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Investigation of Propagation Characteristics of UHF Electromagnetic Wave Due to PD in Switchgear

***Abstract**. In order to investigate the propagation characteristics of ultra-high-frequency (UHF) electromagnetic wave caused by partial discharge (PD) in high voltage switchgear, a simulation model was established by using the finite-difference-time-domain (FDTD) method. The simulation results have useful information for the installation of UHF sensor to detect PDs in switchgear.*

Streszczenie**. Opracowano model numeryczny i przeprowadzono symulacje metodą różnic skończonych w dziedzinie czasu (FDTD) w celu określenia charakterystyk propagacyjnych sygnałów w zakresie ultra wysokich częstotliwości (UHF) generowanych przez wyładowania niezupełne (PD) w rozdzielnicy wysokonapięciowej. Wyniki symulacji umożliwiają poprawną instalację czujników do wykrywania wyładowań niezupełnych w rozdzielnicy.**(Badanie charakterystyk propagacji fali elektromagnetycznej UHF generowanych w rozdzielnicy przez wyładowania niezupełne).

Keywords: Propagation characteristic, Ultra-high-frequency (UHF), Electromagnetic wave, Partial discharge (PD).
Słowa kluczowe: Charakterystyka propagacyjna, Ultra wysokie częstotliwości (UHF), Fala elektromagnetyczna, Wyładowania niezupełne.

Introduction

The switcher is the key equipment in the urban distribution power network, its operation, reliability directly relates to the security and stability of power system [1-3]. Therefore, it is very important to detect the operating status of high voltage switchgear.

Partial discharges (PDs) are major causes leading to insulation faults in switchgear [4]. The main methods used for PD detection in switchgear include an ultrasonic method [5-6], radio frequency (RF) method [7], transient earth voltage (TEV) method [8-10] and UHF method [11-13]. Due to strong anti-interference capability and high sensitivity, the UHF method has a great application vision. In the previous studies on the propagation proprieties of electromagnetic wave, many scholars focus on the gas-insulated switchgear (GIS) and transformers [14-15].

In this paper, the switchgear model is established and the influences of the main components on the propagation characteristics of UHF electromagnetic wave are investigated by using XFDTD software. The simulation results provide theoretical references for the installation of UHF sensor to detect PDs in switchgears.

Modeling

When there is a PD in switchgear, a short pulse current occurs huge the discharge channel, and the transient electromagnetic radiation will be used. There are many different numerical methods for electromagnetic field analysis, including the finite element method (FEM), equivalent source method (ESM) and finite-difference time-domain (FDTD). FDTD can provide a broadband result by solving the Maxwell equation in the time domain rather than frequency domain analysis applied by other electromagnetic simulation methods, and the advantages of FDTD are very important when the structures of simulation are complex.

A. Physical model

The KYN28-12 high voltage switchgear is consisder as an example and its simulated model is shown in Fig.1. The dimension is 1500 mm × 800 mm × 2300 mm.

B. Simulation parameter settings

In the simulated switchgear model, some components, including partition, breaker, cable termination, bus, current transformer, insulator and bushings are taken into consideration. The material parameters of these components are given in Table 1.

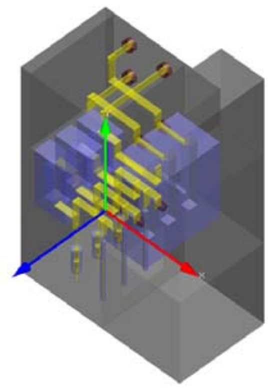


Fig.1 Simulation model of the high voltage switchgear

Table 1. Material parameters of components in simulation model.

Component	Relative dielectric constant ε_r	Electrical conductivity $\sigma/(\mathrm{S \cdot m^{-1}})$
Cabinet	1	5.6e6
Bus	1	5.7e7
Bushing	5.7	1e-8
Insulation	3.6	1e-8

C. Excitation source settings

Partial discharge source can be taken as a line current Gaussian pulse. The time-domain expression and waveform of the Gaussian pulse are shown in equation (1) and Fig.2, respectively.

$$I(t) = I_0 \exp\left[-\frac{4\pi(t-t_0)}{\tau^2}\right] \qquad (1)$$

Where: τ *is* a constant value, which determines the width of the Gaussian pulse; I_0 represent the amplitude of the Gaussian pulse; *t* is a time of the pulse wave; t_0 represent the time for the amplitude of the Gaussian pulse.

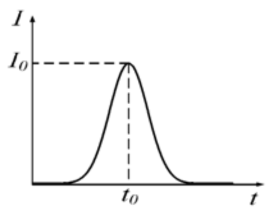


Fig.2 Waveform of the Gaussian pulse

Discussion

After the parameter settings, mesh generation and PD source setting, the propagation characteristics of UHF electromagnetic wave in high switchgear can be investigated.

A. Influence of magnitude of excitations on UHF signal

The source S_1 is placed in mesh (85, 95, 60) inside the switchgear and a detection probe D_4 of 50 Ω placed at (85, 45, 60) is taken as the detection point, as shown in Fig.3. The pulse width of the excitation is 616 ps, and the magnitude is from1 A to 6 A. The waveforms of the UHF signal with different magnitudes of excitations are shown in Fig.4, and the relationship curve between the magnitudes of UHF signals and the magnitudes of pulse source is shown in Fig.5.

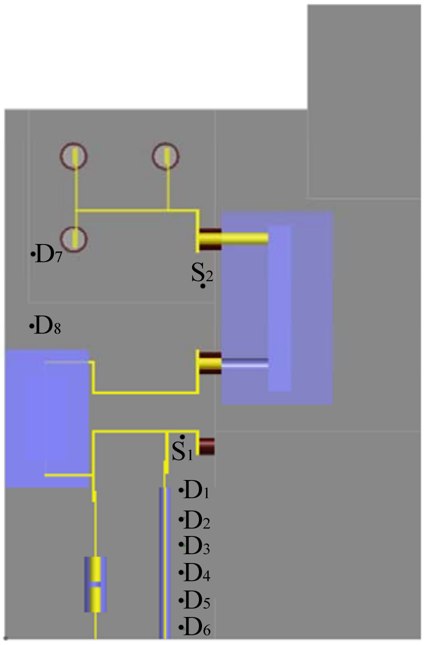
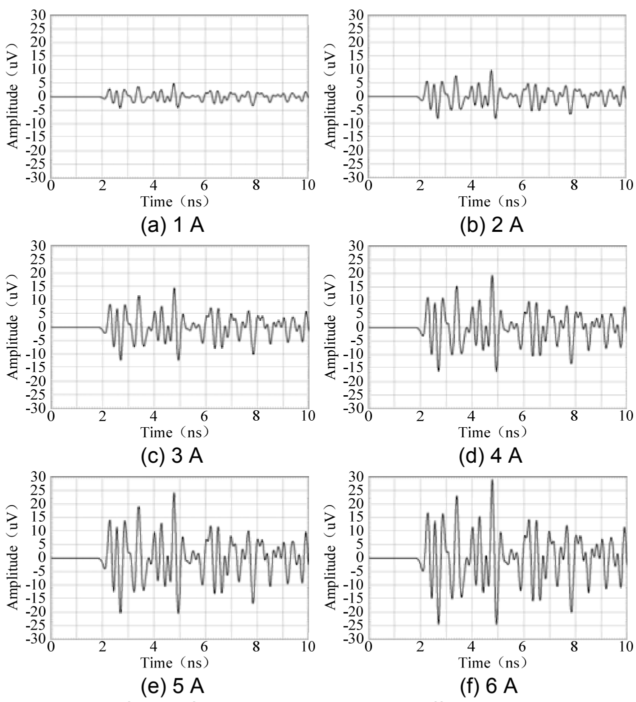


Fig.3 Distribution of source points and detection points



(a) 1 A (b) 2 A (c) 3 A (d) 4 A (e) 5 A (f) 6 A

Fig.4 Waveform of the UHF signal with different magnitudes of excitations

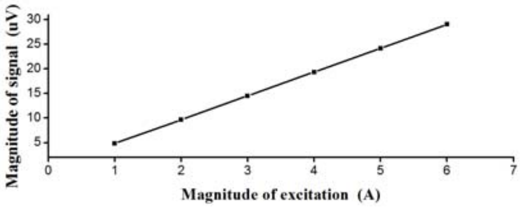
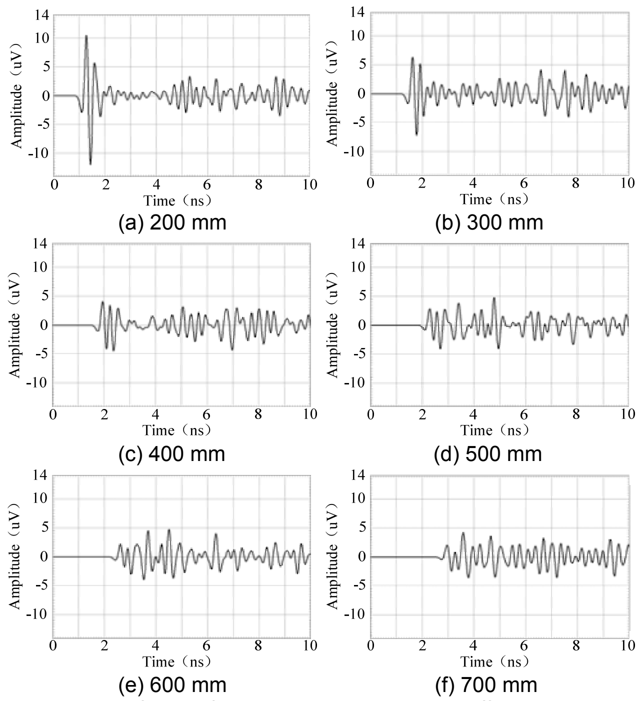


Fig.5 Relationship curve between the UHF signal magnitudes and the pulse source magnitudes

From Fig.4 and Fig.5, it can be found that when the excitation pulse magnitude increases from 1 A to 6 A, the pulse widths of the UHF signals do not change, but the UHF signal magnitude increases from 4.82 uV to 29.06 uV. It is cleared that the UHF signal magnitude is directly proportional to the excitation pulse magnitude.

B. Influence of detection distance on UHF signal

The source S_1 is placed on mesh (85, 95, 60) inside the switchgear and six detection probes (D_1 to D_6) are located at different positions, as shown in Fig.3. The pulse width of the excitation is 616 ps, and the magnitude is1 A. The distance between detection points and the excitation source are 200 mm, 300 mm, 400 mm, 500 mm 600 mm and 700 mm. The waveform forms of the UHF signal with different detection distances are shown in Fig.6, and the relationship curve between the magnitudes of UHF signals and the detection distances are shown in Fig.7.



(a) 200 mm (b) 300 mm (c) 400 mm (d) 500 mm (e) 600 mm (f) 700 mm

Fig.6 Waveform of the UHF signal with different detection distances

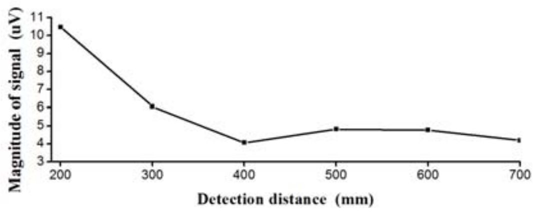
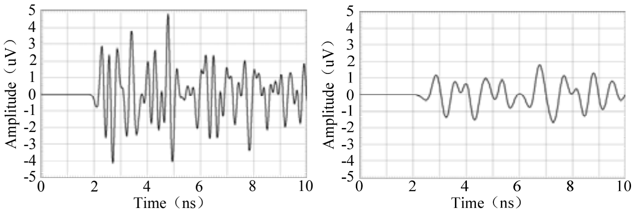


Fig.7 Relationship curve between the UHF signal magnitudes and the detection distances

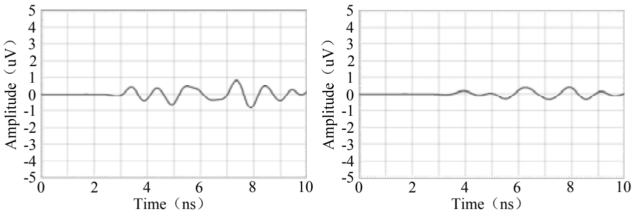
Fig.6 and Fig.7 show that when the detection distance increases from 200 mm to 700 mm, the UHF signal magnitude is found first decrease, then increase and decrease again. This phenomenon occurs due to the reflection of electromagnetic wave in switchgear.

C. Influence of excitation pulse width on UHF signal

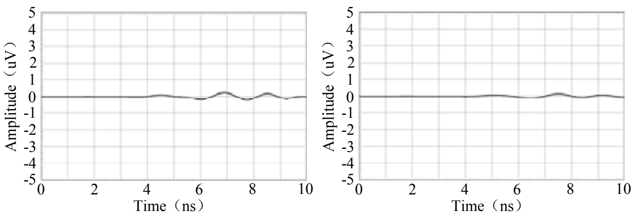
The source S_1 is placed on mesh (85, 95, 60) inside the switchgear and a detection probe D_4 of 50 Ω placed at (85, 45, 60) is taken as the detection point, as shown in Fig.3. The magnitude of the excitation current is 1 A, and the pulse widths of the excitation range from 0.616 ns to 3.696 ns. The waveforms of the UHF signal with different excitation pulse widths are shown in Fig.8, and the relationship curve between the magnitudes of UHF signals and excitation pulse widths were shown in Fig.9.



(a) 0.616 ns (b) 1.232 ns



(c) 1.848 ns (d) 2.464 ns



(e) 3.08 ns (f) 3.696 ns

Fig.8 Waveform of the UHF signal with different excitation pulse widths

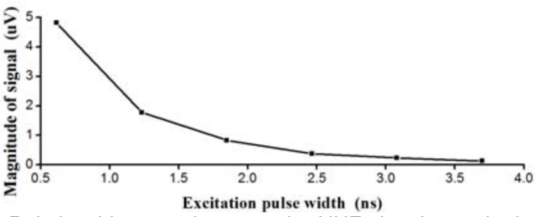
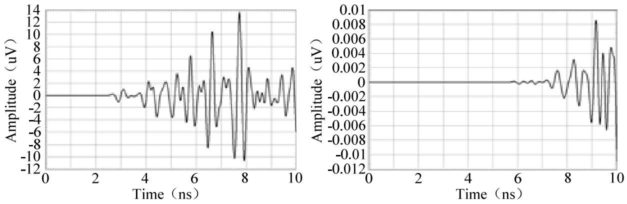


Fig.9 Relationship curve between the UHF signal magnitudes and the excitation pulse widths

From Fig.8 and Fig.9, it can be observed that when the excitation pulse width increases from 0.616 ns to 3.696 ns, the pulse width of the UHF signals increases, but the UHF signal magnitude decreases from 4.82 uV to 0.13 uV in a power function law.

D. Influence of metal board on UHF signal

The source S_2 is placed on mesh (95, 150, 60) inside bus room and two detection probes D_7 and D_8 of 50 Ω, placed at (32, 160, 60) and (32, 160, 60), are taken as the detection points, as shown in Fig.3. The distances from the two detection points to the excitation pulse are the same, but they are separated from the metal board. The magnitude of the excitation is 1 A, and the pulse width of the excitation is 616 ps. The waveforms of the UHF signal at the two detection points inside and outside the bus room are shown in Fig.10.



(a) Inside the bus room (b) Inside the bus room

Fig.10 Waveform of the UHF signal inside and outside the bus room.

Fig.10 shows that the amplitude of the UHF signal inside the bus room is much stronger than that outside the bus room. This is due to the shielding effect of the metal bar on the electromagnetic wave.

Conclusion

The simulation model of a KYN28-12 high voltage switchgear is established. Based on this model, the influences of the magnitude of the Gaussian pulse current, the width of the Gaussian pulse, the distance between PD source point and detection and metal board in switchgear on the UHF waveform are investigated by using FDTD method.

From simulation results and analysis, some conclusions can be drawn as follows:

1) The UHF signal magnitude is proportional to the excitation pulse magnitude.

2) With the increase of the detection distance, the UHF signal magnitude is first decrease, then increase and decrease again.

3) With the increase of excitation pulse width, the UHF signal magnitude decreases in a power function law.

4）Due to the shielding effect of the metal bar on the electromagnetic wave, the UHF sensors should separately be installed in all rooms of the switchgear.

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