INFLUENCE OF THE EXISTENCE OF THE EPOXY SPACER ON THE PROPAGATION PROPERTIES OF PARTIAL DISCHARGE INDUCED ELECTROMAGNETIC WAVE IN STRAIGHT 154 KV GIS MODEL TANK

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Abstract: This paper deals with influence of the existence of the epoxy spacer on the transmission rate of PD induced electromagnetic wave (EMW) propagating through 154 kV straight gas insulated switchgear model tank. The results showed that the transmission rate of EMW in the presence of the spacer was lower than one without spacer. Transmission rate of EMW of a particle on the conductor was higher than one of a particle on the tank. The frequency spectrums of EMW originated from two types of foreign particle of high voltage particle (HVP) and tank free particle (TFP) were compared. EMW of HVP was large in the frequency of 4 GHz or less while EMW of TFP was distributed up to the frequency of 6 GHz or more. When the method of evaluating energy and amplitude is examined mutually, transmission rate of energy is lower than transmission rate of amplitude. The error margin between the measurement and calculation in the presence of the spacer based on the energy evaluation is smaller than one based on amplitude evaluation. Therefore, the evaluation of propagation properties of EMW, it is necessary to examine the EMW energy as well as EMW amplitude.

1 INTRODUCTION

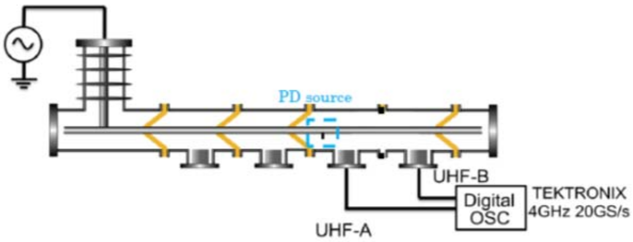
Research on insulation diagnosis of electric power apparatus such as gas-insulated switchgears (GIS) and transformers by detecting partial discharge (PD) signals, especially the ultra high frequency (UHF) signal, with, the PD induced electromagnetic wave (EM wave) propagation mode characteristics considered, has been conducted recently [1]. When applying the UHF method to GIS insulation diagnostics, it is necessary to investigate the effects of the structure and components of GIS such as turnoff part and a spacer on the EM wave propagation in GIS. It is because the EM wave propagating in GIS is affected by a discontinuity part of impedance such as L-shaped structure, T-branch, spacers and so on. Therefore, it is important for reliable diagnosis technique to clarify TE and TEM mode propagation characteristics at the impedance discontinuity part in GIS.

So far, investigation of EM wave propagation characteristics on several GIS structures has been doing [2]. However, the investigation of EM wave propagation characteristic through the spacer is still not clear. Because the spacer exists in all joint parts in actual GIS, the investigation of EM wave properties through the spacer is very important. The results are useful for improvement PD diagnosis technology such as decrease the number of sensor and increase accuracy of determining of PD location.

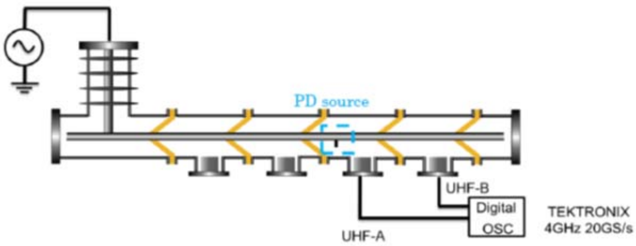
In this paper the influence of the existence of spacer on propagation properties of PD-induced EM wave measured with UHF sensors in 154 kV straight GIS is discussed. The PD sources are a particle on the high voltage conductor (HVP) and a free particle on the tank (TFP). PD induced electromagnetic wave was measured by UHF sensors and observed by oscilloscope and spectrum analyzer.

2 EXPERIMENTAL SETUP AND PROCEDURE

Figure 1 shows configuration of the experimental setup to investigate the effect of the presence of spacer on propagation properties of PD-induced EM wave in straight 154 kV GIS. The disc-type UHF sensors A and B were attached to the gas partitions at the center. The discharge source was a particle on the conductor (HVP) or a free particle on the tank (TFP) as shown in Figure 2. The particle attached on high voltage conductor is a 15 mm long needle-shaped foreign particle with diameter of 0.25 mm located in the gas partition. This gas partition was filled with SF_6 at 0.25 MPa. The spacers are metal flange-type (MT) spacers. MT spacer was made of an epoxy resin material filled with alumina (Figure 3). The applied voltage Va was close to the PD inception voltage (PDIV), and the PD-induced EM waveform was acquired and recorded by a digital oscilloscope (Tektronix, TDS 7404B, 4 GHz, 20 GS/s) and a spectrum analyzer (Advantest, R3267, 8 GHz). The sensor and oscilloscope were connected with a low-loss coaxial cable (Gigatec,12DSFA-10M-NPNP) whose attenuation rate was 1.5 dB/10m. Basically, the measurement was performed by two sensors at the same time.

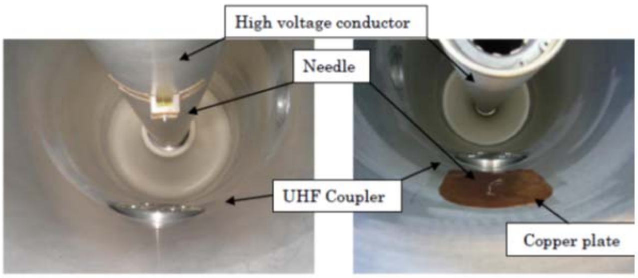


(a) Without spacer (WOS)



(b) With spacer (WS)

Figure 1: Configuration of straight model GIS



(a) HV particle (b) Free particle on the tank

Figure 2: Photograph of partial discharge source

Figure 3: Photographs of metal flange type spacer

3 EXPERIMENT RESULTS

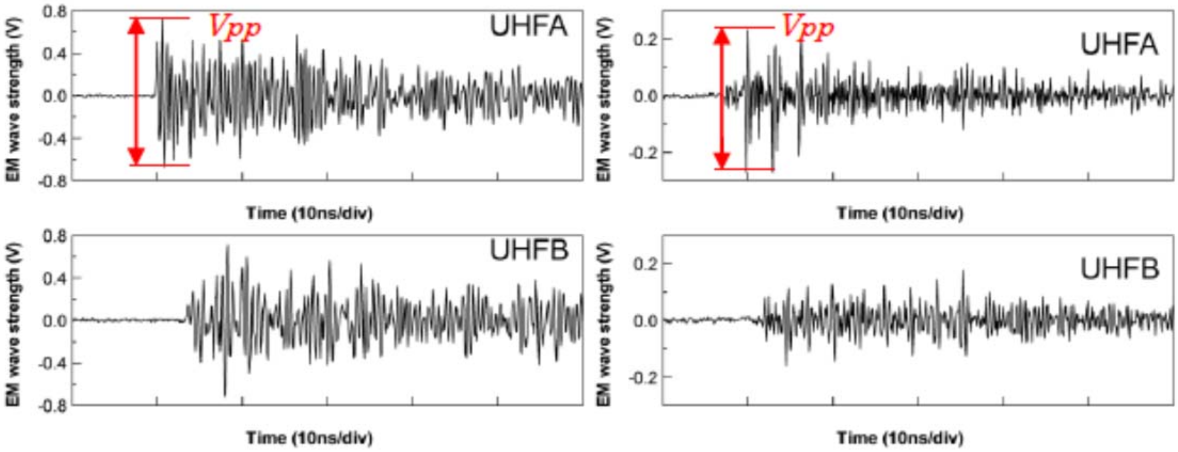
Figure 4a and 4b show typical waveform of propagating PD-induced EM waves measured with each UHF sensor in straight 154 kV GIS model without spacer (WOS) for a particle on the conductor (HVP) and a free particle on the tank (TFP), respectively. Figure 5a and 5b show ones in the presence of the spacer (WS).

From the practical viewpoint in readiness of the detection of insulation diagnosis based on PD signal, the peak to peak value of EM waveform amplitude Vpp is often used. Vpp is defined as the difference between the minimum and maximum value of EM wave amplitude value from the view point of the signal detection. In addition, the transmission rate (TR) of EM wave propagation is defined as the percentage of Vpp measured by UHF sensor B to Vpp measured by UHF sensor A.

Figure 6 shows sensor position dependence of Vpp for measured EM waves in straight model GIS. It is clear that for HVP Vpp of EM wave emitted by PD increased slightly in WOS but it decreased significantly in WS. Moreover, for TFP Vpp measured with both UHF A and UHF B in WS are smaller than ones in WOS. In addition, based on the foreign particle type, the value of Vpp of TFP was lower than one of HVP.

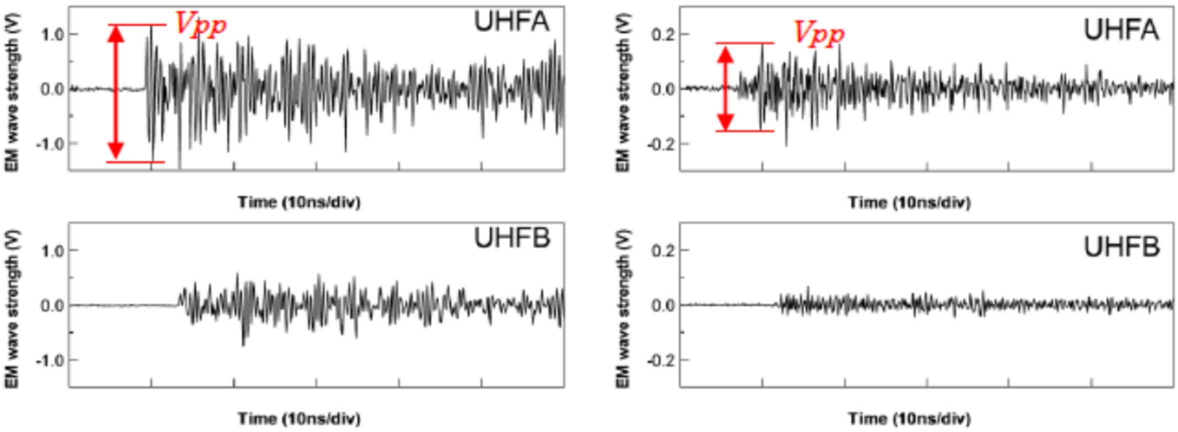
The transmission rate of PD induced EMW are shown in Figure 7. Vpp and TR of TFP are lower than ones of HVP. It means that the EMW induced by PD at TFP propagates in the tank difficultly then lowering of Vpp and TR. The examination by the frequency spectrum acquired with spectrum analyzer is necessary to prove it. It is also shown in Fig. 7 that TR of WS are lower than TR of WOS. It is considered that the presence of the spacer causes the reflection of EMW at the interface of the spacer and the gas insulation and then reduces the transmission rate.

Figure 8 shows frequency spectrum of PD induced EMW in GIS with and without spacer measured by UHF A and B for HVP and TFP. In this figure the background noise were subtracted from frequency spectrum of each sensor acquired with spectrum analyzer. It seems that there is no difference in the spectrum measured with UHF A between WS and WOS. On the other hand, the signal decay measured with UHF B in WS is larger than WOS in the high frequency of 4 GHz or more. Moreover, the signal intensity of HVP is larger than one of TFP in the area of the low frequency. In the band of especially 1 GHz or less, the signal intensity of TFP was very small. On the other hand, the signal intensity of TFP was comparatively larger than that of HVP in the region of the high frequency of 6 GHz or more. Thus, the particle position and the presence of the spacer cause big difference in the frequency spectrum distribution.



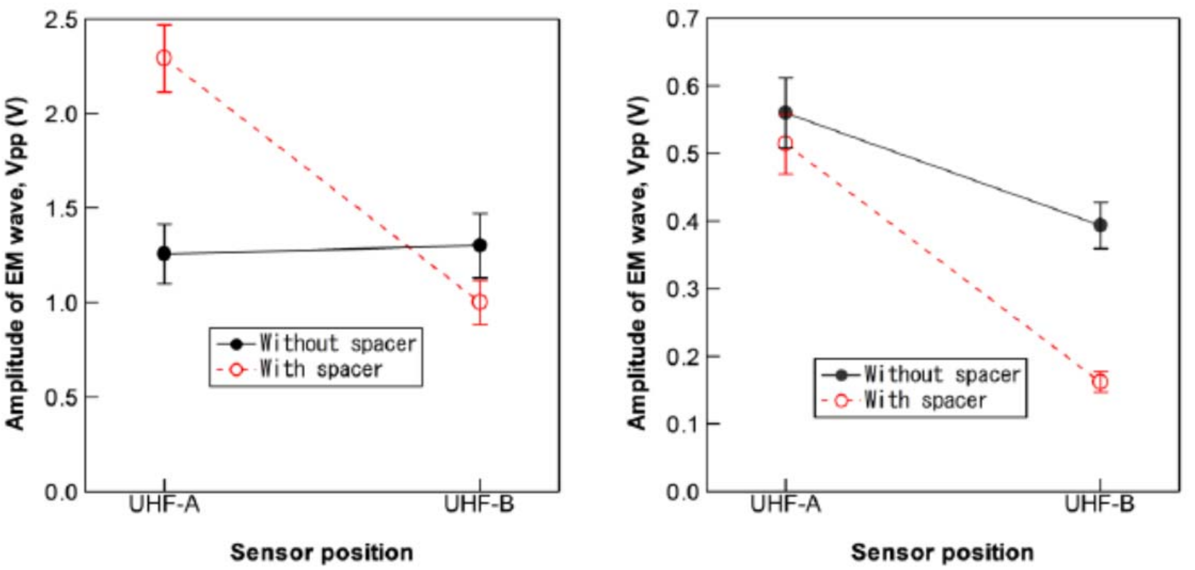
(a)High voltage conductor side particle (b) Tank side free particle

Figure 4: Propagating PD-induced EM wave without spacer



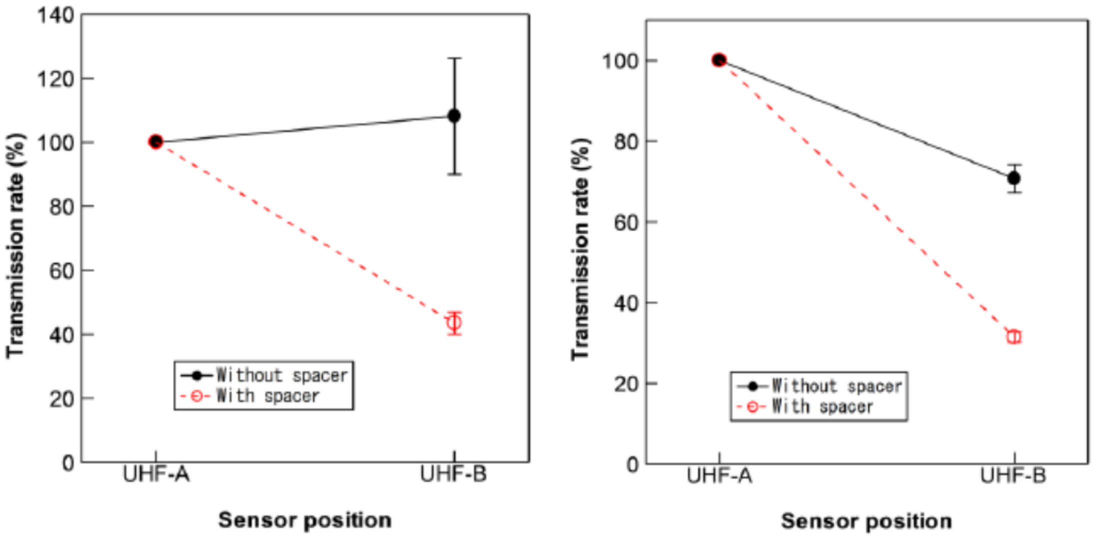
(a)High voltage conductor side particle (b) Tank side free particle

Figure 5: Propagating PD-induced EM wave with spacer



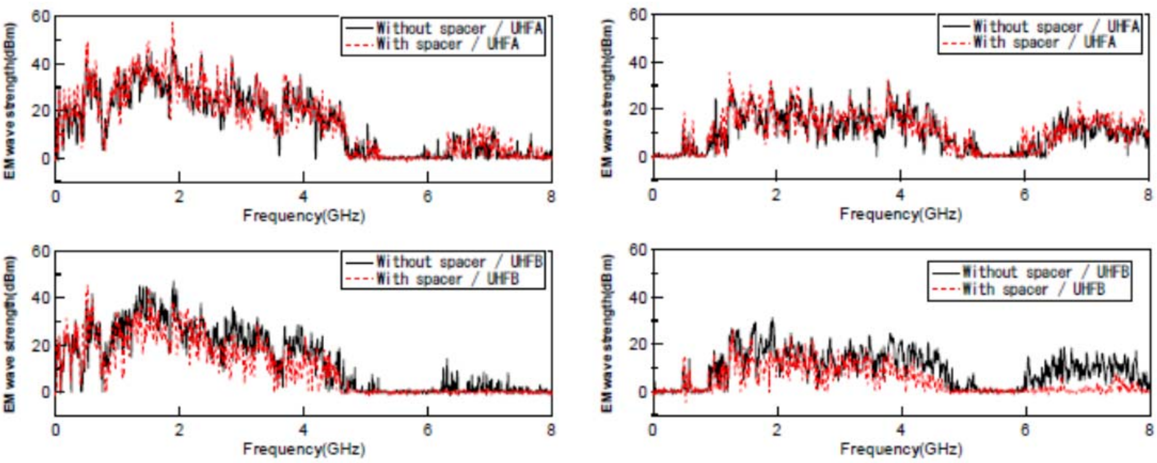
(a) High voltage conductor side particle (b) Tank side free particle

Figure 6: Sensor position dependence of Vpp for measured EM waves in straight model GIS



(a) High voltage conductor side particle (b) Tank side free particle

Figure 7: Transmission rate of EM wave propagating through straight shape154 kV GIS Model Tank



(a) High voltage conductor side particle (b) Tank side free particle

Figure 8: Sensor position dependence of spectrum for measured EM waves

4 DISCUSSION

4.1 Vpp and Transmission Rate of PD induced EMW

In Figure 6 Vpp HVP WS detected in UHF B was lower than Vpp HVP WOS although Vpp HVP WS detected in UHF A was much higher than Vpp HVP WOS. It is considered that the installation of the spacer causes the discontinuity impedance so that the PD induced EM wave is reflected on the spacer surface. The reflected wave superimposes with the incident wave so that the total EM wave which measured with UHF A become larger than the original wave in the presence of the spacer. On the other hand, it can be interpreted that the PD induced EM wave which was able to pass the spacer attenuated greatly.

It is shown in Figure 7a, in the case of HVP, although TR WOS exceeds 100%, TR WS has decreased up to about 40%. It is because of that there is no reflection of the spacer in WOS. In Figure 7b in the case of FPT, TR decreases up to about 70% for WOS and to about 30% for WS. Here TR of EM wave has decreased for WS. It is originated from the decrease of propagation speed of the higher-order mode like TE and TM mode in the presence of the spacer. The propagation speed of EM wave become slower than usual speed of light in the presence of the spacer.

4.2 FDTD Analysis

The Finite Difference Time Domain (FDTD) analysis was used to simulate PD induced EMW propagation in 154 kV GIS. The condition, model, and assumption of simulation are arranged in a similar way as in the previous report [1]. The FDTD simulation results are shown in Figure 9 and 10. The results were compared with measurement results and were analyzed from the following two viewpoints:

(i) Relative transmission rate (TR) based on the ratio of the amplitude of EMW, Vpp between the sensors.

(ii) Relative transmission rate based on ratio of the total of energy (TR_E) of EMW, E between the sensors.

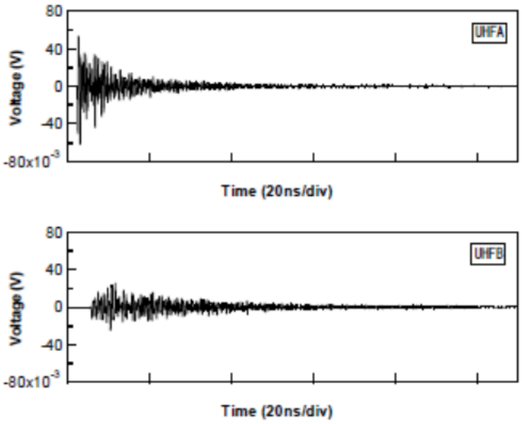


Figure 9: Calculated waveform of voltage through straight shape 154 kV model GIS without spacer at coaxial cable for HVP

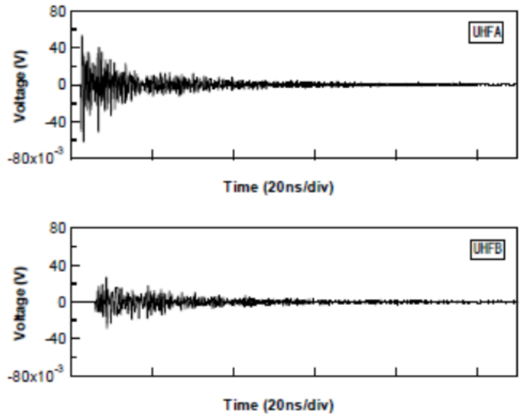


Figure 10: Calculated waveform of voltage through straight shape 154 kV model GIS with spacer at coaxial cable for HVP

4.3 Relative transmission rate based on the amplitude of EMW, Vpp

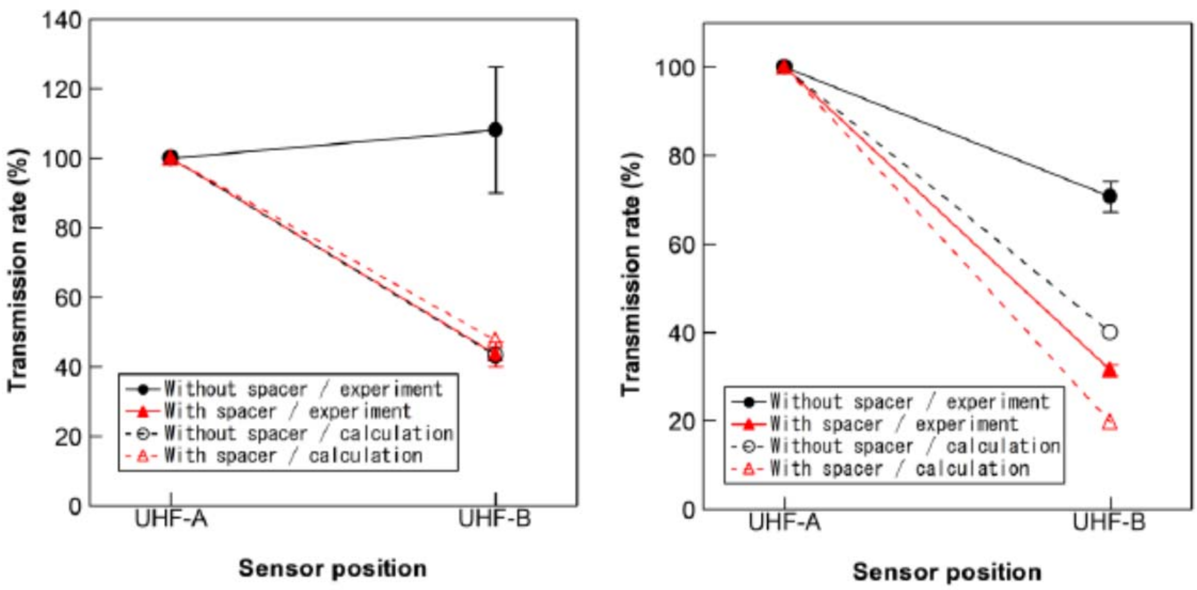
Figure 11 shows comparison simulation and measurement results of TR of PD induced EMW. The calculation results using FDTD analysis show that for HVP, TR WOS is 43.2% and TR WS is 47.6%; and for TFP TR WOS is 40.0% and TR WS is 19.7%. There was an error margin between the measurement and simulation results of about 10% in WS, and 60% and 40% in HVP and TFP WOS, respectively. The error margin of TR WS both HVP and TFP was smaler than one of TR WOS.

The disagreement between the analysis condition and the measurement condition is the major causes for the error margin. For example: the disagreement in the position and the direction where inputting shape of excited wave, and the size of PD, cause the difference of the results were large.

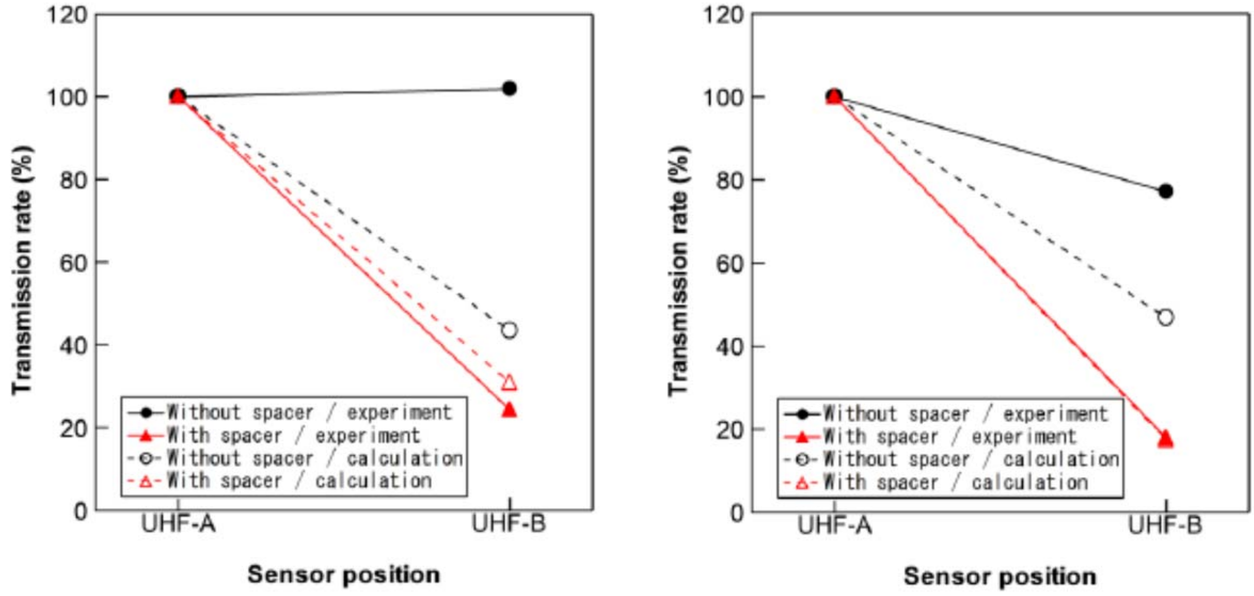
Moreover, the limitation of PC memory is a cause. The overlay of an incident wave and the reflected wave of the electromagnetic radiation is one of the causes.

4.4 Relative transmission rate based on the ratio of the total of energy wave between sensors

Up to now, the EMW propagation characteristic has been evaluated in EMW amplitude value, Vpp. This technique has the overlay with an incident and reflection wave in GIS internal structure. Therefore, it is difficult to define TR single meaning. Moreover, the error margin due to the difference of PD size may arise easily. The TR obtained from the ratio of the acquired EM wave gross energy as another evaluation method of the EMW propagation is discussed. The ratio of energy of each sensor was defined as relative TR_E.



(a) High voltageconductor sideparticle (b) Tank side free particle
Figure 11: Calculated transmission rate of EM wave propagating through straight shape154 kV GIS model tank



(a) High voltage conductor side particle (b) Tank side free particle

Figure 12: Energy transmission rate TR_E of EM wave propagating through straight shape 154 kV GIS model tank

If TR_E is transmission rate of energy, E is EMW energy measured at UHF sensor A and B (J), P is power (W), V is voltage (V), I is current (A), R is resistor (Ω), then:

$$TR_E = (E_{UHF\,B} / E_{UHF\,A}) \times 100 \quad (1)$$

$$P = V \times I = V^2/R \quad (2)$$

$$E = \int P dt = \int (V^2/R)\, dt \quad (3)$$

Relative TR_E of UHF-B when the energy value of UHF-A assumed to be 100% is defined as TR_{EAB}, and it is shown in Figure 12.

The analysis and the measurement results are compared. The errors margin of TR_E both HVP and TFP for WS are small, less than 5%. On the other hand, ones for WOS are more than 20%. When the method of evaluating energy (4.4) and amplitude (4.3) is examined mutually, TR of energy is lower than TR of amplitude. Therefore, when the EMW amplitude is considered, it is also necessary to examine the EMW energy.

5 CONCLUSIONS

The influence of the presence of the insulating spacer in 154 kV GIS tank model on the PD induced EM wave was examined by experiment and FDTD analysis. The results are summaraized as follows.

The amplitude Vpp and the energy of PD induced EM wave of WS were lower than WOS. The frequency spectrum of two types of foreign (HVP and TFP) were compared. EMW of HVP was large in the frequency of 4 GHz or less. EMW of TFP was large in the frequency of 6 GHz or more. The discharge waveform, frequency spectrum, Vpp, and energy transmittances have changed due to the difference of these frequency elements. When the method of evaluating energy and amplitude is examined mutually, TR of energy is lower than TR of amplitude. The error margin between the measurement and calculation in the presence of the spacer based on the energy evaluation is smaller than one based on amplitude evaluation. Therefore, when the EMW amplitude is considered, it is necessary to examine the EMW energy.

6 ACNOWLEDGEMENT

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7 REFERENCE

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