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Sensor-based non-intrusive condition monitoring technologies for GIS/GCB

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SUMMARY

Non-intrusive monitoring of partial discharge (PD) in gas-insulated switchgear (GIS) taking advantage of a PD coupler and identification technology to determine the PD location is presented.

Dielectric capability in GIS can be assessed by monitoring electromagnetic waves caused by PD inside GIS enclosures. Antenna based PD couplers are practical means to measure the electromagnetic wave which represents the PD signal. They are mounted on the exterior of the GIS without affecting GIS operation. High sensitivity is required because of the need to detect attenuated electromagnetic waves coming out from inside the enclosure through insulators such as insulating spacers.

A PD source can be located by time of flight methodology using PD couplers. The online PD monitoring system can identify the location of the PD with resolution of 0.3 m by software calculating the difference of the timing of the PD signals detected by the PD couplers.

Non-intrusive monitoring of discharge in dead-tank gas circuit breaker (GCB) is also discussed. Key technology to monitor and detect PD such as the PD coupler and the identification of PD location can be applied. Detection of discharge such as prestrike or re-ignition inside GCB and identification of location of discharge can help the assessment of its performance especially for the EHV GCB where two-break interrupters are often applied.

KEYWORDS

High voltage equipment, Maintenance, Switchgear, Non-intrusive condition monitoring, Antenna, Sensor, Partial discharge

1. Introduction

Monitoring of partial discharge (PD) and location technology for PD is presented along with monitoring of discharge in dead-tank circuit breakers (GCB).

Monitoring of PD inside gas insulated switchgear (GIS) is essential to assess insulation defects in GIS. The use of antenna based couplers is one of the practical means to measure the electromagnetic waves caused by PD signals. The couplers are mounted on the external side of the GIS without affecting GIS operation. High sensitivity is required because of the need to detect attenuated electromagnetic waves coming from inside the metallic enclosure through the insulators. The location of the PD can be identified considering the time difference of PD signals detected by PD couplers. The online PD monitoring system can identify the location of the PD with a resolution of 0.3 m by software calculating from the time of flight method by the PD coupler.

Key technology to monitor and detect PD such as PD coupler and the identification of PD location can be applied to monitoring of discharge in dead-tank gas circuit breaker (GCB) to assess its performance.

2. PD monitoring in GIS

Electromagnetic waves, vibration, light emission and decomposed SF_6 gas can be observed due to PD in a GIS tank. The measurement of electromagnetic waves is the most sensitive method for PD detection. Either internal or external PD couplers can be used to detect electromagnetic waves.

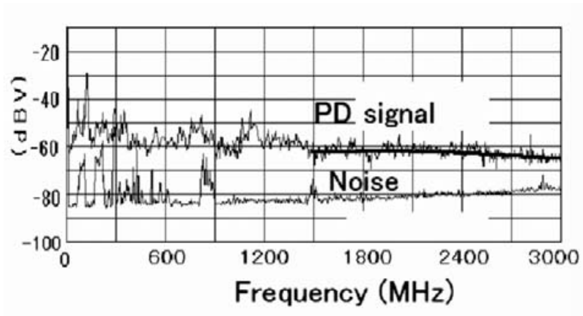

Figure 1 Spectra of electromagnetic waves of PD radiated from insulating spacer

2.1 Electromagnetic wave detection

Electromagnetic waves generated by PD in SF_6 gas has a spread in frequency higher than 1 GHz. Figure 1 shows the measured spectrum of the electromagnetic wave emitted from a needle artificially attached on the conductor surface in a 275 kV GIS[1]. Both the PD signal and noise are constant between 1.5 and 3 GHz where no remarkable resonance frequency due to the GIS structure is observed, and the noise level is more than 10 dB lower than the PD signal. The results show that electromagnetic wave detection with a frequency band higher than 1.5 GHz can achieve a high S/N ratio.

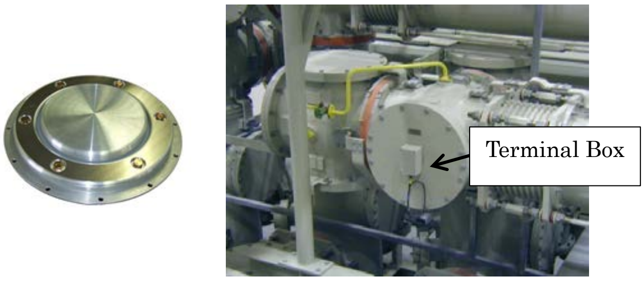

Figure 2 Internal PD coupler and terminal box

Two types of PD couplers are applied to electromagnetic wave detection. Internal PD couplers are mounted in the GIS with their output derived through a terminal box. Figure 2 shows an outline view of

Figure 3 External PD coupler

internal PD couplers and a terminal box behind which the PD coupler is mounted.

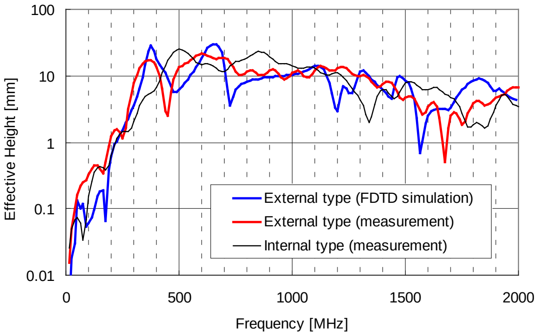

Figure 4 Analytical and experimental results of sensitivity characteristics

External PD couplers are introduced to detect the electromagnetic PD waves radiating from the insulating spacer between the metallic flanges of GIS[2]. Figure 3 shows an external PD coupler mounted on the external side of the insulator. Since the sensitivity of external PD couplers are generally lower than internal PD couplers, polarized electromagnetic wave characteristics were considered to obtain the same sensitivity as an internal PD coupler with an external coupler. Electromagnetic waves transmitted through a metallic aperture such as a slot have a uniform plane of polarization. This enables high sensitivity on the detection of PD because no polarization effect is observed on noises. Figure 4 shows the effective height of the sensitivity according to the frequency of the electromagnetic wave analyzed and measured on external PD coupler and compared with the measurement on internal PD coupler. Measurement results agree well with the analysis on external PD couplers and sensitivity comparable to internal PD coupler can be obtained for the frequency range higher than 500 MHz.

Non-intrusive monitoring of PD came to have ability for detection same as internal PD coupler.

2.2 Portable PDM

(a) Base unit and PC (b) Handheld units

Figure 5 Portable partial discharge monitoring system

A portable partial discharge monitoring system (PDM) is one piece of non-intrusive equipment needed to detect PD. Figure 5 shows a photograph of a base unit and handheld units for a portable monitoring system. A handheld unit detects electromagnetic waves with external antenna. When a handheld unit detects a PD signal, LEDs mounted on the handheld unit illuminate depending on the strength of the PD signal detected. It is connected with a base unit to transfer the measured data to a laptop PC for detailed analysis. PD signals measured with voltage waveform is displayed on the laptop PC, and the assumed factor causing PD is evaluated. One of the two handheld units supports acoustic emission (AE) detection using an AE sensor. Detection of acoustic emission is another diagnosis method of PD.

Each handheld unit is operated by battery and its weight is as low as 600g. Its portability enables efficient diagnosis without taking time to set up for the measurement such as connection of power cables.

3. Identification of location of PD in GIS

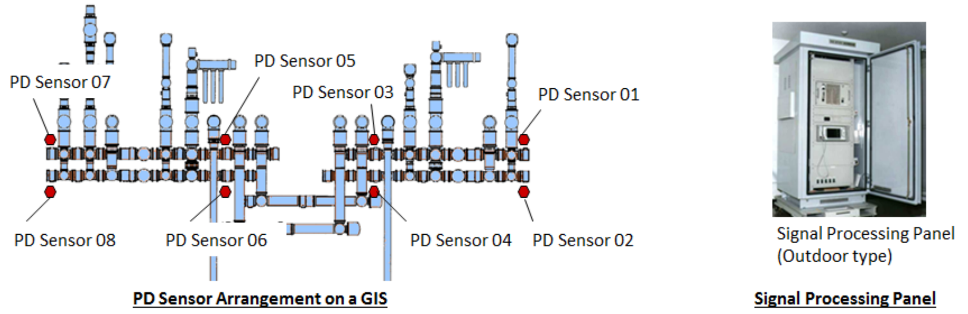

Figure 6 Online partial dischage monitoring and diagnosis system

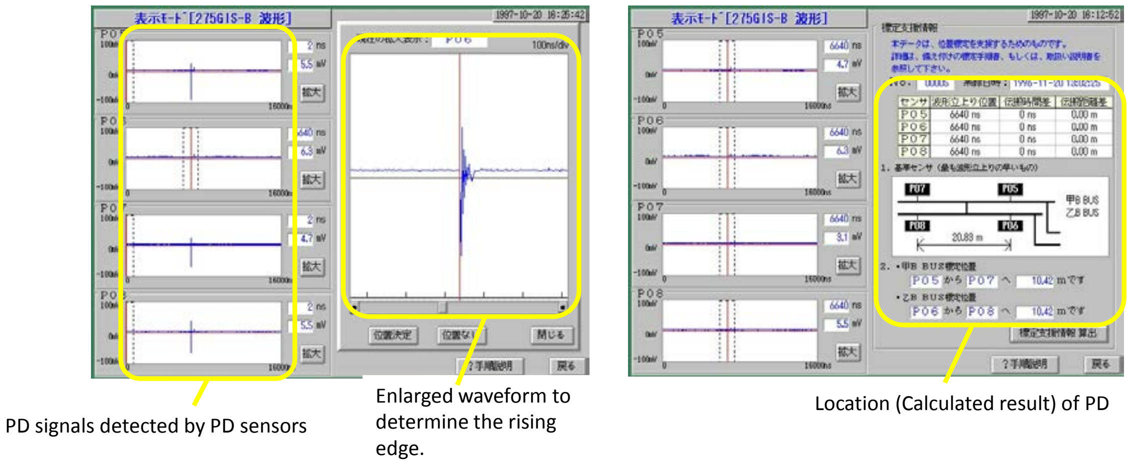

Figure 7 Screenshot of the HMI display for partial dischage location

Online PD monitoring system can identify the location of origin of the PD in a GIS. Figure 6 shows the PD coupler and signal processing panel for an online PD monitoring system. Both internal and external PD couplers can be applied. The signal processing panel can collect PD signals detected by multiple PD couplers.

PD signal data collected in the signal processing panel can be displayed with the HMI software for identification of PD location. Figure 7 shows a screenshot of the HMI display. PD signals detected by the couplers are displayed and each waveform can be enlarged on the display to determine the rising edge of the PD signal. Once the rising edge of each PD signal is determined, the location of the PD is calculated and its distance from each PD coupler is displayed.

Location of PD is calculated with the time difference of electromagnetic wave signals detected by each PD coupler. Figure 8 shows the principle

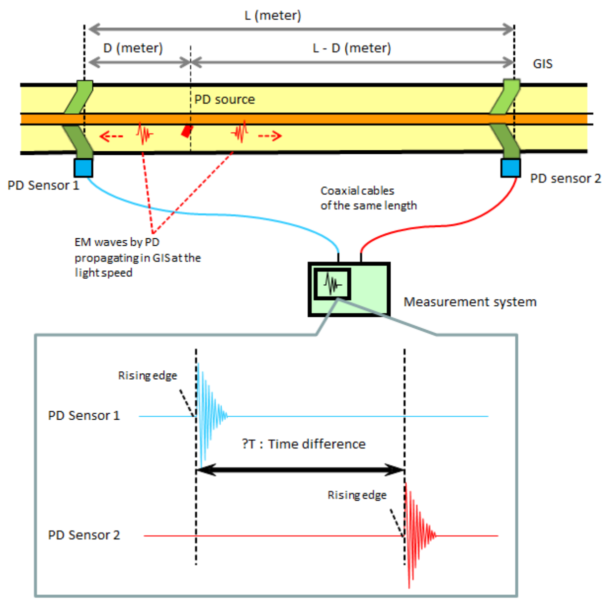

Figure 8 Principle of PD location

of PD location. Since the electromagnetic wave caused by PD propagates in GIS with the speed of light, distance of the PD, D, from the PD coupler detecting the earliest rising edge of the PD signal is calculated with the following formula:

$$D = \frac{L - \Delta T \cdot V_{PD}}{2}$$

$$V_{PD} \approx 3.0 \times 10^{8} [\mathrm{m/s}]$$

where L and ΔT is the distance and time difference between the two PD coupler respectively, with a resolution of 0.3 m.

4. Application to detection of discharge in dead tank gas circuit breaker (GCB)

Detection of discharge by prestrike or restrike in the interrupter and the identification of its location can help the assessment of the performance of the gas circuit breaker. Key technology to detect the electromagnetic waves generated by discharge and identify their location in the GCB was studied and presented for live tank GCBs[4]. The concept can also be applied to dead tank GCBs under specific considerations in the location of the sensors.

4.1 Detection of electromagnetic wave outside GCB

Electromagnetic waves caused by the discharge inside a dead tank GCB radiates from the bushing insulator. The bushing conductor acts as a monopole antenna and the electromagnetic wave propagates especially with frequencies having wave lengths of 2 or 4 times the bushing insulator length. On the other hand, electromagnetic waves with frequencies higher than 100 MHz propagate with constant attenuation of the strength of the signal source inside GCB enclosure regardless of its frequency[3]. Figure 9 shows an experimental setup of the measurement of electromagnetic waves generated by the discharge inside a GCB and radiated from the bushing. Figure 10 shows the attenuation of the electromagnetic wave measured at 5 locations in the vicinity of the bushing insulator as shown in Figure 9 based on the magnitude measured inside the enclosure of GCB. Since the length of the bushing conductor facing the internal surface of the bushing insulator is 2.2 m, high magnitude of the spectrum is observed when the frequency is 35 MHz and 70 MHz whose half and quarter wave length is 2.2 m. Attenuation was measured for frequencies higher than 140MHz and constant attenuation of -10 dB is observed at all locations of measurement. In the case of a large discharge, such as a restrike or pre-arcing, occurs inside the gas circuit breaker, a discharge signal is expected to be detected when high sensitivity PD coupler is mounted on the ground which is several meters distant from the bushing of the circuit breaker.

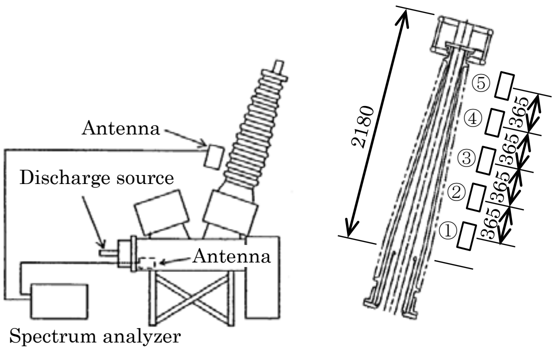

Figure 9 Excperimental set-up and measurement point for electromagnetic wave

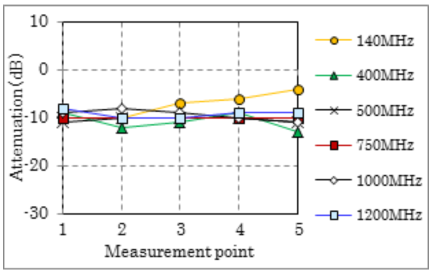

Figure 10 Magnitude of the spctrum at each measurement point

4.2 Identification of discharge location in GCB

Basic principle of identification of discharge location is by measurement of the time difference of electromagnetic waves detected by three antennas[4]. In the case of the application to dead tank GCBs, electromagnetic waves are radiated through bushings not directly from GCB poles, therefore, at least four antennas would be necessary as shown in Figure 11 to apply the concept above, which is studied for live tank GCBs without any restrictions to radiation of electromagnetic waves. The location and number of antenna is specifically determined for each application by dimensions of the GCB and restrictions on antenna location.

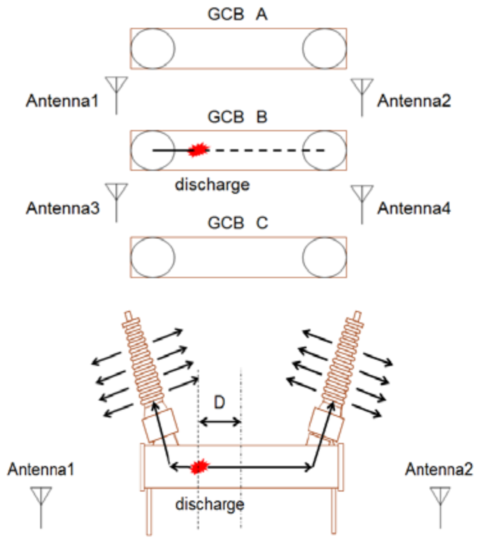

Figure 11 Location of four antennas for dead tank GCB

5. Conclusion

Antenna technology applied to non-intrusive monitoring of PD and the identification technology of discharge location in GIS is presented, and the basic concept of non-intrusive detection of discharge inside dead tank GCBs using antenna technology is discussed.

- Two methods of PD detection methods are presented. UHF detection of electromagnetic wave radiating from the insulating spacer using PD coupler is an effective means for monitoring of PD in GIS.
- Sensitivity of external PD coupler can be also comparable with internal PD coupler when polarized electromagnetic PD waves radiating from the insulating spacer between the metallic flanges of GIS is considered.
- Location of PD can be identified when the PD is monitored continuously with an online system. It can be calculated with time difference for the electromagnetic wave to reach two antennas.
- Non-intrusive detection and identification of location of the discharge in live tank GCBs can be extended to dead tank GCBs with specific considerations. Number and location of the antenna and utilization of the detected discharge data should be investigated further.

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