Propagation Property of Partial Discharge Induced Electromagnetic Wave in Power Transformer and Comparison of UHF Sensor Characteristics

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Abstract : This paper deals with propagation characteristics of electromagnetic (EM) waves emitted by partial discharges (PDs) in air for a transformer tank model. The EM waves were detected with UHF sensors installed on the internal surface of the model tank. Simulation using a finite difference time domain (FDTD) method was also performed to closely discuss the experimental results. Moreover, characteristics of two kinds of UHF sensor were compared for frequency spectra of PD signals.

1. INTRODUCTION

Recently, the number of aging power transformers has been increased. By economical point of view, insulation diagnosis method with higher accuracy is required. For the insulation diagnosis method in oil-filled type power transformers, gas dissolved analysis (DGA) method is practically used for a long time. However, there exists a problem in time response for DGA method. Therefore, the needs for higher accuracy and quick response to insulation diagnostic technique for power transformers increase on behalf of DGA. UHF method is one of the candidates as a promising tool for detecting partial discharge (PD) with high accuracy and high sensitivity. Thus, many research works were carried out in the literature. Application to a real transformer in the site is tried [1] - [7].

From these backgrounds, we have been studying PD detection using the UHF method and propagation characteristics of electromagnetic (EM) waves emitted by PD for upgrading the insulation diagnosis technology of transformers.

In this paper, we investigate propagation characteristics of EM waves emitted by PDs in air for a model tank simulating the structure of transformer. When UHF method is actually applied to an existing oil-immersed transformer, the sensor installation place is limited. One candidate place is oil ducts connected to a pipe for a radiator. As the ducts of oil-filled transformer are in the cylinder shape, EM waves propagating in the oil duct is composed of TE and TM mode that have cutoff frequency.

Moreover, we investigate the frequency response and sensitivity of UHF sensors when EM wave emitted by PD propagates into an oil duct. Especially, by changing the length of the simulated oil duct, we discuss the results in terms of high order propagation mode characteristics of EM wave.

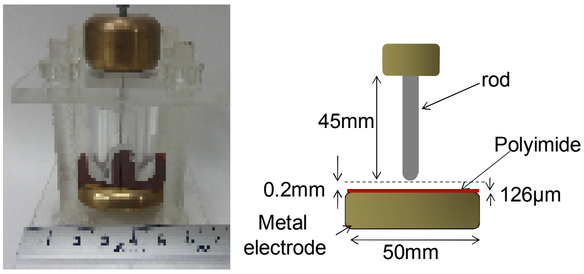
2. EXPERIMENTAL SETUP AND PROCEDURE

A transformer tank model (3,600mm × 1,800mm × 1,800mm and 0.6mm in thickness) was used as a test chamber. Rod-plane electrode as shown in Figure 1(a) was used as PD source, and EM wave emitted by PD was measured in air. Polyimide film of 0.126mm thickness was inserted between the tungsten rod of 1mm in diameter and the tip radius 0.5 mm and the plane electrode made of brass. A gap of 0.2mm was formed between the fixed electrode and the film. The electrode system was arranged in front of the center of an installed sensor at the position 335mm in height from the floor face, and 1,000mm apart from the tank wall where the UHF sensor was located.

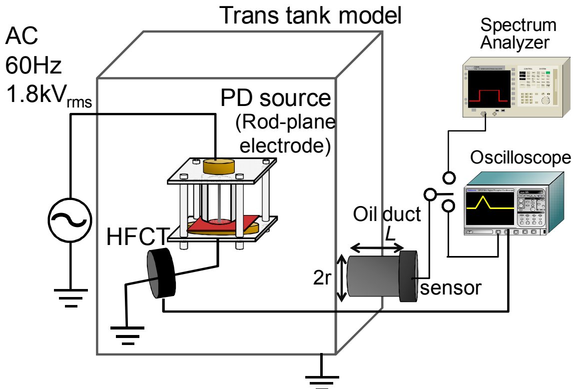
Figure 1(b) shows configuration of an oil duct simulating that of oil-filled transformer. Experiments were conducted under four conditions, i.e. without and with oil duct model of 220mm in inside diameter and three different lengths L=100, 200 and 400mm. Two kinds of UHF sensors were used in the experiments. Figure 2(a) and (b) show a disk type sensor with 200mm in diameter and 50mm in thickness, and a D-dot sensor (PRODYN technologies, - grand plane type and frequency cutoff 1GHz.).

PD was generated in the rod-plane electrode system by ac applied voltage 60Hz of 1.8kV$_{rms}$ at 60Hz. PD current was measured with a high frequency CT (EMCO 94111-1,1MHz - 1GHz) installed in a ground line connected from the plane electrode. Waveforms of PD current and EM wave emitted by PD were measured with a digital oscilloscope (Tektronix DPO7254, 2.5 GHz, 10 GS/s) simultaneously. Frequency spectrum of EM wave was measured using a spectrum analyzer (Agilent E4404B- , and 9 kHz - 6.7 GHz) in max hold mode for 300 seconds. PD inception voltage of this electrode system was 1.5 kV$_{rms}$. Note that PD in air with several nC to several tens nC occurred at 1.8kV$_{rms}$.

A transient electromagnetic analysis was also made using finite difference time domain (FDTD) software (CTC, MAGNA/TDM ver.7.2.1). A modelling was made in a similar to experiment. Gaussian pulse with flat frequency band to 1GHz was input as a PD source.

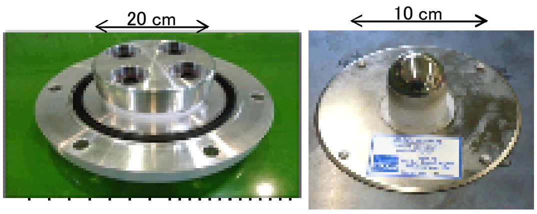


(a) PD source (Rod-plane electrode)



(b) Experimental configuration

Figure 1: PD source and Experimental configuration



(a) Disk type sensor (b) D-dot sensor

Figure 2: UHF sensors used

3. RESULTS

3.1 EM wave arrival time and strength

Figures 3 and 4 show waveforms of EM waves emitted by PD for different oil duct length measured with the disk type sensor and D-dot sensor, respectively, as well as a PD current measured with the CT sensor.

Figure 5 shows results of calculated EM waves by the FDTD simulation.

Arrows in Figures 3 to 5 represent the arrival time of each signal to the sensor. It is obvious that the arrival time of the EM wave increases with an increase of the length of the oil duct. Note that peak to peak value V_{pp} of EM wave detected by each sensor and *di*, *dt* of the PD current are defined in Figures 3 and 4.

Figures 6(a) and (b) show the relation between the time derivative *di/dt* and peak to peak value of the measured waveform V_{pp} for the disk type sensor and D-dot sensor.

To avoid the influence of reflected wave in the tank, V_{pp} of EM wave was defined as peak to peak value observed in arriving 3ns or less from the attainment wave as shown in Figures 3 and 4.

It is evident from Figure 6 that a linear relationship is seen between *di/dt* and V_{pp} for both sensors. Namely, EM wave intensity is in proportion to the time derivative of PD current. It is noticed that the existence of the duct brings decrease in the EM wave intensity (V_{pp}) for the disk type sensor, but not so much decrease for the D-dot sensor.

3.2 Frequency response

Figures 7 and 8 show frequency spectrum of EM waves measured with the spectrum analyzer for the disk type sensor and D-dot sensor, respectively, for different duct lengths. Figure 9 shows FFT (Fast Fourier Transform), of EM wave calculated by FDTD method. It is found from the three figures that the frequency spectrum extends over 500MHz for the oil duct with L=100mm, while the frequency component around 1GHz almost disappears for L=200 and 400mm. Note that the cutoff frequency remarkably appears for the D-dot sensor as the duct length L increases.

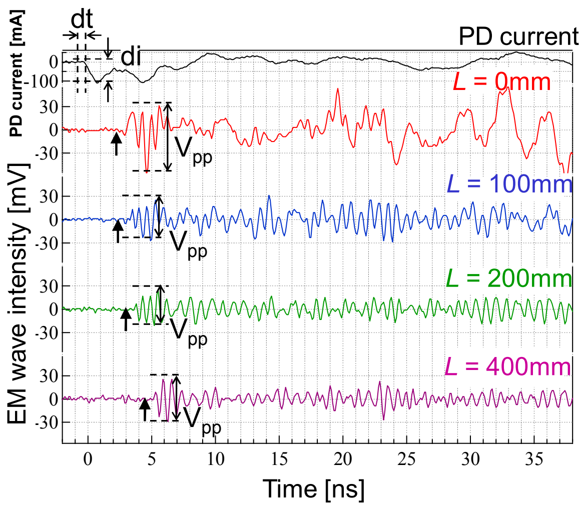


Figure 3: PD current and EM wave detected by the disk type sensor

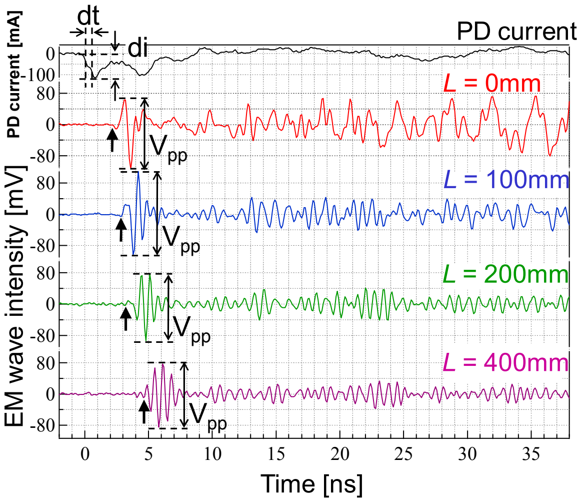


Figure 4: PD current and EM wave detected by the D-dot sensor

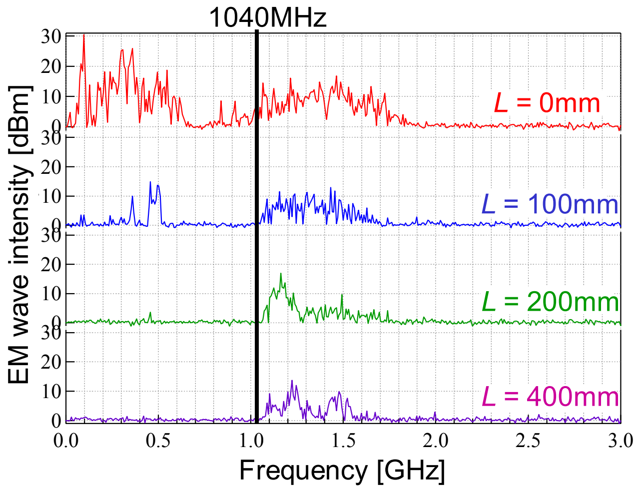


Figure 7: Frequency spectrum of PD-EM wave detected by the Disk type sensor

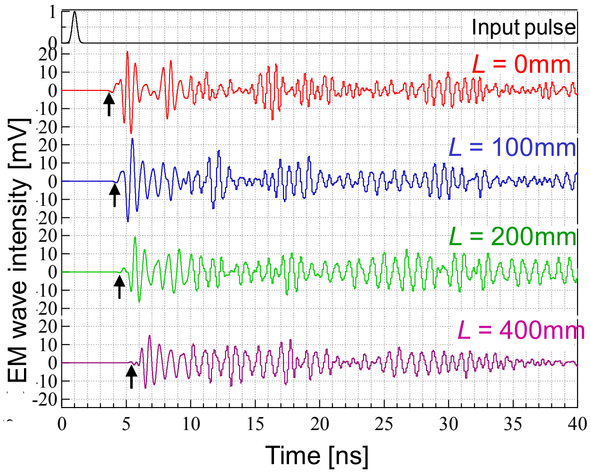


Figure 5: In put pulse and calculated EM wave by FDTD method

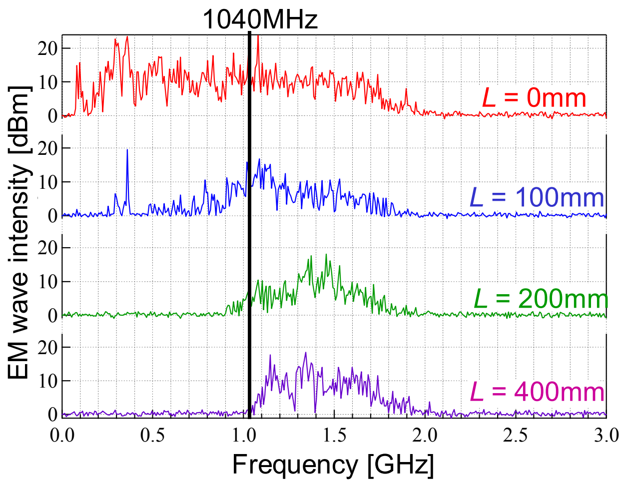
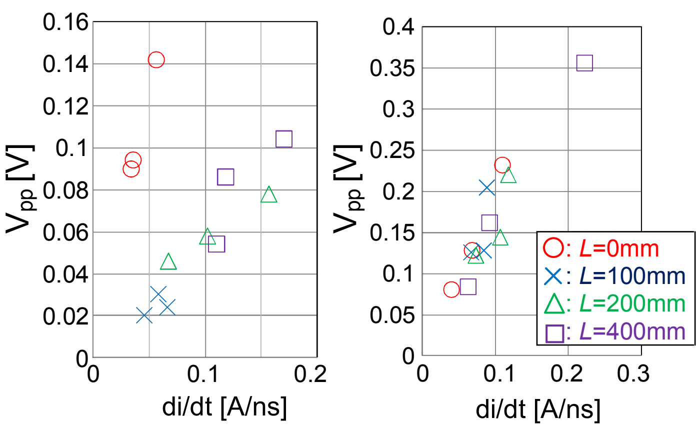


Figure 8: Frequency spectrum of PD-EM wave detected by the D-dot sensor



(a) Disk type sensor

(b) D-dot sensor

Figure 6: Characteristics of - di/dt – $V_{p\text{-}p}$

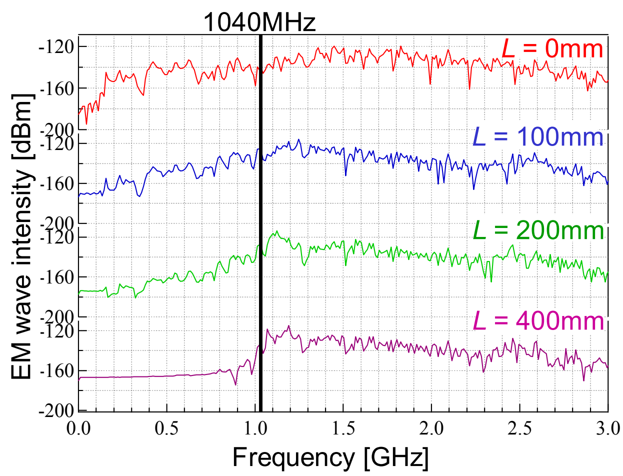


Figure 9: Frequency spectrum of calculated EM wave by FFT

4. DISCUSSION

When the oil duct used is considered to be a circular waveguide, the cutoff frequency f_c of TE_{11} that is the fundamental higher-order propagation mode is 800 MHz as expressed as equations (1) and (2).

$\lambda_{TE11} = 3.41 \times r$ [8] ・・・・・・・・・・・・・・ (1)

$f_{TE11} = c / \lambda_{TE11}$ [8] ・・・・・・・・・・・・・・ (2)

where λ_{TE11} is the wavelength of TE_{11} mode, r = 110mm and c is a velocity of light.

For the results of the disk type sensor, as shown in Figure 7, the existence of the duct causes the frequency component to be cutoff below 1GHz irrespective of the duct length. On the other hand, for the D-dot sensor, as shown in Figure 8, the frequency component above 800MHz remains for the oil duct of the length 100 and 200mm. The difference in the measurable can be interpreted in terms of the sensor's directionality.

EM wave propagates as TM mode as well as TE mode in a cylinder waveguide. TM mode has the electric field component in the direction same as the travelling direction, and the fundamental mode is TM_{01} mode. The cutoff frequency f_{TM01} 1043MHz. Note that the frequency f_{TM01} is expressed as equations (3) and (4).

$\lambda_{TM01} = 2.613 \times r$ [8] ・・・・・・・・・・・・・ (3)

$f_{TM01} = c / \lambda_{TM01}$ [8] ・・・・・・・・・・・・・ (4)

where λ_{TM01} is the wavelength of TM_{01} mode.

It should be noticed that a disk type sensor allows one to detect only the vertical component of the electric field incoming to the surface-normal. On the other hand, D-dot sensor allows the direction of cosine component of the electric field of EM wave incoming to the sensor face. The ability to detect the cosine component for the D-dot sensor can explain the difference in the frequency spectrum measured with the disk type sensor and D-dot sensor.

It was thus understood that EM wave emitted by PD and propagating in the oil duct greatly depends on the propagation mode of TM_{01} and directionality of UHF sensor type used.

5. CONCLUSION

In this paper, we investigated propagation characteristics of EM waves emitted by PDs in air for a model tank transformer. We investigate the frequency response and sensitivity of two kinds of UHF sensors when EM wave emitted by PD propagates into an oil duct. By changing the length of the simulated oil duct, we discussed the results in terms of high order propagation mode characteristics of EM wave. It was found that frequency component almost disappears for existence of oil duct model. Cutoff frequency f_c calculated for cylinder waveguide radius r. It was found that EM wave emitted by PD and propagating in the oil duct greatly depends on the propagation mode of TM_{01} and directionality of UHF sensor type used.

6. REFERENCES

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