The Application of Partial Discharge Measurement and Location on CGIS

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Abstract: While the demand of electric power increases and the installation space of power equipment is fixed in a factory, the cubical gas insulated switchgear (CGIS) is gradually applied to medium voltage system due to its small size and easy maintenance. However, it also takes longer time for the repair of CGIS accident. Therefore, the preventive maintenance (PDM) is very important and the most effective method is partial discharge measurement. Unfortunately, the metal-cladded GIS usually make PDM inconvenient, especially for the partial discharge location. This paper provides a fast and easy method for the location of partial discharge in GIS, it can locate the defect quickly and effectively, and the related strategy can be made in advance.

Keywords: partial discharge measurement, cubical gas insulated switchgear, partial discharge location.

1. Introduction

Gas insulated switchgear (GIS) is applied worldwide in extra-high-voltage (EHV) system due to its small size, good insulation ability, high safety, and easy maintenance. In last decades, due to the highly growing of power demand and the limited space in a semiconductor factory, a cubical gas insulated switchgear (CGIS) is developed to meet the requirement of high electric power demand density in medium voltage (MV) system. Like GIS, the CGIS costs longer duration for repair, and it means that longer planned outage period is required. Hence, the prevention maintenance (PM) of CGIS is very important.

Now a day, partial discharge measurement (PDM) is an effective insulation diagnostics in many fields, and on-line PDM on GIS is also broadly adopted for routine test. Since all live parts of CGIS is in the grounded matel enclosure without spacers and hatches, which are both available for GIS, there is no accessible measuring points for the installation of partial discharge (PD) sensors. Therefore, there is a difficulty of on-line PDM on CGIS. For some customers having test socket for connecting CGIS to the testing leads, off-line PDM is an alternative method. For the customers having no such test sockets, the cable terminals are replaced by test terminals for off-line PDM. Both aforementioned conditions require planned outage, and the PDM becomes low cost-effective. This paper presents a novel method for on-line PDM on CGIS, which takes the cable terminals as an capacitive coupler to measure the PD signals (PDs).

Once the on-line PDM on CGIS shows PDs inside the CGIS, the next step is to locate the PDs. Unlike GIS having many measuring points to locate PDs [1], only few measuring points of CGIS can be used for PD location, and the background noise level in MV system is usually high. Therefore, it is hard to identify the wavefront of PDs in the environment with high background noise level, and the PD location via the time flying method is impractical for PD location. This paper leads the correlation coefficient into the calculation of PD location via time flying method, and the PD location of CGIS becomes practicable.

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A real CGIS with PDs is illustrated as example to show on-line PDM on CGIS and PD location by the method addressed in this paper. The measured result shows that on-line PDM on CGIS is practicable and the accuracy of PD location is also good. This will help the field engineer to make relative strategy in advance and the impact of repair of CGIS is also minimized.

2. On-line PDM

According to IEC 62271-203 [2], the PDM on GIS should be done to detect the possible material and manufacturing defects in advance. However, according to IEC 60270 [3], the method of PDM is a kind of off-line test and suits to the routine test and acceptance test in the manufactory. Due to the high level of background noise in MV system and the complex preliminary arrangements for the on-site off-line PDM on CGIS, the off-line PDM on CGIS becomes impractical for PM. In order to overcome such issues, this paper utilizes the capacitive voltage indicators and cable terminals, which are treated as capacitor, to coupling PDs, and the measuring frequency band is raised to ultra-high-frequency (UHF) to minimize the interference of background noise.

A. Methodology

Figure 1 shows the concept of PD propagation via the cable terminal. Once PDs are initiated by the defects insides CGIS, the PD pulse current travels along the conductor toward ground wire, and induces the transient disturbance of magnetic field. As indicated in Figure 1, cable terminal forms a capacitive path for PDs to pass through toward ground, and the PD sensor is attached to the ground wire.

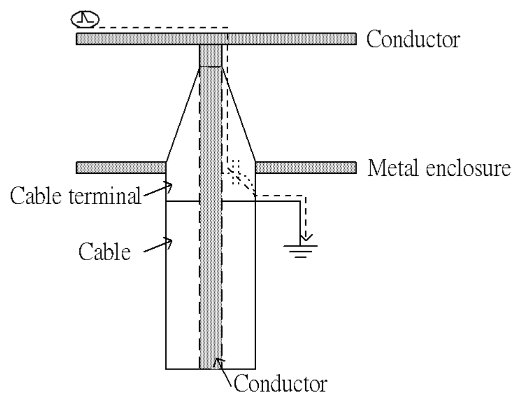


Figure 1. PDs propagation via cable terminal

B. Measuring frequency band

In MV system, because of the various types of loads, the background noise level is usually high, and makes the on-line PDM hard to be executed. Figure 3 shows the common background noise measured in MV substations in semiconductor manufactories [4]. The distribution of background noise disperses too wide to be filtered out by band rejection filter. Encountering such condition, the UHF PD sensor is used to raise the measuring frequency band to avoid the interference of background noise. Figure 4 shows a proper selection of measuring frequency band can increase signal to noise ratio (SNR) [4], and the on-line PDM becomes practical.

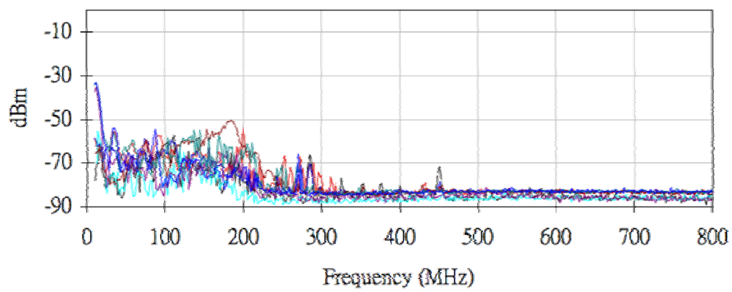


Figure 3. Background noises measured at MV substations in semiconductor manufactories

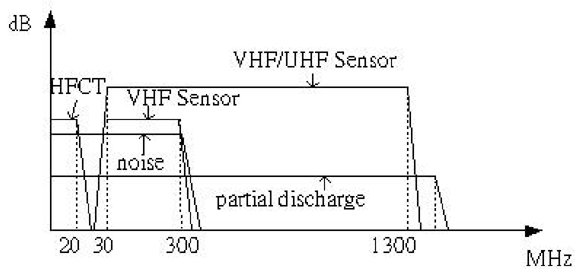


Figure 4. Spectrums of signals and PD sensors

3. PD location

Because of all accessories being enclosed in metal enclosure of the CGIS, the PD location is required to point out where the defect is. This paper applies time flying method on PD location. Unfortunately, the accuracy of this method is easily affected by the high background noise due to the distorted waveform. Therefore, this paper leads correlation coefficient to calculate PD location to enhance the accuracy.

A. Methodology

Figure 5 shows the diagram of time flying method. As indicated in Figure 5, the known variables are section length (L) and the difference between arriving time of PDs, and there are two unknown variables: propagation velocity (v) and the location of PD (x), and it means that two different equations are required at least.

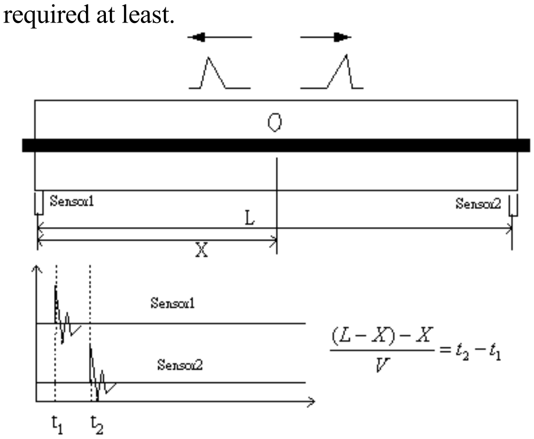


Figure 5. Diagram of time flying method

Fortunately, there are usually several feeders of a CGIS, and the amount of measuring points is enough for calculation of PD location. In CGIS, the calculation of PD location will be different according to the position of PDs, and the all possible PD positions should be checked.

PDs at the busbar

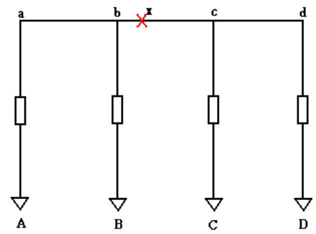


Figure 6. PDs at busbar

Assuming that PDs locate at the busbar section bc, and is “x” away from node b as shown in Figure 6. The measuring points are at nodes A, B, C, and D, and the relative time delay is Δt_{AB}, Δt_{CB}, Δt_{DB}. Because the parts of CGIS are modular, the length of busbars (ab, bc, cd) are supposed to be equal to each other. The propagation velocity (μ_{bus}) of PDs in busbar can be calculated by (2), and then the distance bx can be calculated by (3).

$$ab = \frac{\mu_{bus}}{\Delta t_{AB}} \tag{2}$$

$$bx = \frac{ab}{2}\left(1 - \frac{\Delta t_{CB}}{\Delta t_{AB}}\right) \tag{3}$$

where μ_{bus} is propagation velocity of signal in the busbar, ab is the length of busbar section ab, and bx are the distance between PDs and node b.

PDs at the branch

Assuming that PDs locate at the branch Bb, and is “x” away from node b as shown in Figure 7. The measuring points are at nodes A, B, C, and D, and the relative time delay is Δt_{AB}, Δt_{CB}, Δt_{DB}. Because the parts of CGIS are modular, the length of busbars (ab, bc, cd) are supposed to be equal to each other. Because the branch is also busbar type of conductor, the propagation velocity of PDs in busbar and in branch are assumed to be the same (μ_{bus}). The relative distance and the time difference are shown in (4) and (5).

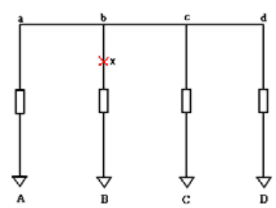


Figure 7. PDs at branch

$$ab + 2bx = \mu_{bus} \times \Delta t_{AB} \tag{4}$$

$$2ab + 2bx = \mu_{bus} \times \Delta t_{DB} \tag{5}$$

where μ_{bus} is propagation velocity of signal in the busbar, ab is the length of busbar section ab, and bx are the distance between PDs and node b in sequence.

By solving (4) and (5), the PD location can be calculated according to (6).

$$bx = (\frac{ab}{2})(\frac{\Delta t_{AB}}{\Delta t_{DB} - \Delta t_{AB}} - 1) \quad (6)$$

B. Correlation coefficient

The calculation of PD location via time flying method requires the time difference between arriving time of PDs, and time difference is usually calculated by rise time or fall time to judge the time delay. However, in MV system, the waveform of PDs is usually distorted by the background noise, and the accuracy of time delay is hence insufficient. In order to get higher accuracy of time delay, the correlation coefficient is adopted.

Correlation coefficient (ρ_{xy}) means the degree of signal's similarity, and can be get by (7).

$$\rho_{X,Y} = \frac{E[(X - E[X])(Y - E[Y])]}{\sigma_X \sigma_Y} \quad (7)$$

where E[·] denotes expectation, and σ_X and σ_Y are standard deviation of signals X and Y, respectively.

Assuming the PDs measured at node A and node B are $X_A(t)$ and $X_B(t)$, the time delay (k) of these signals is defined that $\rho_{xy}(k)$ will be maximum as shown in (8)

$$\rho_{xy}(k) = \frac{E[(X(t) - E[X(t)])(Y(t+k) - E[Y(t+k)])]}{\sigma_x \sigma_y}$$

4. Field Measurement

The on-line Partial Discharge Measurement (PDM) on the 24 kV CGIS is done by attaching TM (Transient Magnetic) sensor to ground parts of cable terminals of CGIS or by connecting the test leads to the voltage indicator of CGIS as shown in red lines in Figure 7.

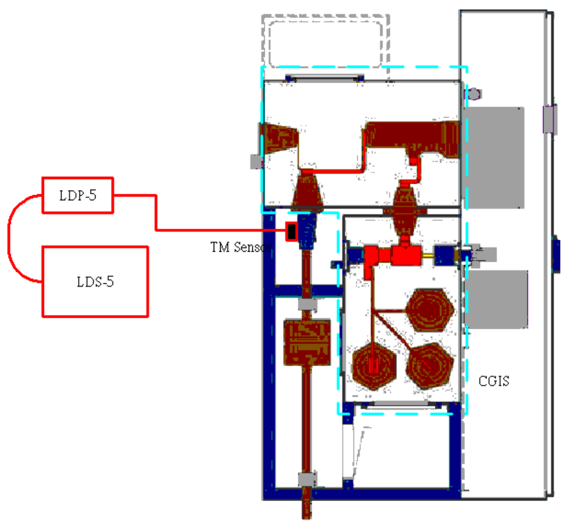


Figure 7. Diagram of on-site off-line/on-line PDM

A. On-line PDM

During periodic on-line PDM on CGIS, the phase-resolve patterns of PDs are shown in Figure 8, and the readings of R and T phases were 70 pC and 26 pC respectively. There was no PD activities detected in S phase.

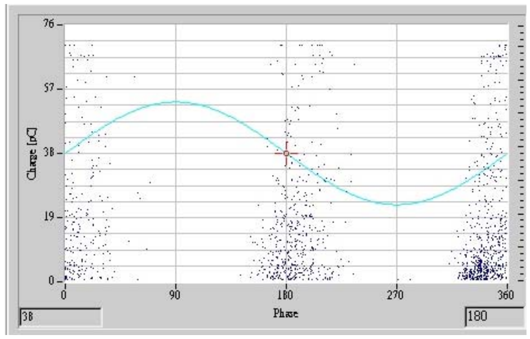


Figure 8. Phase-resolved patterns of CGIS

Moreover, the most frequency components of measured PDs were below 100 MHz that was classified as low risk signals based on authors' experience.

B. PD location

The configuration of the CGIS under investigation is shown in Figure 9, and the measurement points A, B, C, and D were at feeder 426, 425, 424, and 423 in respective. However, feeder 424 was not energized and no measurement was taken at that C point.

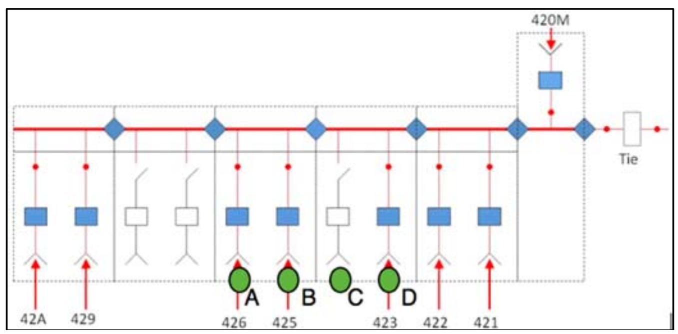
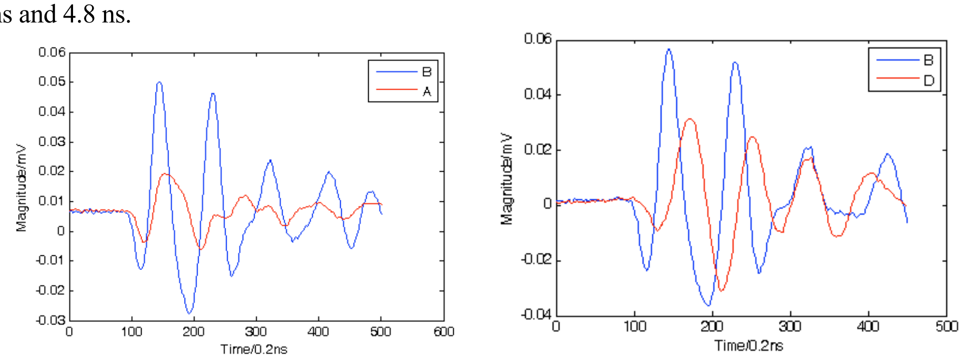


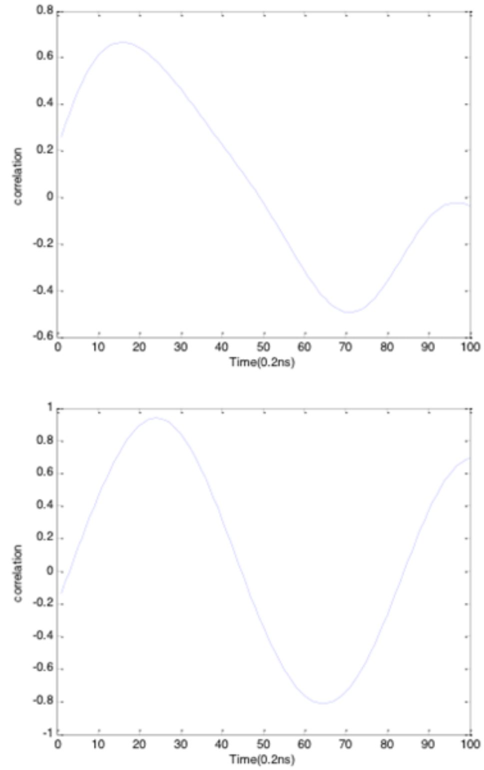
Figure 9. Configuration of interested CGIS feeder

The waveforms of PDs at node A, node B, and node D were measured by Lecroy Wavefunner 64 xi with 5 GS/s, and are shown in Figure 10. The calculation results of correlation coefficient are shown in Figure 11. The calculation results of Δt_{AB} and Δt_{DB} are 3.2 ns and 4.8 ns.



(a) waveforms at A/B points (b) waveforms at B/D points

Figure 10. Time difference measurement



(a) A/B (b) B/D

Figure 11. Correlation coefficient

If PD locates at busbar (suspect A), the propagation velocity is 125 ms/us (40 cm/3.2 ns), and bx is 10 cm (125 m/us x (3.2 ns – 1.6 ns)/2). Therefore, the calculated PD location was at the right side of node “b” and 10cm away from it, which is at the middle position between 425 and 424.

If PD locates at branch (suspect B), bx is 20 cm ((40 cm/2) x (3.2 ns/(4.8 ns – 3.2 ns) -1). This implies that PD source location is at the branch 20cm away from node ”b”

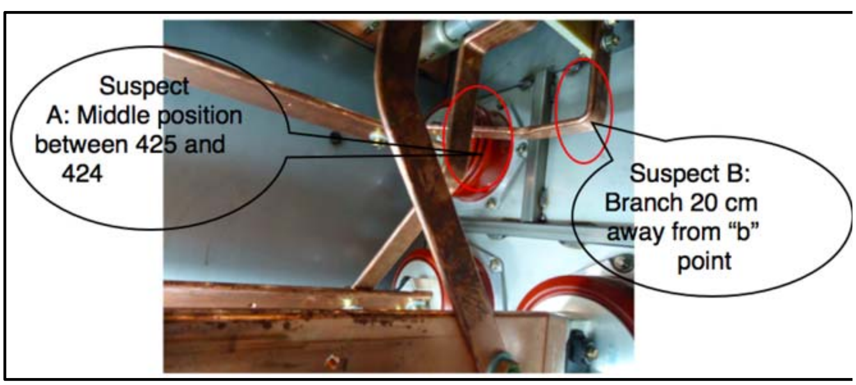


Figure 12. Suspected PD source location

Figure 12 shows the suspects of PDs. Due to the simple structure of the branch, it is less chance to have PDs and suspect B is supposed not to be the PD source. The suspect A is the busbar socket and is assembled in field.

C. Repair

Figure 13 is the busbar socket located by PDM, and there is some pollutants. After the replacement of busbar socket and insulating sleeve, the CGIS was re-energized in duration of 30 minutes. An alternative on-line PDM was carried out though the coupling capacitor and a 10 MHz high-pass filter, and the result was shown in Figure 14, which indicted that no PD activity existed. Hence the replacement of busbar socket was thought to be successful.

Figure 13 busbar socket with pollutants

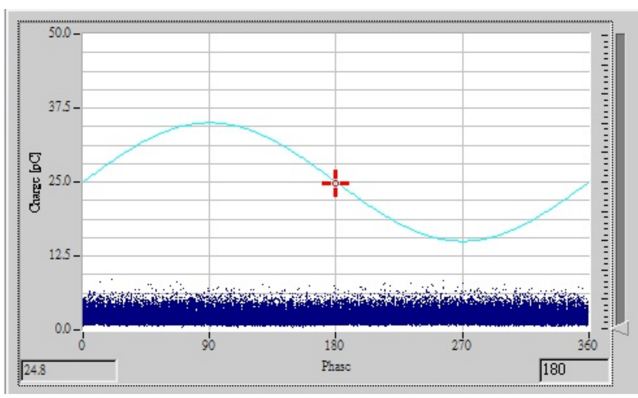


Figure 14. Phase-resolved pattern of on-line PDM on CGIS

5. Conclusion

This paper deal the method for PD source location in the MV GIS. For unknown propagation velocity of GIS, for getting the PD source location, it is necessary to assume the bus and branch are the same. The PD source location and the propagation velocity can be calculated with the width of GIS and the measurement of any three accurate data.

When the PD signals are distorted by background noise, the time difference between the peaks of waveforms or the zero crossing of the waveforms can not be calculated accurately. Hence, this paper leads in the correlation coefficient to improve the accuracy of time delay calculation. The advantages of the correlation coefficience are the simple argorithm and easy implementation, and is suitable for the time delay calculation.

According to the field experiences, on-line PDM on CGIS is an effective PM for insualtion diagnostic. As combining with PD location, the repair cost and the outage time could be reduced.

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