMENT

Fuji Electric has for long years studied and developed external diagnosis equipment to be used for transfromers, GIS's and cubicles. The external diagnosis equipment presented in the following are those of transportable type and a sort to be used as a maintenance tool during the maintenance and inspection works, whose main object is to diagnose whether there is any abnormal condition in the main equipment or not. However, these can be utilized also as a sensor in the equipment supervisory system.

2.1 Transformer

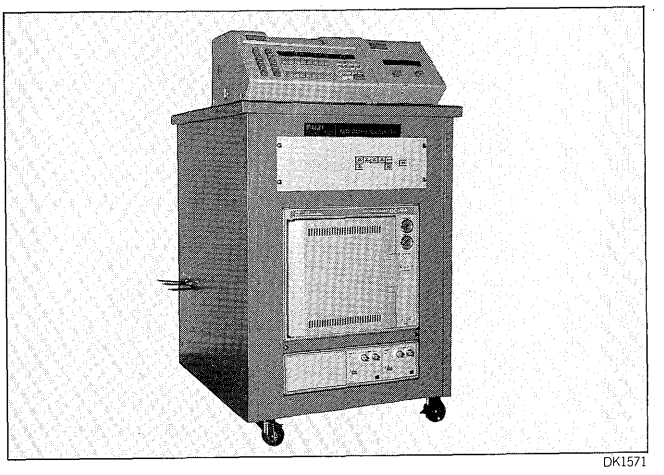
As for external diagnosis equipment for transformers, first we introduce a precision type auto-analyzer of dissolved gases in oil and partial discharge supervisory equipment.

2.1.1 Auto-analyzer of dissolved gases in oil

When any local overheating or discharging phenomena is produced in the internal mechanism of an oil-immersed transformer, gas will be generated due to pyrolysis of insulators and insulating oil located near by the spot. Oil-filled gas analyzer, by sampling oil in the transformer under operation, analyzes gas solved in it, localizes the troubled spots and determines the degree of deterioration in the transformer: it is an efficient method of diagnosis, constituting a main stream in the technique of diagnosis on transformer deterioration.

Analyzing of gas in oil requires a complex and skill demanding work as extracting and analyzing gas sampled out of oil but with the automatic analyzer of gas in oil developed recently by Fuji Electric, this complicated work can be carried out from A to Z of the operation with this single instrument in an automatic way. Furthermore, this

Fig. 1 Auto-analyzer of dissolved gases in oil



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instrument is easy to handle and no special skill is needed for operating the apparatus, so that efficiency of analyzing work is much enhanced. *Fig. 1* shows an outer view of the instrument.

As an automatic gas-in-oil analyzing equipment uses a 2-column simultaneous working type gas chromatography of exclusive use, it features in that it can analyze as many gases as nine like H_2, O_2, CH_4 (methane), CO, CO_2, C_2H_4 (ethylene), C_2H_6 (ethane), and C_2H_2 (acetylene) that have much to do with deterioration of transformers in as short a time as one hour. Also, the method of extracting gas out of oil is through use of a bellows piston so that the extracting efficiency is extremely high.

Still further, a data transmission is provided as option for the equipment so that transformers can be supervised at all time on line.

On the other hand, as it uses the intelligent type extert system COMEX developed by Tokyo Electrical Engineering College as a tool for diagnosis on insulating oil, it is optimum for insulating oil diagnosis for oil-immersed transformers. Up to now, this diagnosis has been made by experts in diagnosis on basis of multitude of data and their own experience in a suitable manner, but now, this work can be assigned to COMEX requiring no intervention of specialists.

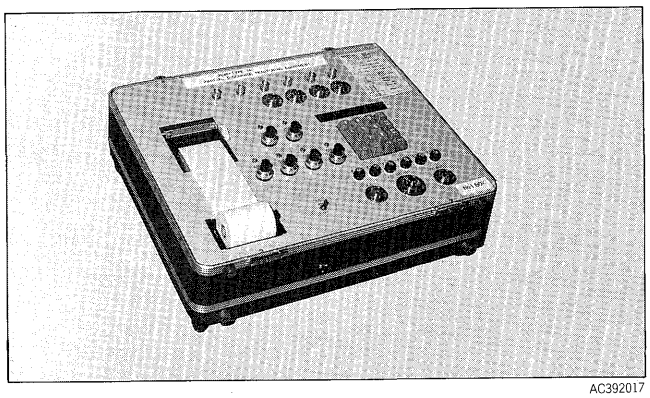
2.1.2 Partial discharge supervisory equipment

This partial discharge supervisory equipment is developed with an aim of detecting early partial discharges constituting a symptom of anomaly in the internal mechanism of transformer by supervising at all time transformer under operation.

When partial discahrges take place inside the transformer, pulse current of higher harmonics and ultrasonic waves are generated. The equipment is used for detecting these two physical volumes simultaneously, distinguishing noises and detecting the partial discharge. *Fig. 2* gives the conceptual diagram.

Discriminating internal discharge from external noise is important and here in this instrument, the correlationship between current pulse and ultrasonic pulse is noise discriminated by microprocessor. It has, though depending on the measuring place, a detecing sensitivity of about 200 pC. And it can localize instantaneously the spot where the partial discharge takes place with an error of about ±20 cm.

Fig. 3 Portable type partial discharge supervisory equipment (main body)



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Transportable partial discharge supervisory equipment is housed in five trunks including sensor unit and other parts. It can be set up and connected at work site and start supervisory function. *Fig. 3* shows an outer view of the main body.

2.2 GIS

As for external diagnosis equipment, outline of the partial discharge measuring equipment and acoustic test equipment is described.

2.2.1 Partial discharge measuring equipment

As a method of detecting partial discharge in the interior of GIS, various methods such as insulating spacer method, enclosure electrode method, electromagnetic coupling method and vibration detection method and others. However all of them presented a problem of eliminating noise for enhancing the detecting sensitivity.

As Fuji Electric has developed simple portable type GIS partial discharge measuring equipment utilizing waveform discriminating noise eliminating circuit. The following is the description on this newly developed product.

Fig. 2 Block diagram showing construction of partial discharge supervising system

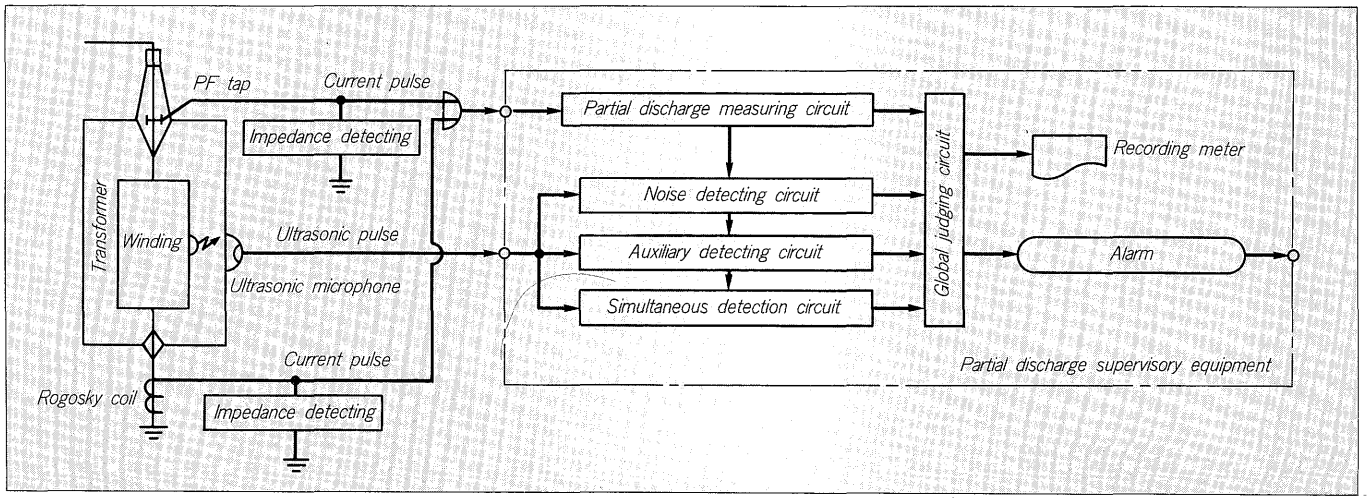


Fig. 4 External noise eliminating circuit (minimum unit)

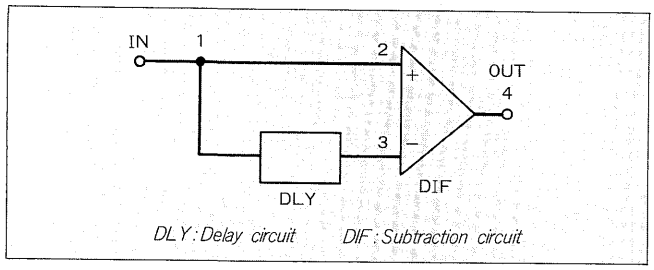


Fig. 5 External noise elimination (principle)

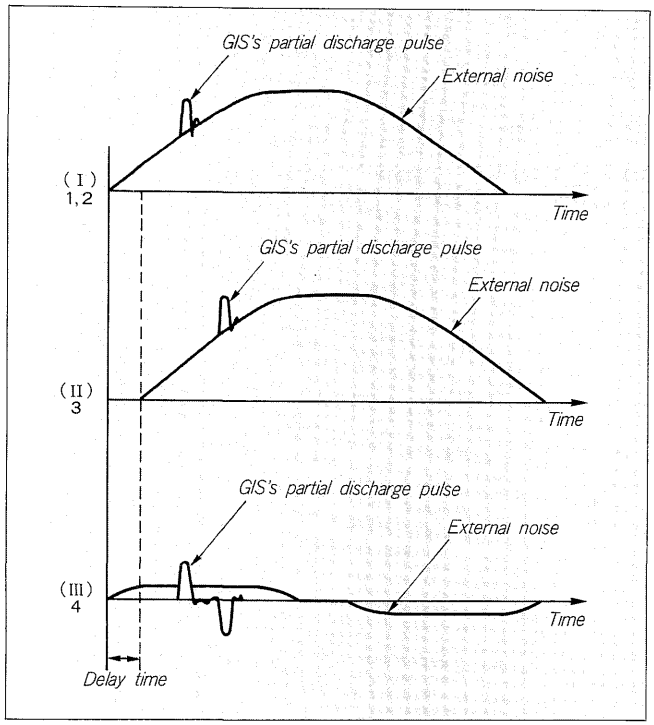


Fig. 6 Metal dust detecting equipment

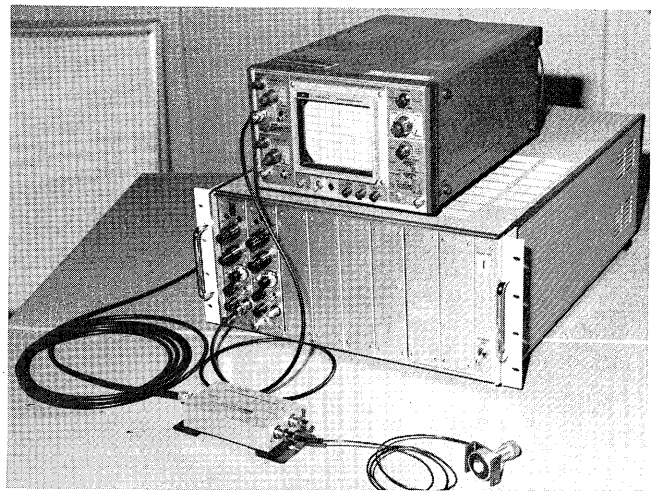
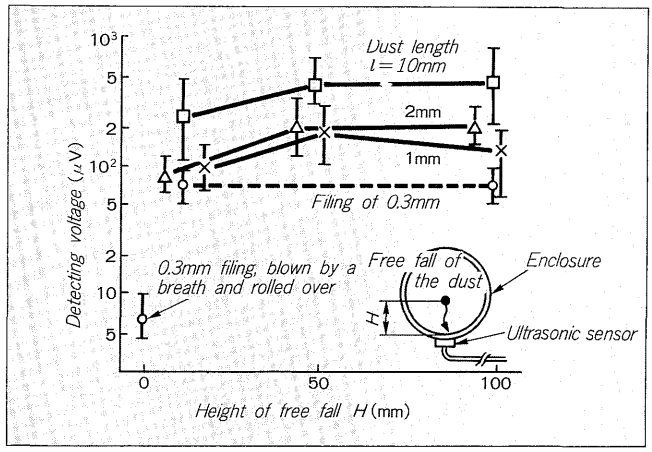


Fig. 7 Detecting sensitivity of the ultrasonic sensor



When a partial discharge takes place in the internal mechanism of GIS, a steep high-frequency pulse current will be generated. By detecting this with a probe terminal, the partial discharge can be easily measured. Elimination of external noise took up a hint from the waveform of partial discharge pulse of GIS. The pulse width of the partial discharge pulse of GIS is in order of several ns. For this, the pulse-width of external noises as those of air corona or thyristor noise is several tens to 100 times wider in comparison with the pulse width of partial discharge of GIS. Elimination of external noise is effectuated by the waveform discriminating noise eliminating circuit composed of delay circuit and subtraction circuit shown in *Fig. 4*. In delay circuit, the input from the probe will be delayed by the period corresponding to the pulse width of partial discharge pulse of GIS. From this, when we subtract the component not delayed, the external noise will be eliminated and made smaller and the partial discharge pulse in the GIS will be detected. The principle of noise elimination is shown in *Fig. 5*.

2.2.2 Acoustic test equipment

When metal dust exist in the internal of GIS, the efficiency of internal insulation will be lowered. And it is this acoustic test equipment that is developed with an aim of discovering the harmful metal dust in the early phase.

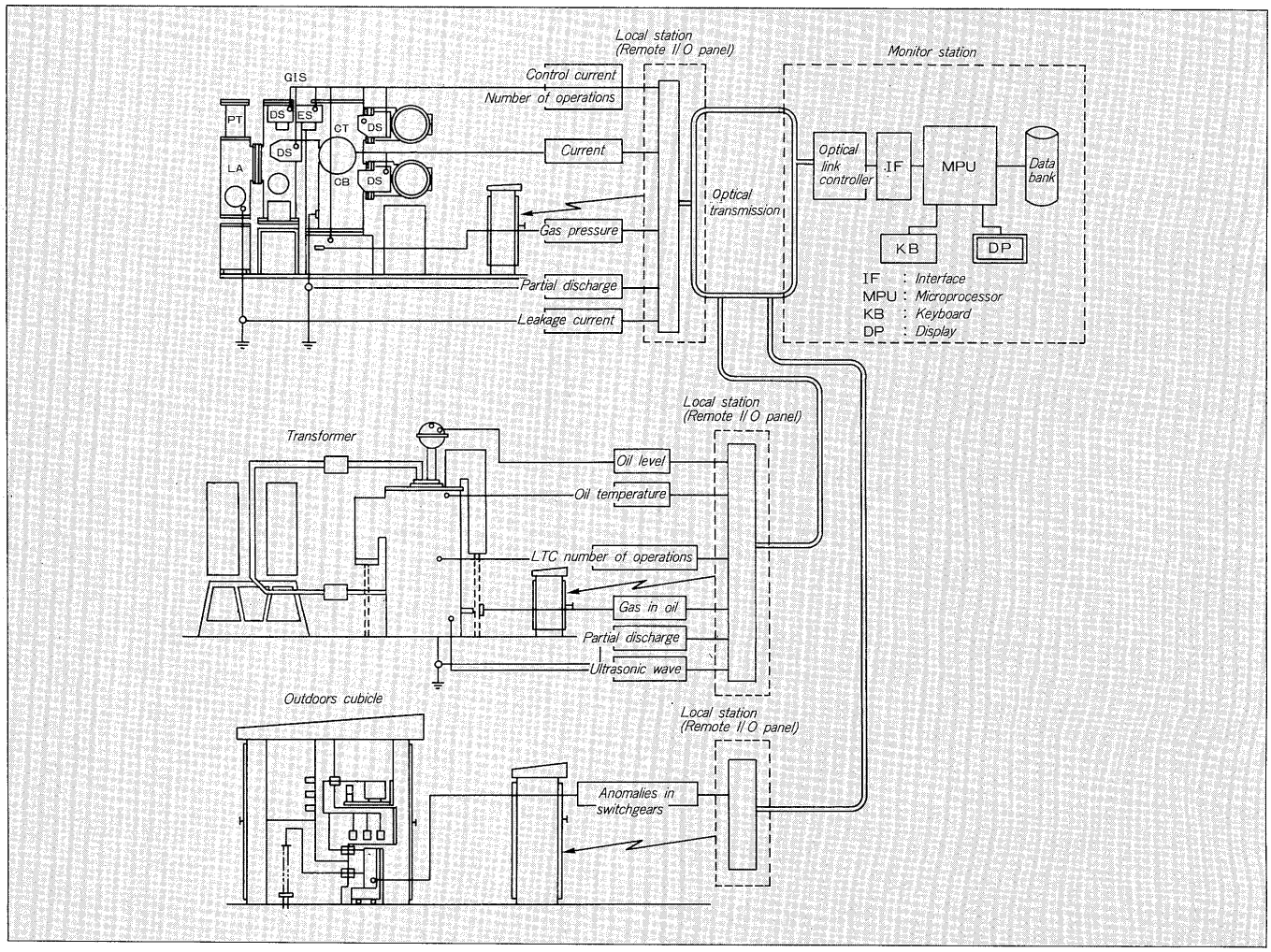
Metal dust within the GIS, receiving the static electric force by impressed voltage, repeats the operation of going up and coming down. This equipment detects vibratory sounds produced when the metal dust in movement bumps against the enclosure with ultrasonic-wave microphone by amplifying it with an amplifier. *Fig. 6* shows an outer view of the acoustic test equipment.

The sensitivity of the acoustic test equipment is that it can detect, as it was known from the result of a test in which dust is made to free fall from a height H, the sound of an aluminum filing of 0.3 mm (0.1 mg) when it is rolled over by a human breath. *Fig. 7* shows the result of the experiment.

3 EXAMPLE OF SUBSTATION EQUIPMENT SUPERVISORY SYSTEM PROJECTS

3.1 System construction

Fig. 8 Conceptual diagram of substation equipment supervisory system composition



Substation equipment supervisory system is composed of sensor unit to be attached to equipment to detect the equipment status, local station at site that transmits and processes the signals from the sensor to central processor equipment located in the main building, and monitor station that receives these signals. At the monitor station, supervising and diagnostic are carried out. *Fig. 8* shows the conceptual diagrm of the system.

Local station transmits signals from sensor to monitor station located in the main building after making due arrangement of received signals and putting them in good order. Local station will be installed for each transformer, GIS and cubicle so that, in this way, it can cope with future expansion. For transmission to monitor station, a optical digital transmission through light fiber, which is excellent in anti-noise characteristics and quantity of information transmission is adopted.

On the other hand, monitor station features, in order to facilitate the daily supervision, in (1) equipment diagnosis (diagnosis of anomalies, supporting of judgement by maintenance personnel), (2) supervision (daily monitoring and trend monitoring), and (3) inspection forecast.

3.2 Diagnostic items and sensor

Troubles in the substation equipment can be, roughly, clasified into failure of the following three items: (1) insulation failure, (2) continuity failure and (3) mechanical failure. Thus, physical value serving as index of deterioration of each item is detected for effectuating diagnosis. *Fig. 9* summarizes the diagnostic items and applied sensors.

3.3 Sensor composition

The composition of each sensor is as described in the following.

3.3.1 For GIS

For applied sensors in GIS, examples of monitoring on partial discharge, switching anomalies, and leakage current are introduced.

(1) Partial discharge

Principle and diagnostic method are already described in Paragraph 2.2 Partial Discharge Detector is composed as follows: 4 sensor outputs are connected in parallel to change-over switch to input into converter. *Fig. 10* shows an outer view of the detector. This detector is composed

Fig. 9 Diagnostic items and applied sensors

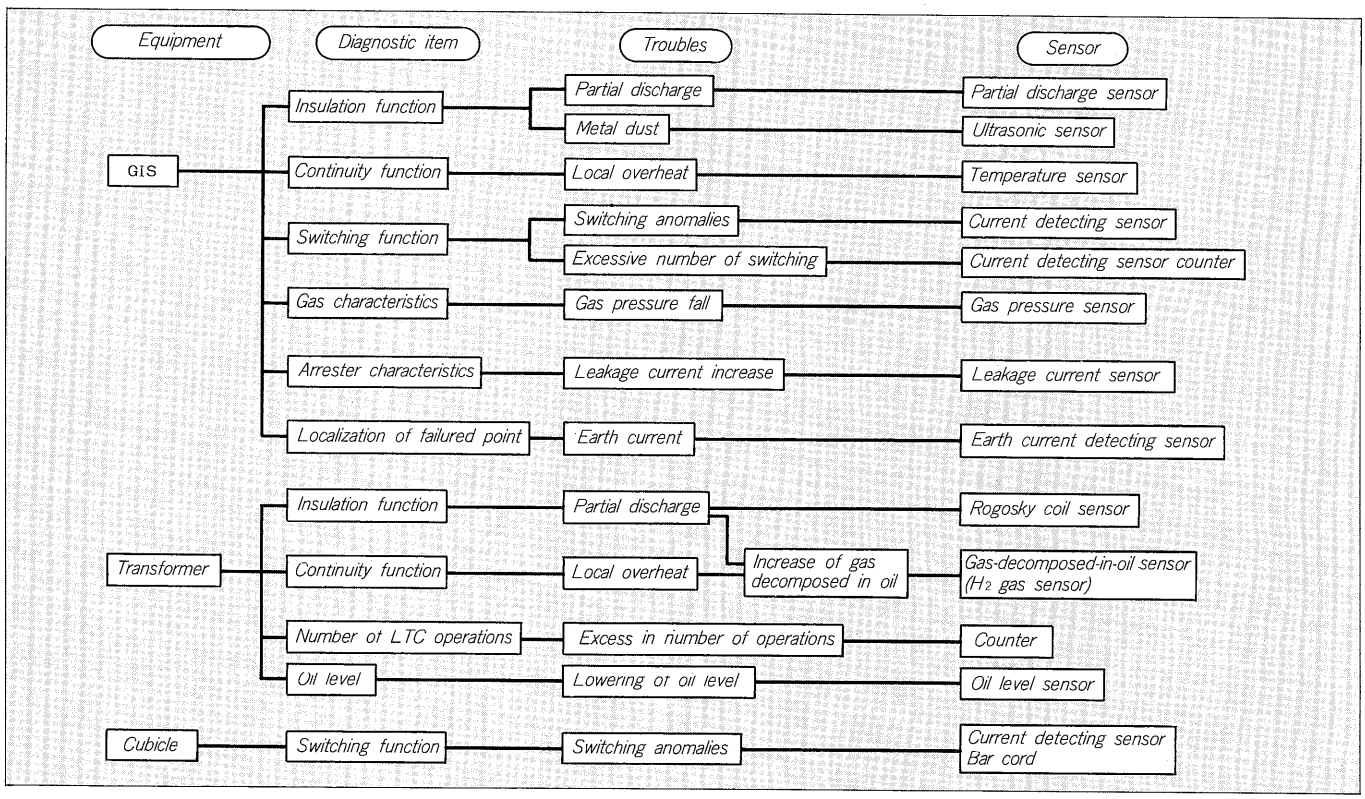


Fig. 10 GIS partial discharge detector

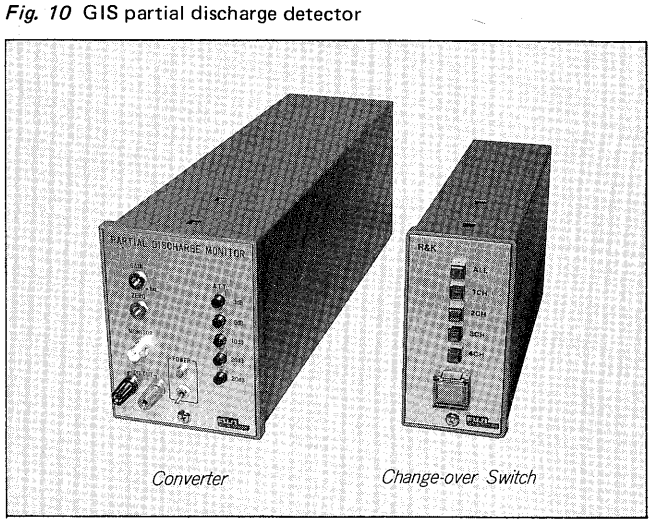
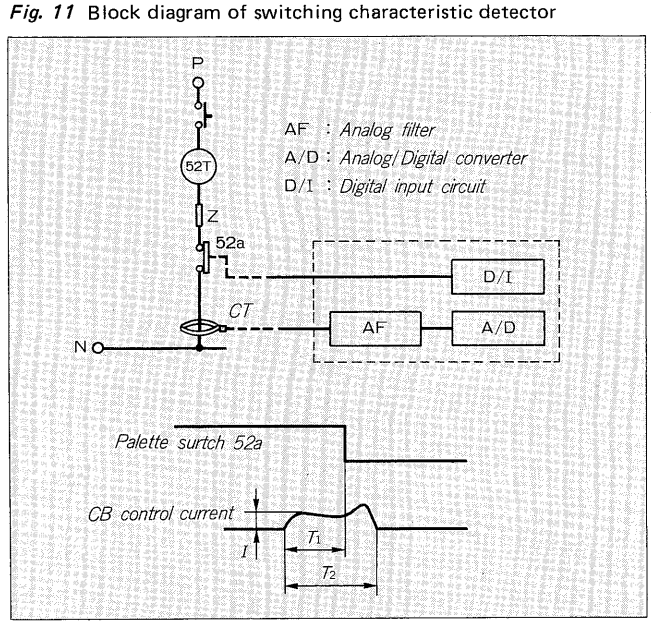


Fig. 11 Block diagram of switching characteristic detector



of detecting impedance, external noise eliminating circuit, peak hold circuit and converting circuit into 2 – 20 mA signals.

(2) Switching anomalies

The composition is shown in block diagram of *Fig. 11*. Switching characteristics detector is composed of analog filter for eliminating higher harmonics contained in the input signals from control current detector and A/D converter for transmitting data to monitor station. Also, it includes digital input circuit that converts the palette switch signal of closing and trip circuits that serve as the reference for judging suitability of switching chacacteristics into ON/OFF DATA. *Fig. 12* shows the control current detecting sensor. This current sensor is made compact in its shape for detecting direct current by mold forming the through-type cut core and Hall elements.

(3) Leakage current from lightning arrester

Electrically equivalent circuit of metal oxide type lighting arrester can be expressed by a parallel circuit of

Fig. 12 Control current detecting sensor

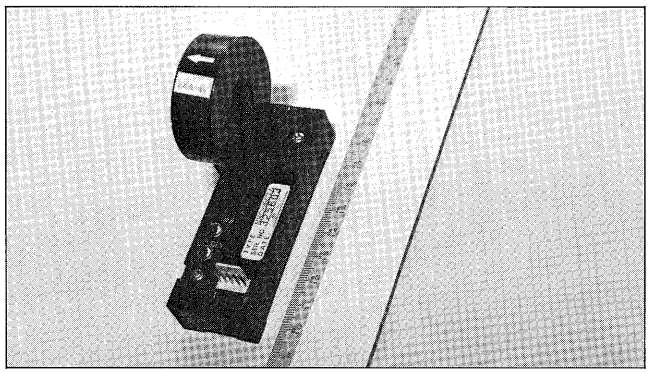
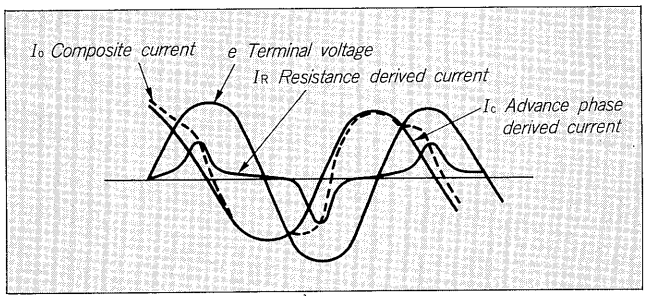


Fig. 13 Leakage current waveform of lightning arrester



resistance and static capacity. When elements are deteriorized, resistance derived current will be increased. Thus, by taking up the capacity component elimination method, only the resistance omponent leakage current will be extracted to diagnose the state of deterioration of the metal oxide type lightning arrester. *Fig. 13* shows the waveform of the leakage current.

3.3.2 For transformer

As for applied sensor for transformers, here analysis of gas in oil and monitoring of oil level will be described, and as for partial discharge, since it was already described in Paragraph 2.1, the description is omitted here.

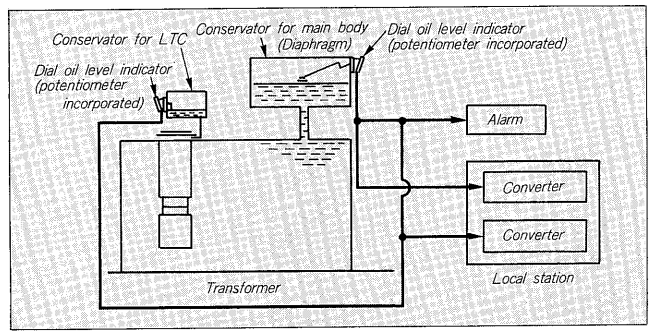
(1) Gas in oil (hydrogen gas)

Principle is already described in Paragraph 2.1. However, there are some types of detectors that monitor concentration of H_2 gas by utilizing the fact that H_2 is always the main constituent of the dissolved gas. H_2 gas concentration supervisory equipment is compact in size and is optimum for on-line monitoring.

(2) Oil level

This oil leve detector is composed of dial oil level indicator with potentiometer incorporated and converter that remote indicates the oil level. The incorporated potentiometer is interlinked with the indicating needle of the dial oil level indicator. The change in resistance of the potentiometer in proportion with the indicating needle of dial oil level indiator is converted into potential difference by the converter and outputs it in a form of 4 to 20 mA signals. *Fig. 14* shows a composition diagram of this oil level detector. The oil level indicator for main body detects the oil level by the change in position of the diaphragm and the oil level indicator for LTC, by the change in position of the float.

Fig. 14 Composition of oil level detector



4 CONCLUSION

We have introduced the outlines of the contents of diagnosis equipment for substation equipment and those of projects for equipment supervisory system that Fuji Electric has been tackling. Enhancement of functionality of sensors and progress of computer processing technology in recent years are something to be wondered at.

With this context, supervisory systems will be adopted also for the sector of power installations and with this adoption, their maintenance will be made more efficient and to a higher degree. Further, studies are already under way for introduction of intelligent substations that have adopted the fruits of frontier technologies as knowledge engineering.

Fuji Electric is determined to continue further its studies on optimum sensors concurrently with developing of external diagnosis equipment on substation equipment as well as automatic supervisory system on basis of the fruits of diagnosis technique that its has come to cultivate for many years.

In order to wrap up these diagnosis equipment into something practical, it is indispensable to have council and advice from our Customers, so that we request further cooperation and guidance for the future as well.