PARTIAL DISCHARGE INDUCED ELECTROMAGNETIC WAVE PROPAGATION ANALYSIS AND DETECTION USING UHF SENSOR IN TRANSFORMER

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Abstract: This paper deals with optimum UHF sensor design and fabrication suitable for oil-filled transformer as well as the sensor characteristics and sensitivity check. As one promising UHF sensor, we make design of small loop antenna and fabricate it, investigating antenna characteristics and sensitivity in detecting PD in a model transformer.

1 INTRODUCTION

In diagnostic technique for transformers, UHF method is one of the candidates as a promising tool for detecting partial discharge (PD) with quick response, high sensitivity and wide range. Lots of the research work have been done on PD measurement of transformers [1-12]. Field application of the method is also tried [1, 3].

In applying the UHF method to oil filled transformer, electromagnetic wave emitted by PD exhibits complicated phenomena such as reflection, resonance because of the existence of windings, iron core, pressboard and so on. Therefore, it is needed for the application of the UHF method to practical diagnosis to understand EM wave propagation properties in the transformer. To enhance dramatically the reliability of the diagnosis, such as precise PD location identification and increase of the PD detection sensitivity, it is strongly required to understand the propagation properties of EM waves caused by PD occurring inside the transformer.

From this point of view, the authors have investigated insulation diagnostics technique for oil-filled transformers using UHF method through both experiments and simulation technique using finite difference time domain (FD-TD) method [11,12]. In previous works, we investigated the effect of existence of the winding and oil duct on EM wave propagation characteristics by experimental and numerical simulation [11].

In oil-filled transformer, EM wave emitted by PD occurring in the winding propagates through the slits between the windings and insulating materials such as pressboard (PB). Furthermore, we compared various UHF sensors installed in the oil duct of an oil-filled transformer. We also investigated the influence of PD source type on the frequency characteristics of PD emitted EM waves propagating in the transformer [12].

This paper deals with optimum UHF sensor design and fabrication suitable for the oil-filled transformer as well as the sensor characteristics and sensitivity check. As one promising UHF sensor, we make design of small loop antenna and fabricate it, investigating antenna characteristics and sensitivity in detecting PD in a model transformer.

2 EXPERIMENTAL

Figure 1 shows experimental circuit. Figure 2 depicts a winding model, which was installed in a model transformer tank with the size of 3600x1800x1800. As a PD source, a needle plane electrode (NP) and intersection PD model (SS) were used (Figure 3). The NP model consists of the needle made of tungsten with a tip radius r =0.01 mm and diameter of 1.0 mm, and plane electrode made of SUS with diameter of 76 mm, with a pressboard PB inserted between the two electrodes with a gap space of 1 mm. The SS model consists of two insulated coil bars facing each other with 4 mm space between them and artificially cut defect. The PD source was located inside the winding model as shown in Figure 2. Electromagnetic wave (EMW) emitted by PD and PD current pulse were measured using UHF sensor and a detecting resistance connected in series with the PD source, respectively.

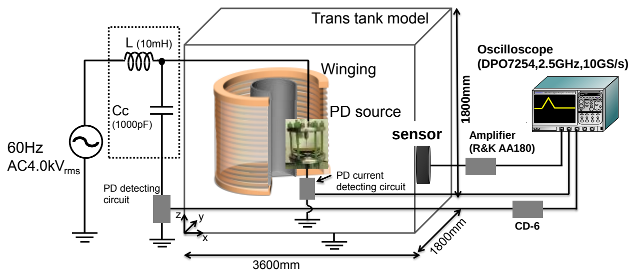


Figure 1 Experimental circuit

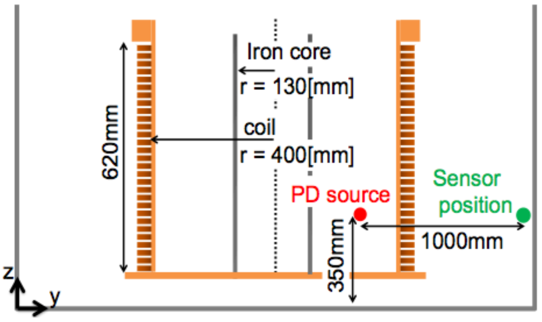
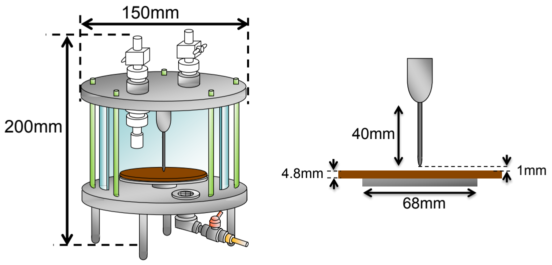
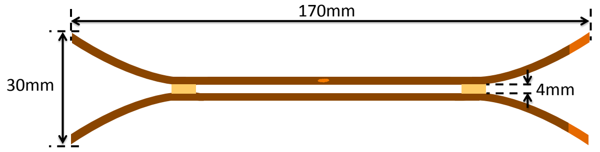


Figure 2 Winding model



(a) NP model



(b) SS model Tendency)

Figure 3 Needle plane NP electrode model and intersection coil model

The charge of PD was estimated using a PD measuring device (CD-6) with carrying out calibration in advance. These signal waveforms were measured with a digital oscilloscope (Tektronix DPO7254, 2.5 GHz, 10GS/s).

3 UHF SENSORS AND ELECTROMAGNETIC WAVE CAUSED BY PD SOURCE

Three different UHF sensors were used: a D-dot sensor (PRODYN, AD-30 A cutoff frequency 1 GHz), and two loop antennas fabricated with semi-rigid cable. Figure 4 shows frequency characteristics of EMW measured with the D-dot sensor for NP and SS models as well as reflection coefficient S11 of scattering parameter of D-dot sensor measured with a network analyzer (ADVANTEST, R3765CG, 300kHz-3.8GHz). As can be seen in the figure, the D-dot sensor has almost flat frequency characteristics of S11 over 1.5 GHz. It is obvious from the figure that the frequency component of PD EMW measured for NP model continuously extends over 1.3 GHz, while that for SS model dominates less than 500 MHz.

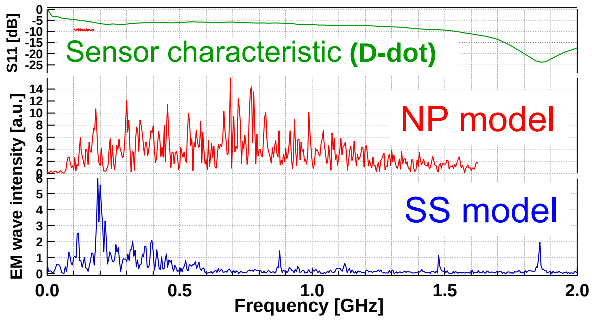


Figure 4 Frequency characteristics of D-dot sensor and EM waves of each PD source

The result indicates that the difference in the frequency component of the EMW characteristics between the two PD source models NP and SS arises from each different discharge mechanism. It should be noticed that the dominant frequency component of NP and SS models lies around 720 and 200 MHz, respectively. Two types of loop antenna were designed so as to match their resonant frequency to each dominant frequency for the two defect models and fabricated using semi-rigid cable. The antenna design was made so that a circumference of the loop sensor becomes one tenth of the wavelength of EMW at the specific frequency of 720 and 200 MHz for NP and SS models, respectively. The resultant radius of the loop sensors was determined to be 9.5 and 31 mm for 720 and 200 MHz, respectively. Note that the above calculation for the design was made using the following equations:

$$\lambda = \frac{c}{f/\sqrt{\varepsilon_r}} \qquad (1)$$

$$r = \frac{\frac{\lambda}{10}}{2\pi} \qquad (2)$$

where λ is the wavelength, c is the speed of light ε_r is the relative permittivity of the insulating material used in the semi-rigid cable (Teflon, =2.05). Hereafter, let Loop9.5 and Loop31 represent the fabricated antenna with the radius of 9.5 and 31 mm, respectively. Figure 5 shows thus fabricated loop antennas. Figure 6 also shows frequency dependence of the scattering parameter S11 of Loop9.5 and Loop 31, respectively. As can be seen in the figure, the two loop sensors Loop 9.5 and Loop31 have resonant frequency at 750 MHz and 200 MHz, respectively.

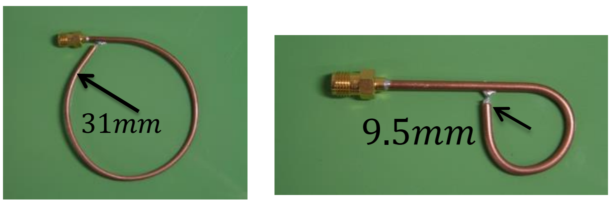


Figure 5 Fabricated loop sensors

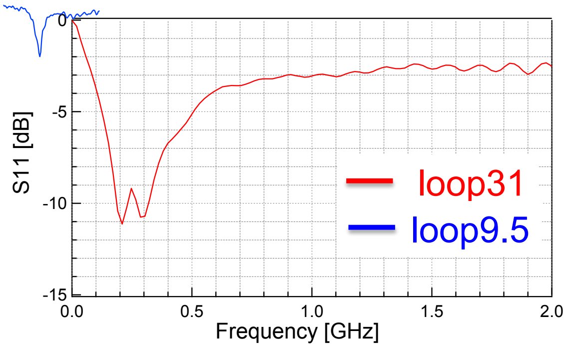


Figure 6 Frequency dependence of scattering parameter S11 of two types of loop antennas.

4 RESULTS AND DISCUSSION

Figures 7 and 8 show typical results of waveforms of PD current and EMW of NP model detected with each loop sensor for NP and SS model, respectively. It is evident from the figures that the two loop sensors allow detection of PD of NP model, while PD EMW equivalent to 148 pC for SS model is not detected with Loop9.5 sensor.

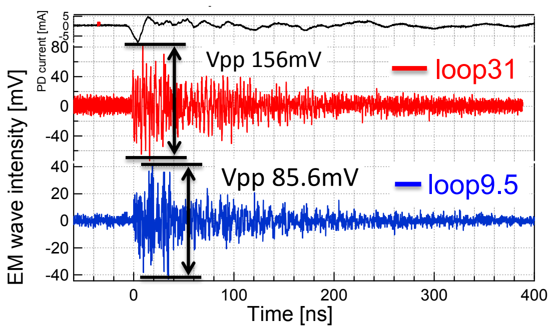


Figure 7 PD current and EMW of NP model detected with each loop sensor (PD charge: 457 pC)

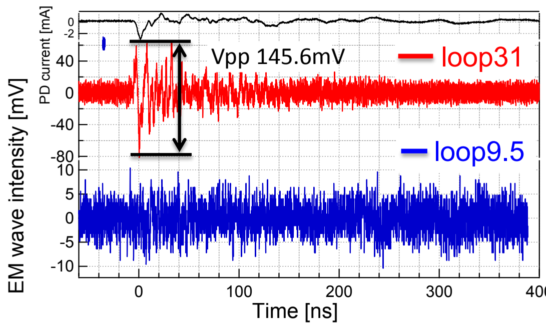


Figure 8 PD current and EMW of SS model detected with each loop sensor (PD charge: 148 pC)

Figures 9 (a) and (b) show relationship between PD charge and peak to peak voltage V_{pp} of PD EMW detected with the two sensors for NP and SS model, respectively. It is seen in these figures that that almost linear relation between the PD charge and EMW intensity of V_{pp} for NP model, while for SS model Loop9.5 does not allow detection of PD EMW. These results can be interpreted in terms of the frequency response of the two loop sensors with the different dominant resonance frequency.

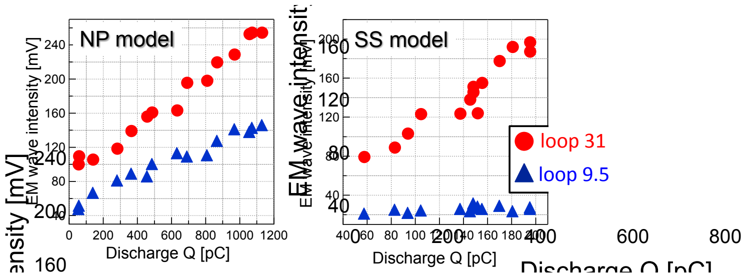


Figure 9 Relationship between PD charge peak to peak voltage V_{pp} of PD EMW detected with the two sensors for NP and SS model

Figures 10 and 11 show frequency characteristics of EMW caused by each PD source measured with Loop31 and Loop9.5, respectively.as well as S11 as a function of the frequency for each sensor. Note that for SS model Loop9.5 could not detect EMW, so that only the result obtained for Loop31 is shown. As seen in the figures, measured EMW is closely related to the sensor's frequency dependent response. Namely, the sensor Loop9.5 does not detect frequency component below 500 MHz. It follows that Loop9.5 cannot detect EMW of SS model whose dominant frequency range extends till 500 MHz. These results suggest the possibility that simultaneous use of the two types of loop sensors with different dominant resonance frequency allow to distinguish PD whether the source stems from NP like discharge or SS type discharge, leading to a PD source identification or location.

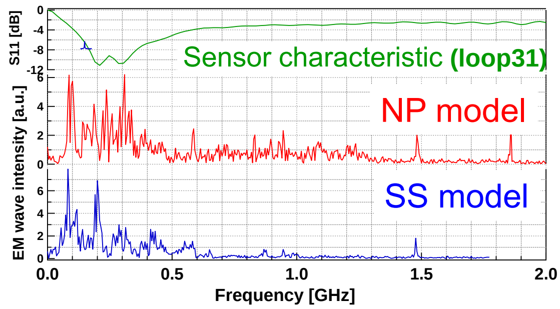


Figure 10 Frequency characteristics of S11 of Loop31 and PD EMW caused for NP and SS model

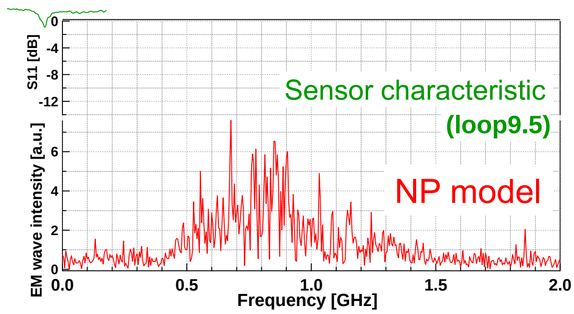


Figure 11 Frequency characteristics of S11 of Loop9.5 and PD EMW caused for NP model

6 CONCLUSIONS

In this paper, we investigated optimum UHF sensor design and fabrication suitable for detecting PD induced electromagnetic waves for oil-filled transformer, as well as the sensor characteristics and sensitivity check. As one promising UHF sensor, we make design of small loop antenna with different resonant frequencies at 750 and 200 MHz, which arose from dominant frequency component of the PD sources of the needle plane electrode (NP) model and the intersection coil bar (SS) model. We also fabricated the, investigating antenna characteristics and sensitivity in detecting PD in a model transformer. The experimental results suggest the possibility that simultaneous use of the two types of loop sensors with different dominant resonance frequency allow to distinguish PD whether the source stems from NP like discharge or SS type discharge, leading to a PD source identification or location.

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