Measurement of Partial Discharge Induced Electromagnetic Wave using Loop Antenna

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Abstract—**Partial discharge (PD) detection by detecting the released energy in the form of electromagnetic (EM) wave during discharge using Ultra-High Frequency (UHF) antenna is one of the methods to determine insulation system quality of power apparatus. The main advantage of UHF PD detection system by using antenna are the capability to detect PD signal without firstly shut down the power apparatus. Therefore, the PD measurement system based on EM wave induced by PD detected by the sensor is needed. First, the sensors which be able to detect PD induced EM wave in ultra wide band need to be designed and manufactured. Second, the characteristics of PD induced EM wave measured by the sensors need to be investigated. This paper deals with measurement of PD induced EM wave by using loop antenna. The results show that the further the distance of loop antenna to PD source is, the lower Vpp is. This is due to EM wave attenuation. At the distance 225 cm from PD source, Vpp of PD is equal to Vpp of the background noise (BGN). Therefore, the maximum distance of the loop sensor to PD source is 225 cm.**

Keyword—partial discharge, electromagnetic wave, loop antenna

I. INTRODUCTION

High voltage insulation is the most important part of a high voltage equipment used in an electric power system. The main task of the insulation is to withstand the high electric field between phases or phase and neutral. In excessive high electric field due to the appearance of field enhancement sites like void or protrusion, partial discharge (PD) may occur. The appearance of PD in the electrical insulations may indicate the insulation aging and in the long term this may further reduces the integrity of the insulation leading to the failure of the equipment. Diagnosis of PD in the early stage is needed to prevent the breakdown of the high voltage equipment. Diagnosis of PD is considered to highly represent the actual condition of the equipment. PD detection is the first step in power apparatus diagnosis. In order to maintain the reliability and availability of the power system, it is needed to design the online measurement system.

PD occurring in power apparatus releases energy in various form such as light emission, acoustic wave, heat, and the electromagnetic wave which can be detected by the suitable sensor. The impulse current flowing from the PD source may be detected by detecting impedance or high frequency current transformer clamped in the PD current path. The measurement should be conducted in the power apparatus which means it is near high voltage part. The light emission may be detected by photomultiplier which required dark room or enclosed equipment. The acoustic wave may be detected by acoustic sensor but it sensitive to the vibration noise. The electromagnetic wave may be detected by antenna. Although it is sensitive to the external noise, the placement of the antenna inside the metal enclosed equipment is considered to reduce noise significantly.

Power apparatus is generally in the form of metal enclosed equipment. The released energy from PD such as light, heat, and EM wave is disable to pass through metal enclosure, so they must be detected by internal sensor. However, PD induced EM wave may leak from the dielectric window of power apparatus. EM wave may propagate through the dielectric window and detected by external sensor. The PD measurement by using external sensor has many advantages such as safe and easy in sensor installation. Therefore, the PD measurement system in metal enclosed equipment will be developed based on EM wave induced by PD detected by external sensor. First, the sensors which be able to detect PD induced EM wave in ultra wide band need to be designed and manufactured. Second, the characteristics of PD induced EM wave measured by the sensors need to be investigated.

Various antennas have been developed for PD induced EM wave measurement so far [1-9]. The loop antenna is chosen for PD detection in this research because it has good characteristics, small, simple, and cheap [6-9]. The measurement of PD induced EM wave by using loop antenna is reported in this paper. In addition, PD was measured by high frequency current transformer for result comparison. The basic characteristic of PD induced EM wave such as PDIV and PD waveform is reported.

II. EXPERIMENTAL SETUP

A. Artificial PD source

PDs signal were generated by artificial PD source using a needle-plane with a gap of 1.5 cm. The steel needle with tip radius of 10μm and curvature angle of 30°. This model generates corona discharges which is a type of partial discharge commonly found in high voltage insulation system. The needle-plane electrode kit is shown in Figure 1. The electric field at the tip of the needle electrode is estimated by using the following equation [10]:

$$Em = 2V / (r \ln 4d/r)$$

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Where V is the applied voltage, r is the radius of the needle tip and d is the electrode separation.

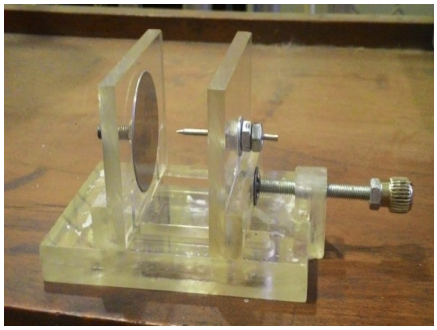


Figure 1. Needle-plane electrode system

B. *Experimental Setup*

Experimental setup was arranged as shown in Figure 2. Artificial PD source was put in the center inside aluminum box (sized 50 x 50 x 50 cm3) to simulate metal enclosed electrical equipment. Sensors used to measure PD were loop antenna and HFCT. The loop antenna was placed at the distance 23, 35, and 55 cm from PD source. The measurement result by loop antenna was compared with the measurement result by high frequency current transformer (HFCT). Partial discharges occur when high voltage is applied to the artificial PD source. PD was detected by HFCT and loop antenna. PD was measured by digital oscilloscope. The data from digital oscilloscope transferred to a personal computer for further analysis to show phase of PD occurrences, magnitude of discharges and PD pulse number which will be shown in Vpp - q - n pattern.

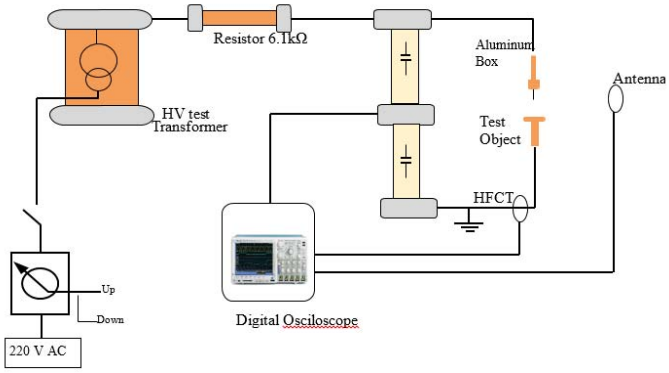


Figure 2. Experimental setup

C. *Measurement Item*

The following parameters will be measured:

1. PD inception voltage (PDIV): the voltage when initial PD starts to occur.
2. PD waveform
3. Vpeak-peak (Vpp), Vpositive-peak and Vnegative-peak of PD waveform.
4. PD phase pattern

III. PD MEASUREMENT RESULTS

A. *Background Noise (BGN) Measurement*

Table 1 shows BGN measurement results measured by HFCT and by loop antenna at the distance 23 cm, 35 cm, and 55 cm from PD source.

Table 1 BGN

Sensor	BGN (mV)	
	BGN +	BGN -
Loop antenna, 23 cm	4.00	-2.80
Loop antenna, 35 cm	4.80	-3.20
Loop antenna, 55 cm	5.07	-3.73
HFCT	6.80	-7.20

B. *Partial Discharge Inception Voltage (PDIV)*

PDIV was detected by loop antenna at 3.73 kV applied voltage. Vpp at PDIV is 42.4 mV. Table 1 shows the magnitude of PD waveform (Vpp) at PDIV measured by HFCT and loop antenna placed at the distance 23 cm, 35 cm, and 55 cm away from PD source. It appears that the further the distance of loop antenna to the PD source, the lower the magnitude of PD waveform at PDIV.

Table 2 Vpp of PD at PDIV

Sensor	Vpp (mV)
Loop antenna, 23 cm	42.4
Loop antenna, 35 cm	14.0
Loop antenna, 55 cm	7.6 (Noise)
HFCT	37.2

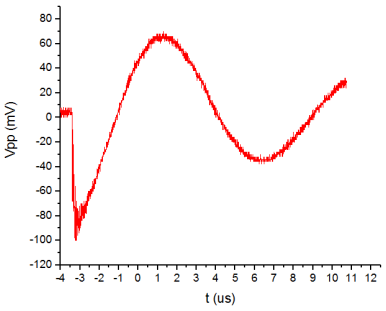
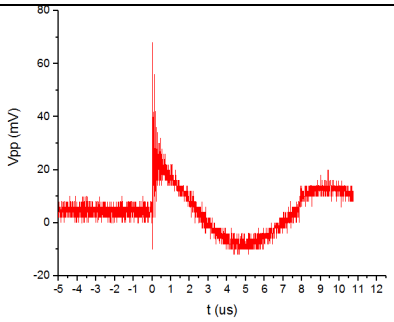
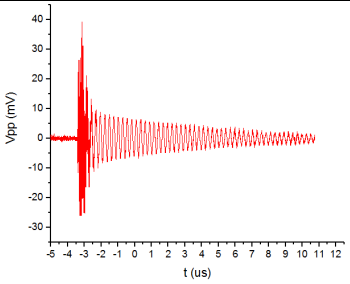
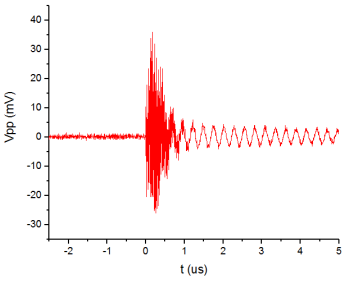
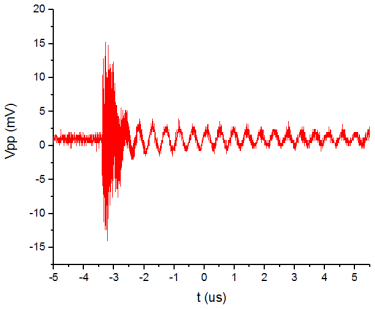
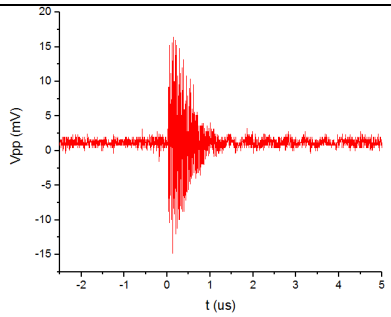
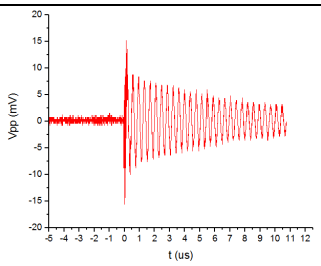
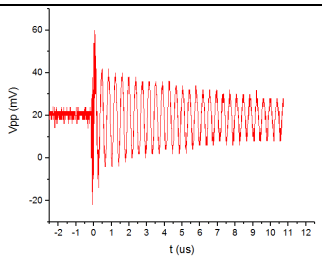
C. *Partial Discharge Waveform*

Table 3 shows PD waveform measured by HFCT and loop antenna at the distance 23 cm, 35 cm, and 55 cm from PD source at 7 kV applied voltage. The distance of PD source to antenna affects the magnitude of PD induced EM wave, Vpp measured by loop antenna. The distance of PD source and antenna has affects the magnitude Vpp of PD induced EM wave. The further the distance of loop antenna to PD source is, the lower Vpp.

D. *Loop Antenna Detectability*

The loop antenna detectability was tested by increase the distance of loop antenna and PD source until the maximum distance where the Vpp of PD is equal to Vpp of BGN. The distance was added step by step: 75 cm, 95 cm, 115 cm, 125 cm, 145 cm, 165 cm, 175 cm, 195 cm, 215 cm, and 225cm. Figure 3 summarizes measurement results of PD waveform at 7 kV applied voltage. It describes the relation of Vpp of PD waveform measured by loop antenna and the distance between loop antenna position and PD source. At the distance 225 cm from PD source, Vpp of PD is equal to Vpp of BGN.Therefore, the maximum distance of the loop sensor to PD source is 225cm.

Table 3 PD waveform at 7 kV

Sensor		PD Waveform	
		PD -	PD +
HFCT	(a)	 (i)	 (ii)
Loop antenna 23 cm	(b)	 (i)	 (ii)
Loop antenna 35 cm	(c)	 (i)	 (ii)
Loop antenna 55 cm	(d)	 (i)	 (ii)

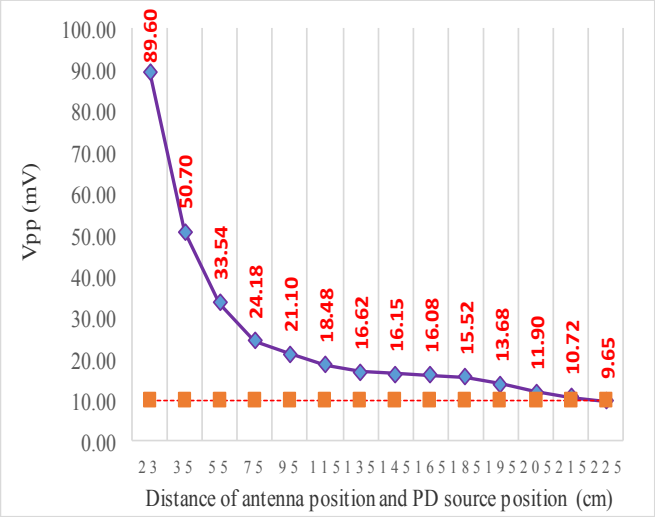


Figure 3 Vpp measured by loop antenna

IV. ANALYSIS AND DISCUSSION

The distance of PD source to antenna affects the magnitude of PD induced EM wave measured by loop antenna. The distance of PD source and antenna decreases the Vpp of PD induced EM wave. The further the distance of loop antenna to PD source is, the lower Vpp is. These results are explain as follows.

The distance of PD source to antenna affects the sensitivity of the loop antenna. If the distance of loop antenna to PD source is further, the sensitivity of the loop antenna reduces. This is due to EM wave attenuation. Intensity of EM wave reduces when EM wave passes through a certain distance. The attenuation may be caused by scattering, absorption, diffraction, and reflection of EM wave. Path loss or path attenuation is obtained from the equation:

$$L = 10\, n \log10\,(d) + C$$

where L is the path loss (dB), n is the path loss exponent (2 for free space, 4 for lossy environment, 4-6 for building, stadium, or indoor environment), d is the distance between transmitter and receiver (m), and C is a constant which accounts for system losses. Figure 4 shows attenuation curve of EM wave resulted from the path loss formulation. It appears that the curve has the similar trend with the experiment results.

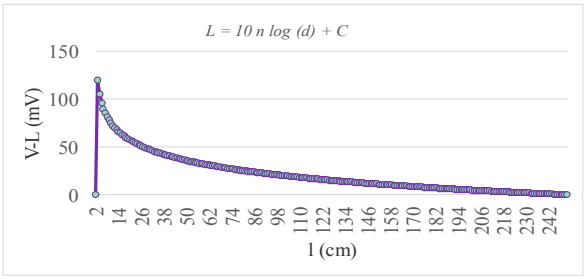


Figure 4 Attenuation curve of EM wave

V. CONCLUSION

This paper discussed the measurement of partial discharge induced EM wave by using HFCT and loop antenna. The results are concluded as follows. The distance of PD source to antenna affects the magnitude of PD induced EM wave measured by loop antenna. The increase of distance of PD source and loop antenna decreases the magnitude Vpp of PD induced EM wave. The further the distance of loop antenna to PD source is, the lower Vpp is. At the distance 225 cm from PD source, Vpp of PD is equal to Vpp of BGN. Therefore, the maximum distance of the loop sensor to PD source is 225 cm.

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