Monitoring and Diagnostic Systems for Power Receiving and Substation Facilities

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Abstract

For the laborsaving and upgrading of maintenance service for power receiving and substation facilities such as oil-immersed power transformers and switchgears, we have been promoting the technical development of cloud-based remote monitoring systems and facility diagnostic systems to be applied to these power receiving and substation facilities by utilizing Internet of Things (IoT) devices. In this approach, various sensors for current, vibration, transient earth voltage, and others are installed in substation equipment and sensor terminals like Partial Discharge (PD) detectors are used to detect the PD which is an early sign phenomenon of equipment insulation breakdown. Using such sensors and terminal devices, the status of equipment and facilities is always monitored to grasp any early sign of an anomaly and to diagnose the abnormality. In addition, based on the quantitative data acquired in the past, we can support maintenance routines such as daily inspections, repair services, and facility renovation planning and can streamline the facility management.

1 Preface

Ultra-high-voltage and high-voltage power receiving and substation facilities consist mostly of power transformers, circuit breakers, and switchgears. These products support the stability and reliability of power supply. Recently, however, longer product life has been considered more important than facility renovation; as a matter of course, aged facilities are increasing. In the conventional maintenance and inspection service, Time Based Maintenance (TBM) was carried out for which periodical maintenance actions are taken at the predetermined period for the purposes of laborsaving, streamlining of processes, and the reduction rate of malfunction occurrence.

Lately, however, the TBM tends to shift to Condition Based Maintenance (CBM) where a trend leading to deterioration and maintenance service is always monitored and carried out shortly before the occurrence of a malfunction, only if maintenance is determined necessary.

Under such circumstances, we followed the significance of CBM and developed facility diagnostic systems by utilizing Internet of Things (IoT) devices. This paper introduces sensor terminals installed in power transformers, and switchgears in the power receiving and substation facilities, including the functions of our cloud services.

2 Outline of Facility Diagnostic Systems and Merits of Introduction

Fig. 1 shows an outline of cloud-based facility diagnostic system ("this system" hereafter). This system is used to collect field telemetry data from various sensors installed in power receiving and substation equipment such as power transformers and switchgears so that the conditions of facility operation can be continually monitored from a remote site. In addition, it can detect an anomaly and grasp the early sign of it through the analysis of operational data accumulated in the cloud. Still more, additional cloud services are available, such as functions that support facility operation and maintenance, diagnostic report, and remaining life assessment. It realizes the most effective life cycle cost for facilities. Advantages available as a result of introduction of this system are as follows:

(1) Real-time monitoring of facility conditions

Conventionally, a visual check was carried out to obtain the field data, such as the number of

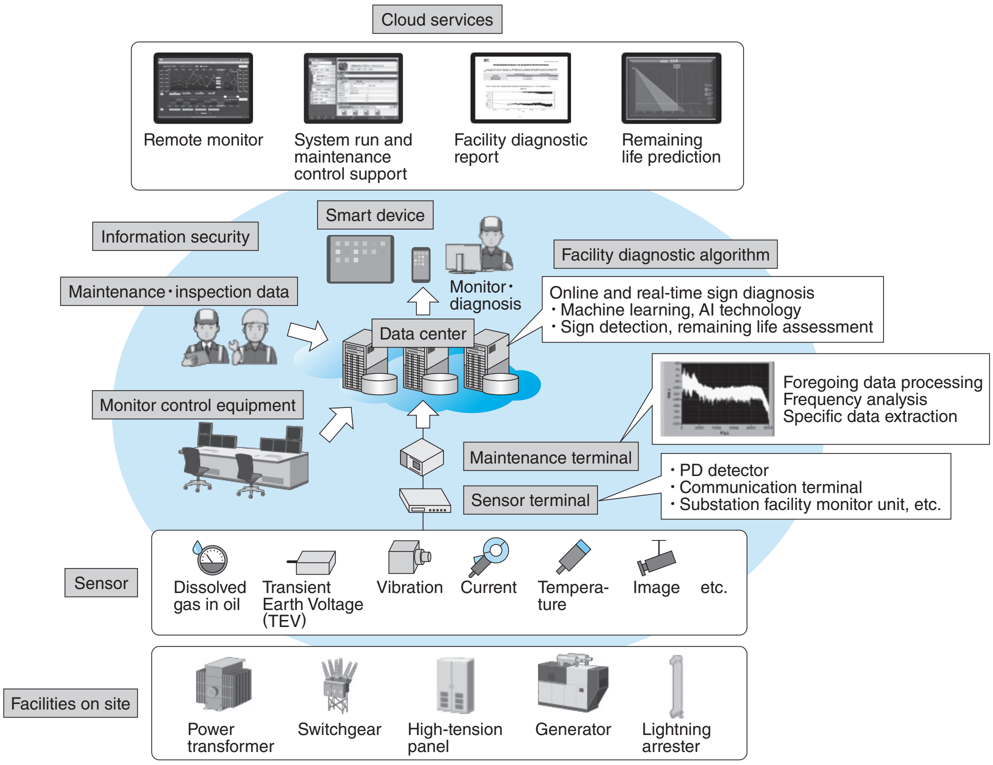

Fig. 1 Outline of Cloud-Based Facility Diagnostic System

An outline of cloud services and a facility diagnostic system is shown.

equipment operations, temperatures, and other readouts in order to grasp the trend of equipment deterioration at the time of the periodic inspection. After going online, however, the status of facility operation can be checked at any location and time through the cloud.

(2) Prevention of failures

In the case of conventional monthly and yearly periodic inspections, any early sign of an anomaly phenomenon occurring in the middle of the previous and next inspection periods could not be discovered until the next inspection begins. When this system is introduced, however, it is possible to prevent failures by making trend checks and analysis into the measured data from facilities to identify early signs of anomaly phenomena at an early stage.

(3) Auto-computation of remaining life

For the remaining life of a power transformer, switchgear, or such facility equipment, this system makes auto-computation once every day. Thanks to this function, labor hours for conventional routines by manual computation can be saved.

(4) Measures taken against lack of technical staff

Regarding the lack of young engineers due to the declining birthrate and retirement of skilled and well-experienced engineers who can make an accurate grasp of facility conditions through expertise, there are concerns on how to pass on such expertise to the up and coming generation. When this system is introduced, it is then possible to support favorable succession of techniques because the system can make quantitative data analysis so that the result of analysis can be used for visualization of facility conditions.

3 Facility Diagnosis for Power Transformers

Fig. 2 shows the monitoring and measuring of items for power transformers and Table 1 shows an example of deterioration phenomena found in oil-immersed transformers. Based on the result of past investigation into deterioration phenomena and abundant expertise we nurtured through many maintenance service businesses, we selected the basic monitoring and measuring items for power transformers, such as load current, insulation oil level, oil temperature, vibration of fans and pumps, ambient temperature, and Partial Discharges (PDs). The diagnostic functions cover transformer remaining life diagnosis, transformer condition diagnosis, and diagnosis for fans and pumps. Fig. 3 shows a transformer diagnostic screen.

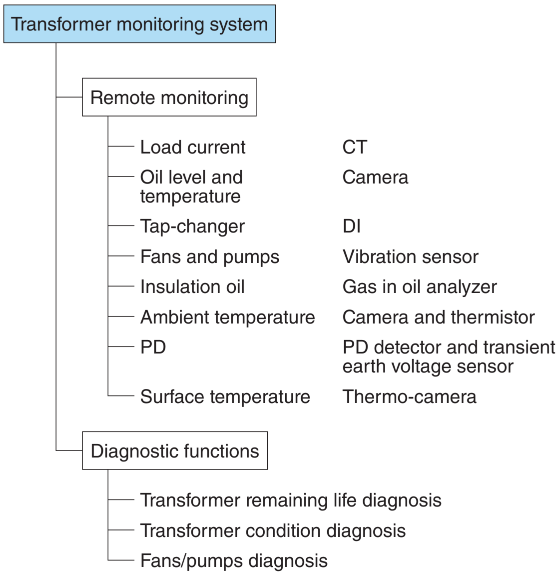

Fig. 2 **Monitoring and Measuring of Items for Power Transformers**

Monitoring and measuring of items for transformer facilities are shown.

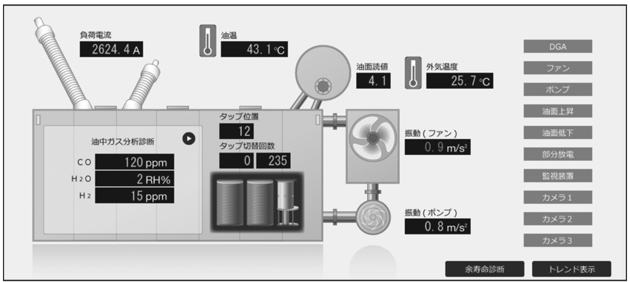

Fig. 3 **Transformer Diagnostic Screen**

Measured values and present status values monitored inside the transformer are displayed in detail.

3.1 Remaining Life Diagnosis for Power Transformers

Fig. 4 shows the remaining life diagnostic algorithm for power transformers. The remaining life is estimated in the comprehensive consideration of three kinds of data shown below.

(1) Operating conditions

Initial setting values are the years of operation, daily operating conditions (load factor), insulation oil temperature, various measured data and cooling system in installation area and environment, and oil deterioration inhibition system.

(2) Concentration

Measured values of carbon monoxide (CO) and carbon dioxide (CO_2) acquired by the in-oil gas analyzer.

(3) Result of furfural analysis

Furfural is a substance dissolved from an insulation oil caused by the decomposition of deterioration generated from cellulose molecules contained in insulation paper. Data is entered based on the result of oil sampling and composition analysis done at the time of yearly inspection.

3.2 Transformer Health Condition Judgment

The condition of a transformer interior can be checked only at the time of component analysis realized by oil sampling that is carried out during a yearly inspection, or in an overhaul inspection. In any event, conditions of deterioration can be confirmed only at the time of inspection done once a year. To attain a better solution, we devised to enable online gas analysis so that the inner condition can

Table 1 **Example of Deterioration Phenomena Found in Oil-Immersed Transformers**

Outlined phenomena caused by internal deterioration in transformer tank (outline of deteriorated parts, deterioration phenomena, and defects) are shown.

Classification	Part	Deterioration phenomena	Outlined defects
Cracks	Bushing	Generation of PD due to cracks around the shield in oil	Acetylene is generated due to the occurrence of feeble discharge caused by concentration of stresses around the rivet of mounting terminal of the shield in oil triggered by vibration during many years of use.
Quality change and destruction	Coil insulations	Insulation paper damage and insulation breakdown due to temperature rise in coils	Insulation paper is damaged as a result of secular deterioration in the vicinity of upper end lead-out of coils, and partial conduction is caused among parallel conductors.
Deformation	Insulation materials of coils	As a result of generation of repeated mechanical force, deformation and insulation breakdown are caused in insulation materials of coils.	Due to the repetition of external short-circuiting, buckling deformation is caused in tap coil insulation. This has led to insulation breakdown as a result of abrasion against neighboring coils.
Frictional wear	Oil transfer pump	Unusual sound is generated due to frictional wear caused around the bearings of the oil transfer pump.	Unusual sound is generated in the vicinity of the bearings of the oil transfer pump.
Quality change	Oil transfer pump	Insulation breakdown is caused due to thermal deterioration in the winding insulation shield of the oil transfer pump motor.	Pump motor is burned out due to insulation breakdown of the insulation varnish used for the windings of the oil transfer pump motor as a result of secular deterioration.

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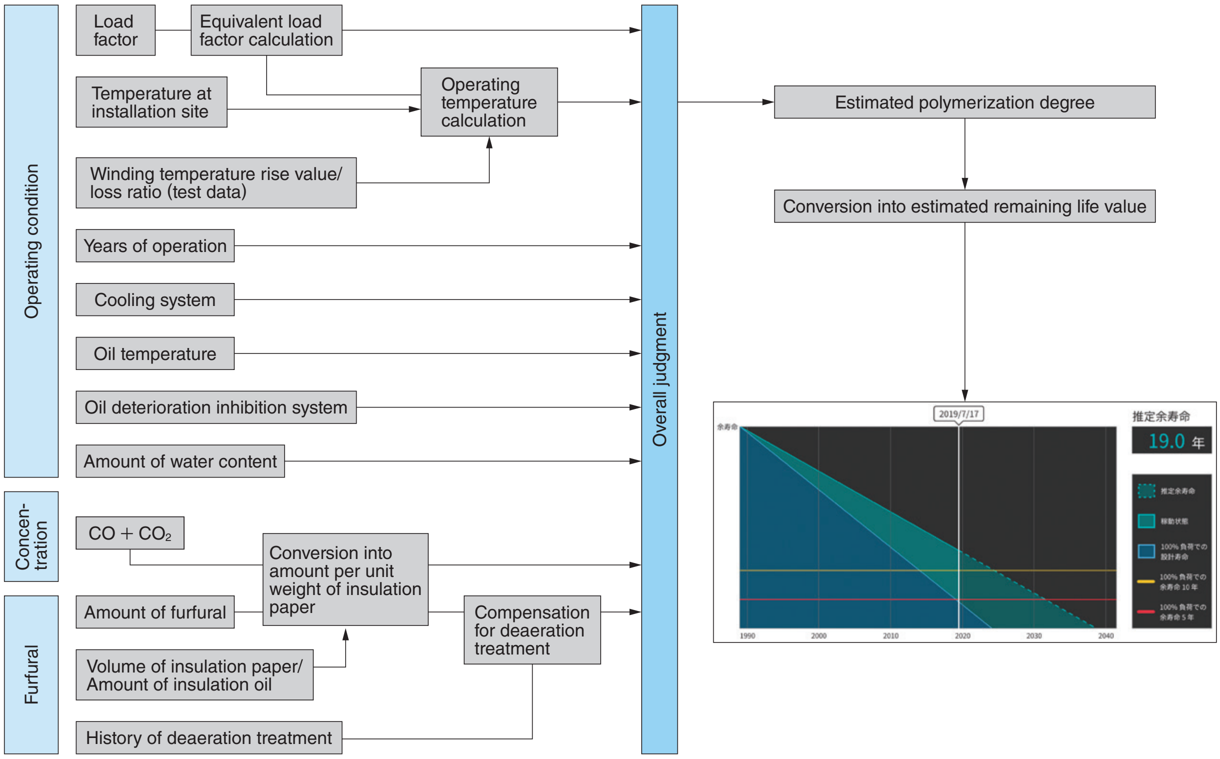

Fig. 4 **Remaining Life Diagnostic Algorithm for Power Transformers**

Various data like operating condition, gas concentration, and furfural are comprehensively examined for the estimation of deterioration status and remaining life diagnosis.

be presumed. Parameters effective to make health condition judgment are methane (CH_4), acetylene (C_2H_2), and ethylene (C_2H_4). With these parameters, it is possible to predict and detect a phenomenon (such as PD, thermal damage 〈700℃ or above〉) caused inside the transformer tank according to the content rate of each element. For this health condition judgment, we adopt the Duval Triangle (generally used for transformer health condition judgment) as shown in **Fig. 5**.

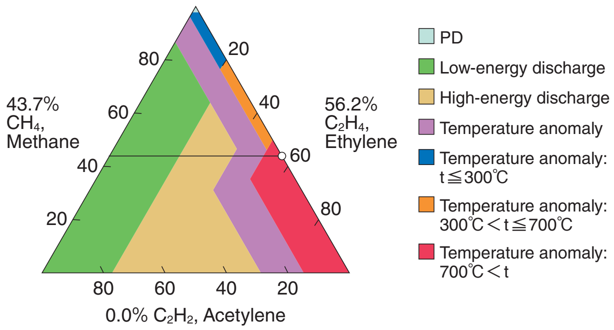

Fig. 5 **Transformer Health Condition Judgment (Duval Triangle)**

Transformer health condition judgment is shown based on composition ratio of gas-in-oil contents.

3.3 Remaining Life Assessment for Fans and Pumps

Cooling fans and oil transfer pumps are auxiliary machines for power transformers used to compose a cooling mechanism intended to remove heat generation from transformers. If these machines are out of order, transformer coils and insulations may be subject to deterioration or ignition due to heat generation. In such a case, we cannot help suspending the operation of transformers.

For diagnostic service for fans and pumps, vibration sensors are newly installed. When the vibration amplitude exceeds the specified limit level, the changing rate is calculated with the use of a moving average function based on the past data so that the period toward the occurrence of failure (remaining life) is estimated. **Fig. 6** shows a fan・pump remaining life diagnostic screen.

Since the cooling fans are duplicated, emergency stoppage does not occur even if a single fan should fail. In practical management, such a faulty fan may be replaced after the occurrence of a failure. If a fan failure can be predicted beforehand, however, it is possible to curtail the number of fans to be installed and this will lead to compact transformer design.

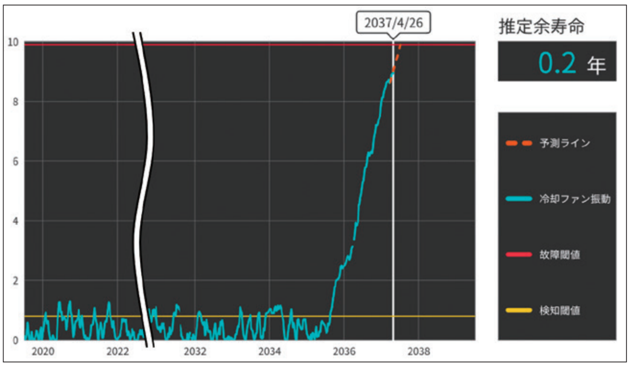

Fig. 6 Fan・Pump Remaining Life Diagnostic Screen

The estimated remaining life of fans and pumps is shown.

- Switchgear monitoring system
  - Remote monitoring
    - No. of VCB operations — Camera
    - Gas leakage — Gas concentration sensor/camera
    - Pole motion time — CT・DI
    - VI vacuum degree — VM sensor
    - Ambient temperature — Thermistor
    - PD — PD detector, transient earth voltage sensor
    - Terminal looseness — Thermo-camera
  - Diagnostic functions
    - Detection of gas leakage sign
    - Trend monitoring for VCB pole motion time

Fig. 7 Monitoring and Measuring Items for Switchgears

Monitoring and measuring items for switchgears for switchgear diagnosis.

4 Facility Diagnosis for Switchgears

The judgment standard for switchgear maintenance is based on the frequency of circuit breaker operations. For this reason, a counter readout is recorded at the time of periodic inspection. In this system, pole open/close timing is measured each time the circuit breaker functions. Based on trends of this operation timing, the state of deterioration is identified. The pole on-off operation timing can be measured in the unit of 0.1 ms based on the period from the motor starting current to the occurrence of change in the behavior of the contact points. Fig. 7 shows monitoring and measuring items for switchgears. For remote monitoring items, the number of circuit breaker operations, PD, gas leakage, and vacuum degree of Vacuum Interrupter (VI) are selected. For diagnostic functions, the detection of forerunning gas leakage and trend monitoring of Vacuum Circuit-Breaker (VCB) pole open/close timing can be itemized.

Fig. 8 shows a VCB diagnostic screen. Each time the VCB operates, the pole open/close timing is numerically displayed. Based on the accumulated data, trend graphs can be displayed.

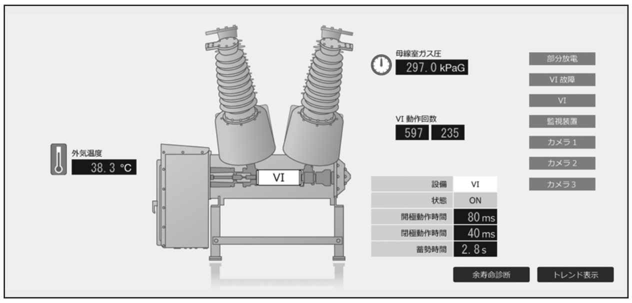

Fig. 8 VCB Diagnostic Screen

The present status of the measured values monitored in a VCB is shown in detail.

Fig. 9 Substation Equipment Monitor Unit

A monitoring and data-gathering unit is shown. It handles various sensor data acquired from power transformers and switchgears.

5 Sensor Terminals

5.1 Monitoring Equipment for Power Receiving and Substation Facilities

Fig. 9 shows an external appearance of substation equipment monitor unit. This unit monitors and gathers various sensor data of power transformers, switchgears, and high-tension panels. Signal inputs from this unit are processed and the collected data are managed on the cloud, relating them to the operating time from "ON" time of EDS/ES and VCB closure control current/trip control cur-

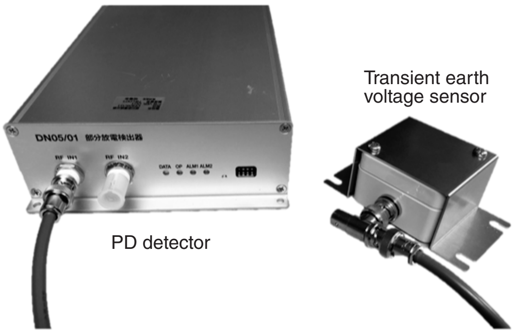

Fig. 10 PD Detector (TEV Sensor)

The unit shown is used to detect a PD that is an early sign anomaly phenomenon of insulation breakdown.

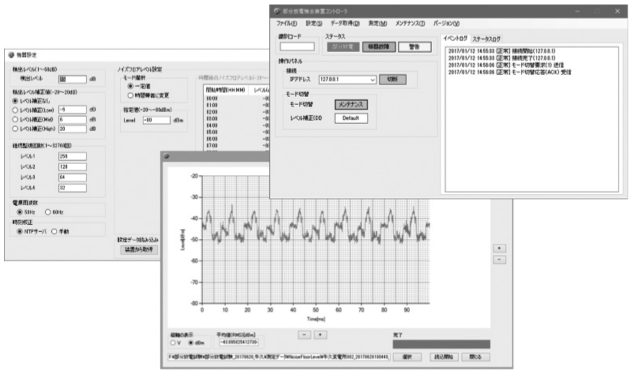

Fig. 11 Controller Screen of the PD Detector

These screens are used for background noise measurement, PD detection level setting, and waveform acquisition.

rent up to the completion of contact operation, plus the ON/OFF status of contact points, so that these data can be used for remaining life diagnosis of facility deterioration. Major data to be monitored and collected are composed of items such as PD, insulation oil temperature, vibration of fans and pumps, and tap-changing positions in the case of power transformers, and PD, contact point parting time, pole open/close timing, power charging time, and gas pressure for switchgears. By making a setup change, equipment to be monitored (transformer or switchgear) can be chosen. The overall size of this unit is W80 × H220 × D132 mm so that the unit can be installed in substation equipment by the retrofit.

5.2 PD Detector

For insulation deterioration diagnosis of power equipment, the detection of PD is effective because PD is an early sign of anomaly phenomenon leading to insulation breakdown. PD can be detected by monitoring the behavior of C_2H_2 gas, but accuracy is low. As such, we developed an exclusive PD detector where a Transient Earth Voltage (TEV) sensor is used. Fig. 10 shows the PD detector (TEV sensor). This sensor is capable of noise removal and periodicity judgment of a high-frequency current that flows along the surface of the apparatus. By doing so, PD is detected. This device is useful for static type substation equipment such as power transformers, switchgears, and high-tension panels. Its features are as follows:

(1) A TEV sensor is adopted.
(2) It is provided with a background noise measuring function.
(3) The PD detection level can be arbitrarily set on customer side.
(4) The PD detection periodicity can be identified with the aid of software. (Periodic continuity can be set on the customer side.)
(5) The device is provided with waveform acquiring function and Fast Fourier Transform (FFT) analyzing function.
(6) Irrespective of substation equipment manufacturer, retrofit installation is possible. (Size: W150 × H52.5 × D226 mm)

Fig. 11 shows a controller screen of the PD detector.

6 Postscript

This paper introduced our activities about facility diagnosis of oil-immersed power transformers and switchgears. For maintenance and inspection jobs for power receiving and substation facilities, by using our diagnostic technologies, it can realize more labor saving and advanced level service and can support facility management works in terms of facility renovation planning.

Going forward, we will continue to develop new sensors and improve accuracies of remaining life diagnosis through the AI analysis based on the monitored data accumulated in the past. Also, at the same time, we will expand the application of monitoring objects to molded transformers and other power conversion equipment. In doing so, we would like to establish more elaborated facility diagnosis technologies.