PROPAGATION CHARACTERISTICS OF PD-INDUCED UHF SIGNAL IN GIS WITH THREE-PHASE CONSTRUCTION

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ABSTRACT

The propagation characteristics of electro-magnetic (EM) wave in GIS is the theoretical basis of partial discharge diagnosis based on UHF method, which is also the prerequisite and guarantee for better application in the actual detection. As most conventional researches have been concentrated on the GIS structure with single phase in a tank, the propagation characteristics of UHF signal in GIS with three-phase construction have not been elucidated yet. This paper deals with the present status and aims to study the propagation and attenuation of UHF signal in such three-phase construction by using FDTD analysis. Not only the radial component of the signal, but also those in axial direction and that perpendicular to radial direction in different circumferential angles are investigated. The propagation rules of peak to peak value (*Vpp*) and cumulative energy are profoundly studied.

1. INTRODUCTION

The survey of CIGRE pointed out that the insulation failure is a major fault type in high voltage equipments [1]. The insulation defects that lead to the failure inside of GIS often produce partial discharge (PD) phenomena at the beginning. Detecting the electromagnetic (EM) wave radiated from PD in Ultra High Frequency (UHF) range is an effective PD monitoring method to early discover and eliminate the hidden danger of insulation failure, and has obtained a wide application owing to its high sensitivity and immunity to noise [2-3].

The partial discharge diagnosis with UHF method is based on the UHF electromagnetic wave signal received by UHF sensor. Thus, in order to deeply understand the propagation mechanism and improve the utilization of UHF technique, it is necessary to investigate on the EM wave attenuation characteristics. At present, many scholars have made particular research. M. Hikita has studied about the influence of insulator, disconnecting part and bent parts such as L-branch and T-branch on EM signal propagation feature, as well as the propagation mechanism in GIS [4]. In the perspective of EM wave mode, Shigemitsu Okabe conducts lots of research about propagation properties [5]. Alistair J. Reid and M. D. Judd propose the use of Finite Difference Time Domain (FDTD) method for modelling and simulation of sensor response to optimize the design of sensor [6]. On the basis of previous research, the authors also have investigated the propagation of the EM signals in different-shaped tanks [7-10].

For the present studies of propagation characteristics, most of all are aimed at GIS with single phase placed in the tank. However, in relatively low voltage grade, such as 126 kV level in China, GIS generally adopts three-phase structure in a tank. The research on the propagation characteristics of UHF signal in GIS with this kind of structure is few in number [11-13]. Therefore, a simulation model is built according to a GIS with three-phase structure in this paper. By using FDTD method, the UHF signal propagation property in different radial positions, directions, and circumferential angles is investigated in detail. And the propagation rules of peak to peak value (*Vpp*) and cumulative energy in each case are profoundly analysed.

2. MODELS AND SIMULATION SETUP

The calculation model is made corresponding to a type of 145 kV GIS busbar with three phases conductors in the tank. The spacers are also eliminated as they contribute little to the decreasing of UHF signal [4-6]. The diameter of the central conductor, the tank and the thickness of the tank wall are 86 mm, 500 mm and 10mm, respectively. The other sizes and the coordinate system are shown in Fig. 1. The coordinate origin is set to the left center of the tank, while y and z axes are along with radius direction and axial direction respectively.

A Gaussian pulse with peak of 15 mA and half value width of 0.35 ns is set along a 30 mm length needle on the high voltage conductor as the protrusion discharge defect. The pulse frequency attenuation is -30 dB at 3 GHz, while the corresponding charge quantity is 5 pC which agrees with the conventional sensitivity requirement of PD detection. Since the HV field causing PD current to flow is predominantly in radial direction, both the needle and the pulse are set vertically to the conductor surface in y direction to be consistent with the actual situation.

Practically, the relative position between the sensor and the PD source is random, so three sensing positions with 90-degree intervals are set in a cross section. And 10 sensing points with 200 mm intervals longitudinally are provided to investigate the signal attenuation on different circumferential angles. A load probe in each position is applied to simulate a monopole antenna as a UHF sensor to receive EM waves, and then the coupling voltage across the load can be obtained. Fig. 1 shows the 10 sensing points at $\theta = 0°$.

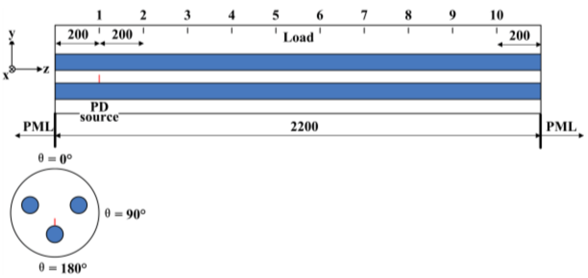


Fig. 1. Simulation model.

3. RESULT AND ANALYSIS

A. Result at $\theta = 0°$

The attenuation results of *Vpp* and the coupled energy from 10 sensing points in different directions at $\theta = 0°$ are drawn together as shown in Fig. 2. From the numerical point of view, as the radial direction is the same as PD source direction, the *Vpp* and coupled energy in *y* are far larger than those in the other two directions, while those in *z* take the second place. The signal in *x* is the smallest as it is mainly generated through reflection. With the increasing of the distance towards PD source, the changing trend of *Vpp* and coupled energy is analyzed. It is found that there is a little change in *x* direction, and both of the *Vpp* and coupled energy firstly increase and then decrease in *y* direction. The changing trend in *z* is similar to that in *y*, but differently, the curves in the middle and latter parts are more stable. Moreover, the changing trends of *Vpp* and coupled energy in various directions basically maintain consistent, except for the middle and latter parts in Fig. 2(c) where there is certain deviation.

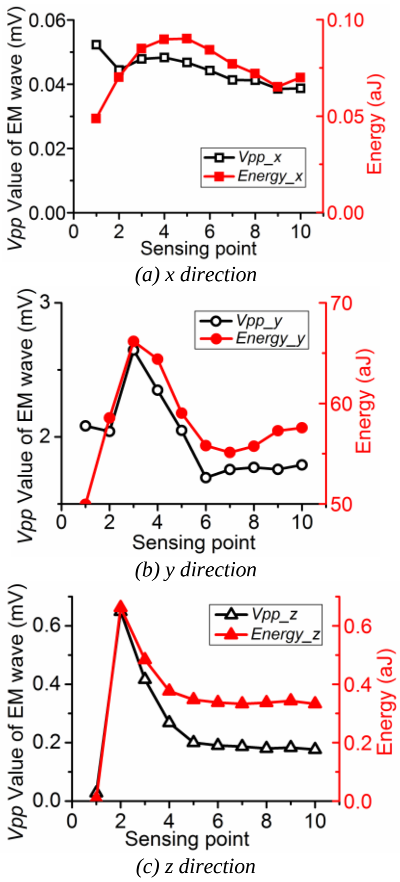
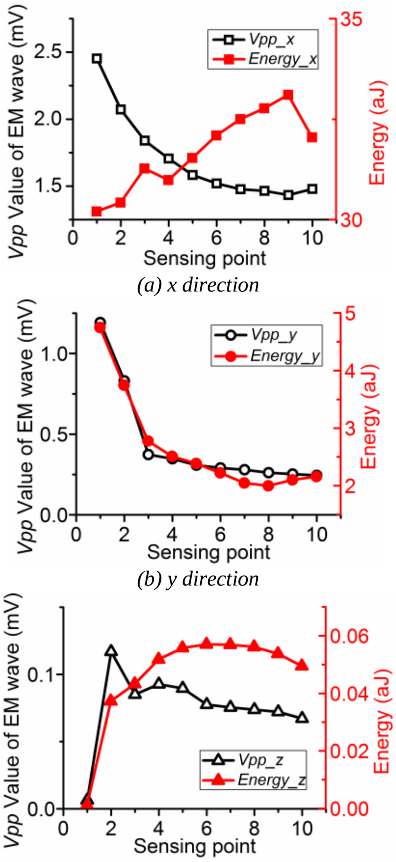


Fig. 2 Contrast of Vpp and Energy in Different Directions at 0°

B. Result at $\theta = 90°$

The attenuation of *Vpp* and coupled energy of the signal at $\theta = 90°$ is shown in Fig. 3. In *x* direction that is along the radial direction, the *Vpp* and coupled energy of signal still remain the largest. However, what significantly different from Fig. 2 is that the changing trends of them are opposite. That is the *Vpp* keeps attenuating, while the coupled energy generally keeps increasing. Both of *Vpp* and coupled energy in *y* keep decreasing. At the same time, the value of the signal components in *z* is the smallest, and still maintains the trend of firstly increasing and then decreasing, which is consistent to the conclusion for the single phase structure GIS [7, 8].

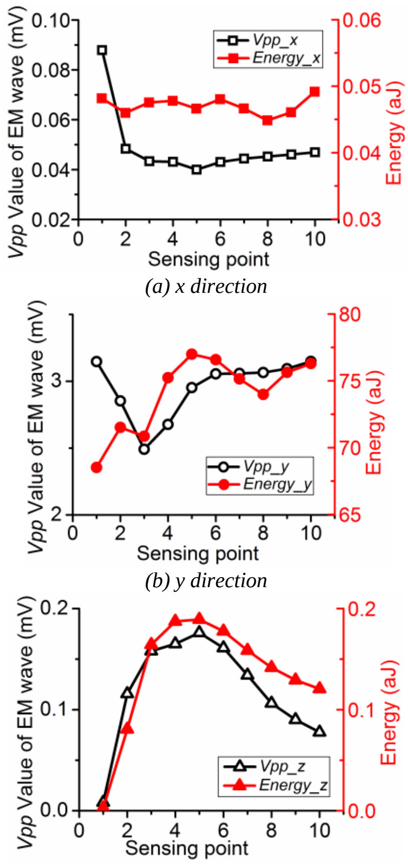


(a) x direction
(b) y direction
(c) z direction

Fig. 3 Contrast of Vpp and Energy in Different Directions at $90°$

C. Result at $\theta = 180°$

Fig. 4 displays the attenuation results of *Vpp* and energy of signals at $\theta = 180°$. It can be seen that the signal in *y* that is along the radial direction is still the strongest. But at the initial stage, the changing trends of *Vpp* and energy are opposite to each other. The *Vpp* firstly decrease and then increase, but the energy increases with fluctuations. As the smallest components, the signals in *x* direction are similar to the case at $\theta = 0°$, which changes relatively stably except for point 1 whose *Vpp* differs much from those on other points. The *Vpp* and energy in *z* continue the consistent trend of firstly increasing and then decreasing, but the amplitude is smaller than that in Fig. 2(c).



(a) x direction
(b) y direction
(c) z direction

Fig. 4 Contrast of Vpp and Energy in Different Directions at $180°$

4. DISCUSSION

Because three-phase high voltage conductors are placed in the tank, GIS will no longer hold the coaxial waveguide structure in single phase GIS. Then the EM wave spread in the tank cannot be simply regarded as the combination of TEM, TE and TM modes. The change of EM mode components directly leads to the variation of signal amplitude and coupled energy in time domain, such as the separation of *Vpp* and energy of radial signal at $\theta = 90°$ and the signal components in the direction that perpendicular to the radial direction on various angles becoming stable.

However, as the axial electric field in the PD source position is hard to be generated, the axial signal still keeps the lowest in the defect position and maintains the trend of firstly increasing and then decreasing on various circumferential angles, which can be taken as the significant reference for longitudinal positioning of the defect. That is, to determine the axial position of the defect according to the lowest point of the axial signals. From the result above, the axial signal at $\theta = 0°$ is the strongest and the signal on the defect location is the most distinct from those on other points. So considering the recognition of signal in the defect position, it is regarded that the circumferential angle of $\theta = 0°$ is the best position for axial signal detection in three-phase construction.

5. CONCLUSION

The propagation and attenuation of UHF signals in GIS with three-phase construction has been investigated in this paper. It is found that non-coaxial waveguide structure changes the formation and propagation of EM wave, which affects the propagation characteristics of some signal components. However, as for the axial signal, the changing trend of firstly increasing and then decreasing has remained, which can still be taken as the reference for axial positioning analysis. And significantly, $\theta = 0°$ becomes the best position for axial signal detection.

This work lays a foundation for rational use of UHF sensor and better conduct of PD detection. In the next step, the propagation mechanism of UHF signal in three-phase structure can be further analyzed in the perspective of frequency domain, etc.

ACKNOWLEDGE

This work was supported by National High Technology Research and Development Program ("863" Program) of China (No. 2011AA05A121), and Program for New Century Excellent Talents in University.

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