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# Simulation Analysis on the Propagation Characteristics of Electromagnetic Wave for Gis Partial Discharge

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**Abstract:** Gas Insulated Substations (GIS) has been commonly used in global power grids presently. However, deterioration of insulators due to some disadvantages will cause Partial Discharge (PD) in the insulation and then reduce GIS reliability, even make it shut down. UHF (ultra high frequency) has been actively studied and well known as an advanced insulation diagnosis method in GIS. In this paper, UHF method for partial discharge monitoring is discussed and the investigation of Electromagnetic (EM) wave propagation inside the GIS is analyzed in great detail. Moreover, based on Finite-diffrenee Time-domain Algorithm (FDTD), the electromagnetic waves by UHF detection technology are simulated and some significant conclusions are drawn also.

**Key words:** GIS, PD detection, UHF method, FDTD algorithm, simulation

## INTRODUCTION

GAS Insulated Switchgear (GIS) is an equipment filled with SF6 gas, an excellent insulator which has been increasingly used in electric power transmission networks because of its high reliability and compactness. However, for the complex structure, manufacture and maintenance technologies and the integrated way to install of various equipments, will cause Partial Discharge (PD) in the insulation (Achatz *et al*., 2005). And also if any impurity exists inside GIS, such as a metallic particle, will make the intensity of the electric field increase locally, then cause PD.In the worst case, serious PD will make

GIS shut down then lead to serious consequence in the power system.

It is an important issue that requiresmonitoring for safe and reliable GIS operation. To detect PD, many studies have been done on the PD deterioration process and phenomena, such as Electromagnetic (EM) waves, ultrasonic waves, light and decomposed gas generated in association with PD. At present, PD monitoring using an Ultra-high-frequency (UHF) technique is effective for evaluating insulation performance and is widely used in insulation aging diagnostics for power apparatuses. In this paper, the basic principle of the UHF method for PD is introduced firstly, then the PD signal diagrams based on the measured signals are analyzed and the different characteristics of the different defects in the PD signals diagram are given. Finally, Finite-diffrenee Time-domain (FDTD) algorithm is used for simulation of the electromagnetic waves in GIS partial discharge and some relevant conclusions are drawn (Ueta *et al.,* 2012).

## UHF METHOD FOR PD DETECTIN

The UHF method have been extensively and successfully applied in GIS substations worldwid, during HV on-site commissioning tests and during in-service condition monitoring. It is to detect the UHF electromagnetic wave signals and obtain information related to the PD. Because of the extremely short rise times of the PD pulses, the frequencies are predominantly in the range 400 MHz to 1.5 GHz. However, the measurements have always been made within a metal-shielded enclosure and usually indoors. In such conditions the system is less likely to be affected by external electromagnetic sources, in particular those produced by PD occurring outside the GIS.

Because of the extremely short rise times of the PD pulses, the frequencies are predominantly in the range 400 MHz to 1.5 GHz. These UHF signals can be detected by two kinds of typically UHF sensors which are internal and external sensors installed on the GIS chamber, as shown in Fig. 1.

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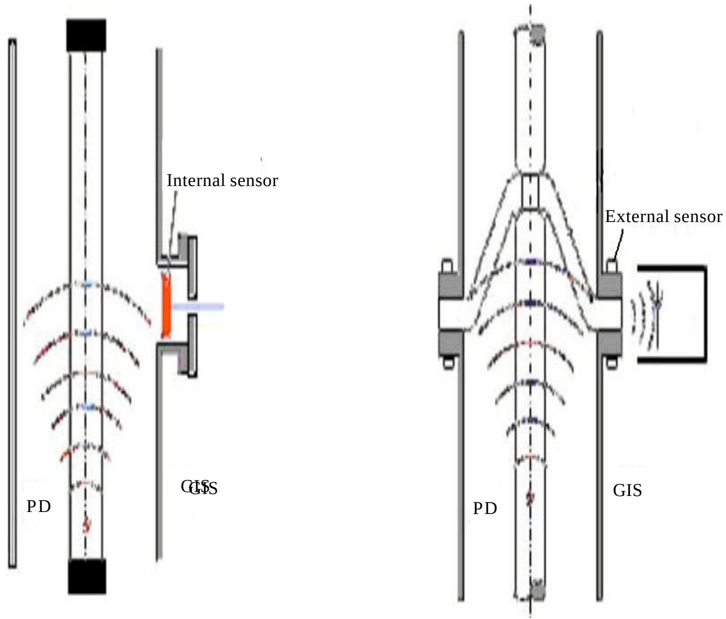



Fig. 1: Two kinds of typically UHF sensors

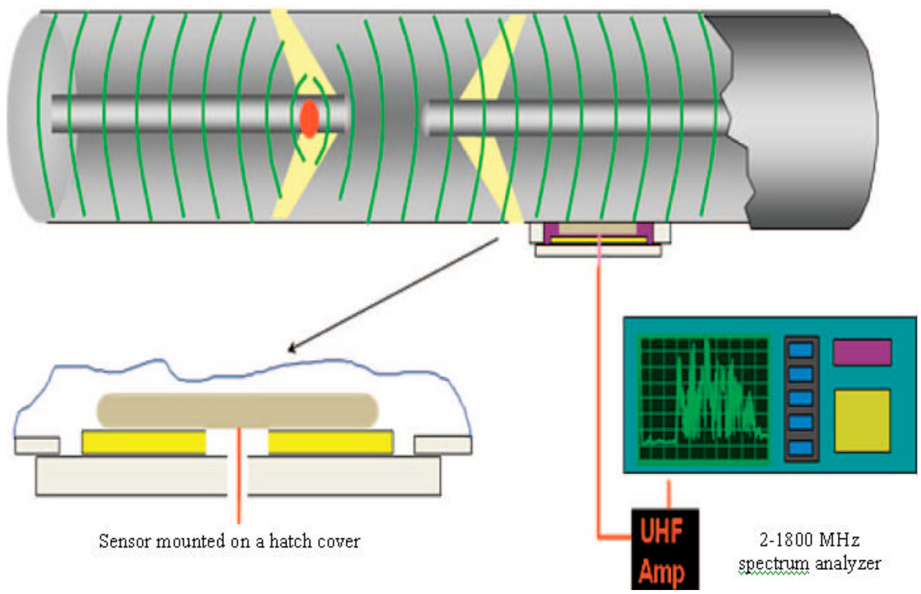



Fig. 2: UHF PD detection system

Generally, the UHF PD detection system is composed of the UHF sensor, the host computer and the date acquisition and analysis software which includes synchronizer for PD phase signal information. The UHF PD detection system is illustrated in Fig. 2.

In order to observe whether there is PD pulse, the sensor is usually installed on the GIS plate insulator or cable connector, as shown in Fig. 3.

The typical PD signals are repetitive PD pulses which are usually related to power frequency, Fig. 4 shows several PD pulses repeat in every 10 ms (half-wave) or 20 ms (full wave) (Rao *et al*., 2011).

The typical GIS PD waveforms caused by different defects are illustrated in Table 1.

## SIMULATION BASED ON FDTD ALGORITHM

**Simulation model:** The Finite Difference Time Domain Algorithm (FDTD) was first proposed by Yee (1966) which is used to solve the numerical calculation of

Fig. 3: Position of the UHF sensor

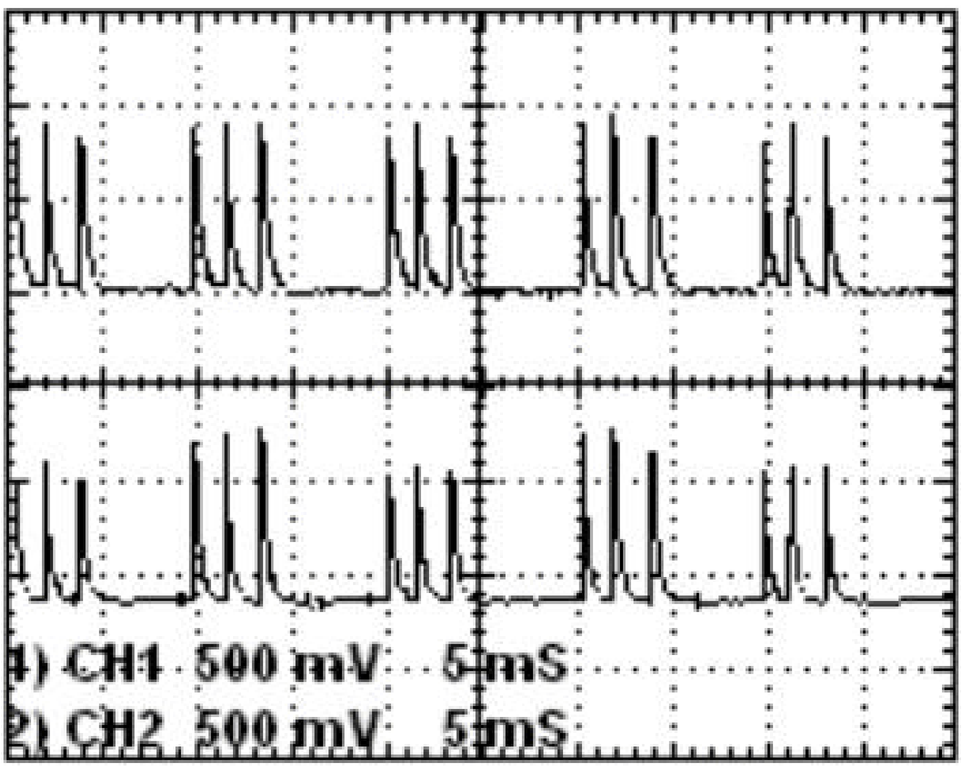
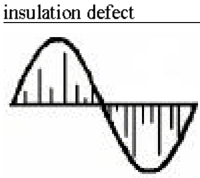
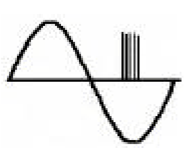
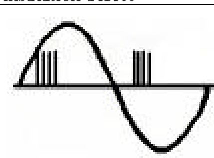
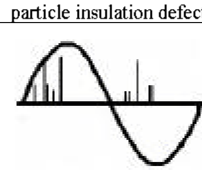



Fig. 4: Partial discharge signal characteristics

Table 1: Typical GIS PD waveforms caused by different defects

| Free metal particle insulation defect | Metallic outshoot insulation defect | Air gap insulation defect | Suspension particle insulation defect | Creep creepage particle insulation defect |
|---|---|---|---|---|
|  |  |  |  |  |

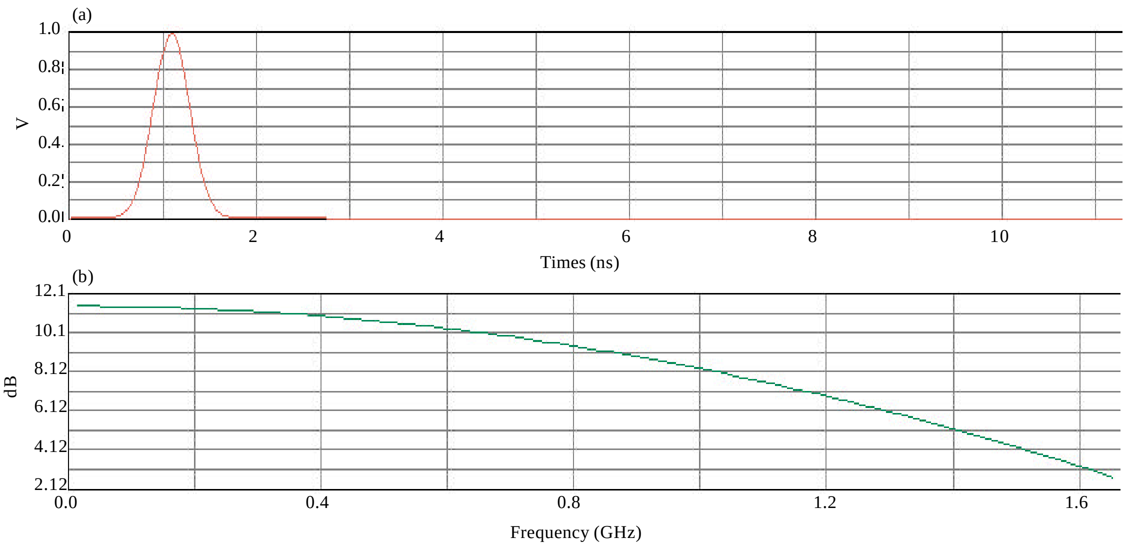



Fig. 5: PD pulse current waveform

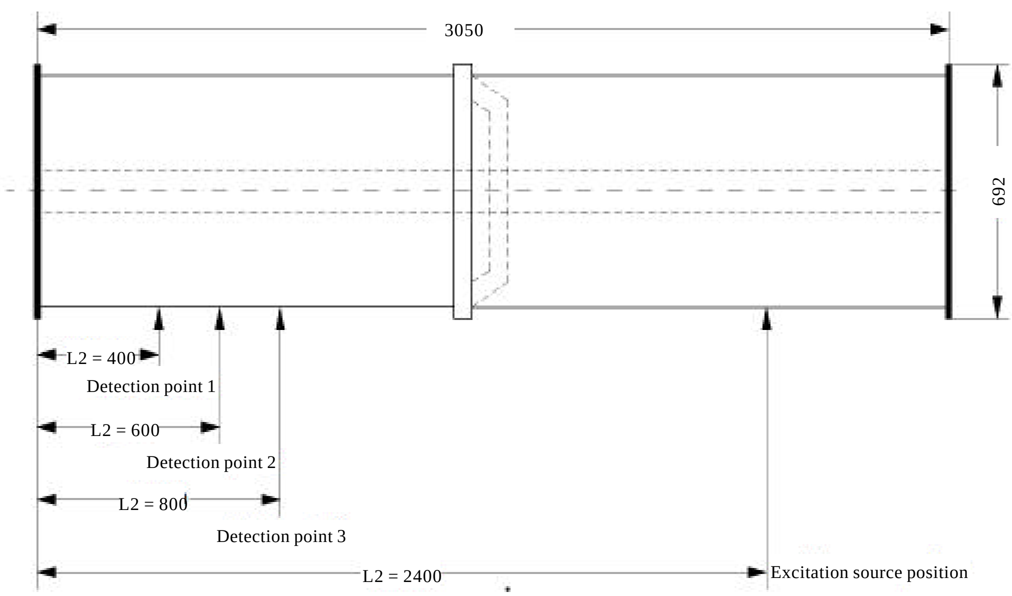



Fig. 6: Simulation position diagram

electromagnetic field. A simulator for analyzing 3-D transient EM fields using the Finite-difference Time-domain (FDTD) method is considered to be the most promising technique for evaluating outputs of UHF couplers obtained after PD pulses propagate through the aforementioned components and for confirming whether the sensitivity of the couplers meets requirements according to CIGRE recommendation. The benefit of the simulation is thought to be capable of saving cost and time regarding the PD tests that will be charged for each withstand voltage test at factory and onsite tests (Hoshino *et al*., 2009).

Here the software of Remcom's XFDTD 6.3 is used to simulate and analysis the PD in GIS. Gaussian function is used to simulate the PD pulses:

$$i(t) = I_0 e^{-(t-t_0)^2/2\sigma^2} \tag{1}$$

In the equation, $I_0$ is the pulse current amplitude; $t_0$ is the decay time constant, $\sigma$ is the initial time. Pulse current waveform for time domain and frequency domain are shown in Fig. 5.

The simulation model as shown in Fig. 6 is set up by the parameters of 252kV GIS offered by Xiamen ABB high

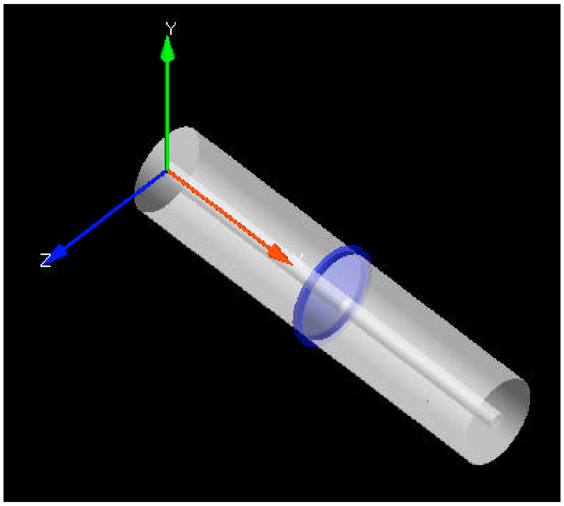



Fig. 7: 3D renderings of GIS model

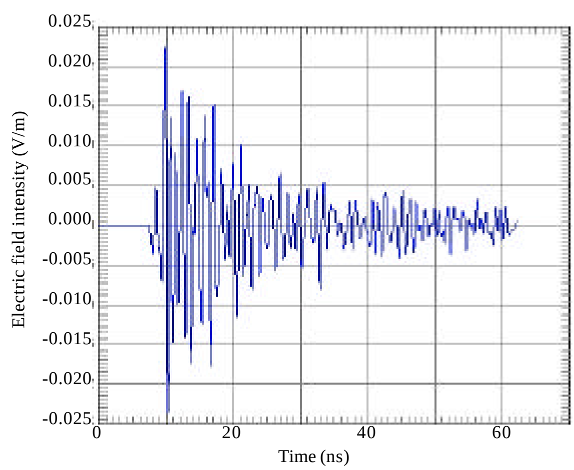



Fig. 8: Field strength of detection point 1

voltage switch Co. Ltd. Excitation source is set at the bottom of the GIS, the three- dimensional coordinate is (123, 24, 37 ) i.e., where the free metal particles PD usually occurs. The other parameters in the modules are as follows:

**Inner conductor diameter:** 115 mm, Inner diameter of the metal case: 600 mm, External diameter of the metal case: 612 mm, gas chamber tube length: 1500 mm.

The conductivity of disk insulator is 0, the relative dielectric constant is 4. Suppose the metal case and the conductor is a perfect conductor and the boundary conditions is 7 PML. The maximum grid settings is 21.551×21.551×21.55 mm, simulation of signal frequency is 1.39 GHz. In order to prevent the reflection of electromagnetic wave, the tube ends are open, as shown

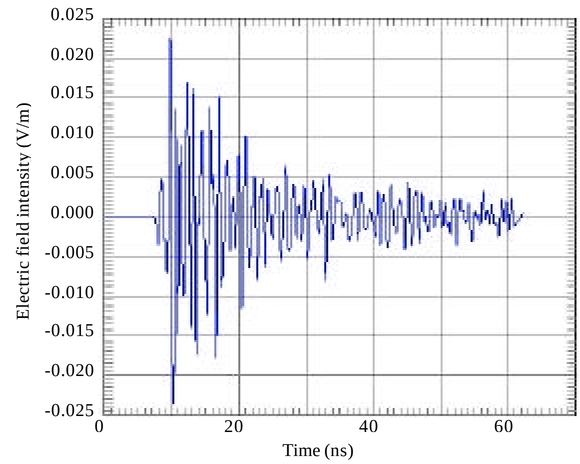



Fig. 9: Field strength of detection point 2

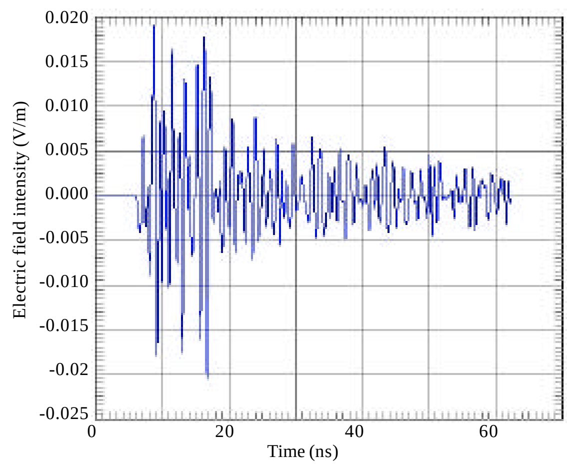



Fig. 10: Field strength of detection point 3

in Fig. 7. Detection points are also illustrated in Fig. 7, detection point 1 (40, 24, 37), i.e., $l_2$ = 400 mm, detection point 2 (49, 24, 37), i.e., $l_3$ = 600 mm and detection point 3 (58, 24, 37), i.e., $l_4$ 800 mm. Figure 7 shows the corresponding 3D model as well.

**Simulation results:** The simulation results of field strength in detection point 1, detection point 2 and detection point 3 are shown in Fig. 8- 10.

Compared with Fig. 11 which is the measure field strength, the simulation results in Fig. 8-10 are similar to the measured results. It proves the simulation model is successful. The reasons for the waveform differences can be as follows:

- The model is approximately equivalent, not very accurate

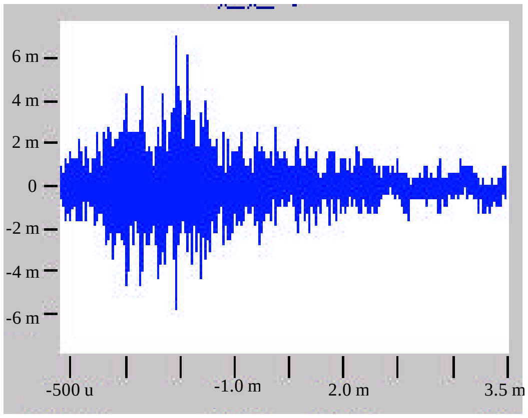



Fig. 11: Measured field strength

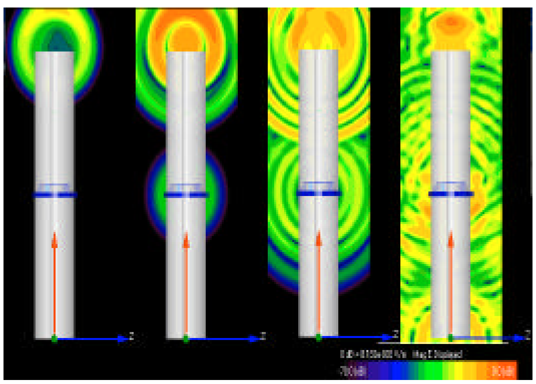


Fig. 12: Strength field distribution at different times in ZX coordinate

- The excitation source is an ideal Gaussian function, however there is waveform differences between the actual PD
- The waveform is obtained under ideal situation, therefore there are a lot of disturbance factors to GIS on the spot

In the meantime, the propagation of electromagnetic wave in GIS is also achieved as shown in Fig. 12 clearly, including the diffusion process, the resonance and the reflection. The electromagnetic wave leaked from insulators can be detected by the external UHF equipment.

## CONCLUSION

Using the FDTD method a PD modelof a GIS is created in this study. Propagating EM waves caused by PD is simulated and analyzed.According to the measured PD signals and the simulation, in Fig. 8-12, the conclusions can be drawn:

- When the PD occurs inside GIS, the PD pulse will excite a steep signal
- Due to its discontinuous internal structure, the electromagnetic wave will cause the reflection and complex resonance while the signal energy will increase with the decreasing distance
- The results suggest that UHF PD fault diagnosis simulation based on FDTD algorithm can simulate the propagation process of PD signals successfully and the results of simulation also provide some more theoretical support for GIS UHF PD monitoring

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