Partial Discharge Measurement for Transformer Insulation Using Wide and Narrow Band Methods in Ultra High Frequency Range

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Abstract— **The ultra high frequency (UHF) detection method of partial discharge (PD) is presented in this paper. The log spiral and conical sensors were developed and used with a spectrum analyzer to detect PDs. Measurements of signals produced by two artificial PD defects were carried out in both broad and narrow band frequency ranges. The effectiveness of the sensors was compared and shown in this paper. Both sensors are capable of detecting the signal emitted by artificial PD defects. The phase resolved partial discharge (PRPD) results from the UHF detection method show strong similarity to those obtained from the conventional IEC 60270 measurement system. For the same PD level, the conical sensor shows higher signal magnitude but the log-spiral sensor offers better noise rejection at frequency below 300 MHz. Both sensors are capable of detecting PDs with magnitude above 30 pC.**

Keywords: conical sensor, log-spiral sensor, Ultra High Frequency (UHF) detection

I. INTRODUCTION

The transformer is one of the most important equipment items in electrical power system networks. Any failures that lead to transformer outage must be avoided. Transformer failure is mostly due to the failure in the insulation and this is usually started by the occurrence of partial discharge (PD).

The PD pulse has a very short duration, typically less than 1 ns of rise time and few ns of pulse width. Thus it is a broad band signal which contains frequency components well into the GHz range. The ultra high frequency (UHF) method to detect PD was discussed in details elsewhere [1, 2]. This method has a number of advantages over other detection methods such as the conventional electrical detection method in the lower frequency range of the spectrum (up to ~1MHz) as defined in the IEC-60270 Standard. It is possible to achieve better sensitivity by using the UHF detection method [1]. Also, it gives better immunity against interference from air corona [2].

The UHF PD detection method is based on the detection of high frequency electromagnetic waves generated by the PD source. The frequencies could be in the range from 300 MHz up to a few GHz. To capture this high frequency signal, an appropriately designed antenna is needed.

For transformer monitoring, the UHF sensor is inserted into the transformer tank to capture the electromagnetic waves emitted by the PD source. There are two ways of installing the sensor: via the oil drain valve [3] or the dielectric window [4]. The size of the oil drain valve imposes a constraint on the sensor dimension. On the other hand, the dielectric window can be created with an appropriate size to accommodate the sensor. However, the placement of dielectric window sensor needs an additional hole to be fabricated on the transformer tank. This is not a trivial exercise. As for the oil valve sensor, this is not required as the sensor can be easily retrofitted into the transformer via the existing built-in oil valve.

To measure the PD signal, an oscilloscope or spectrum analyzer can be used. The advantage of spectrum analyzer (SA) over oscilloscope is its frequency range flexibility [5]. The PD measuring frequency ranges used were broad band, narrow band or at single frequency using zero span method. The broad band frequency range is typically set between 100 and 1500 MHz. The narrow band performs measurement over a narrower specific frequency range while the zero span is applied to capture the phase resolved partial discharge (PRPD) patterns with respect to the power frequency (50Hz) cycle [6]. The disadvantage of using SA is that, due to its measurement principle, a relatively long integration time is needed to build up the spectrum display [5].

This paper investigates the use of two different UHF sensors for PD detection: the conical sensor for installation through the oil drain valve and the planar log spiral sensor for installation through a dielectric window. The sensors are placed inside the transformer tank and connected to a SA to detect PD. Two types of artificial defects were created to produce cavity discharge and surface discharge.

II. TEST SETUP

The experimental setup is shown in Figure 1. A distribution transformer tank with the windings and the core removed was used. The tank was filled with transformer mineral oil and fully enclosed. High voltage connection to a discharge source placed inside the tank was made via a high-voltage bushing. The UHF sensor was placed inside the transformer tank and connected to a spectrum analyzer outside.

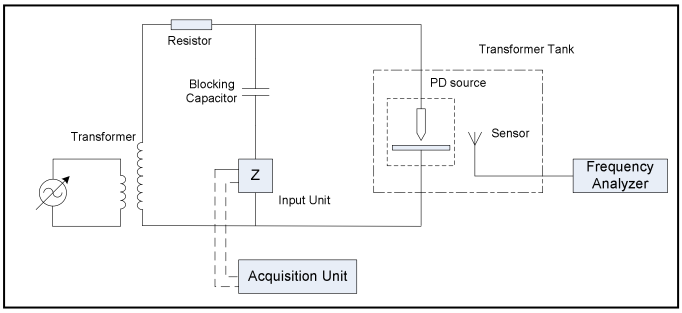


Figure 1: Experiment diagram

Standard transformer pressboard was used to construct two simple artificial PD defects. Cavity discharge was simulated using two flat electrodes separated by a stack of three layers of pressboard with a 2mm diameter hole in the middle layer. Surface discharge was achieved by using a curved electrode instead and with no void in the middle pressboard layer. The PD defect samples were immersed in the oil for 24 hours before tested.

A spectrum analyzer was used to capture the signal emitted by the PD defect model and detected by the antenna in two modes: wide band (up to 1.5 GHz) and narrow band at a specific frequency. An IEC 60270 conventional PD measurement system was used to measure the magnitude of the apparent charge generated by the PD defect source. The phase resolved partial discharge (PRPD) results obtained with this system were also used for comparison with the SA narrow band measurement results.

III. PD DETECTION USING UHF SENSOR

As mentioned earlier, the PD pulse signal spectrum contains the UHF range (300 MHz ~ 3000 MHz). In order to detect the PD signals within this frequency range, the detection system will require UHF sensors with suitable characteristics. In this paper, two types of sensor were developed and used: the conical and log-spiral sensors.

Figure 2 shows the two types of UHF sensor that were used in the experiment. The conical sensor is a monopole sensor type. Its length is 10 cm and the diameter of the opening mouth is 4 cm. It was constructed using copper sheet and mounted on a circular single layer PCB with a diameter of 4 cm. The log-spiral sensor was fabricated by etching the pattern on a single layer PCB.

The conical sensor was connected directly to the measurement system via a 50Ω coaxial cable. The log-spiral sensor is a balanced type and thus cannot be connected directly to the measurement system. A balun was used as a connector between the balanced log-spiral sensor and the unbalanced measurement system. A Chebyshev multi-section matching transformers equation [7] was used to decide the number of stages for the balun. By optimizing the overall length and number of sections, a five-stage balun is adequate to connect the log-spiral sensor which has an impedance of 120 ohms to the 50 ohm coaxial cable.

The balun was constructed on a single layer PCB and has 5 stages of the balance side. The balun has a length of 51 mm and width of 34.5 mm (Figure 3) and designed to work within the frequency range from 300 MHz to 3000 MHz. The coplanar strip (CPS) side is adjusted to achieve 120 ohms as the impedance value of the log-spiral sensor and the coplanar waveguide (CPW) side is set to 50 ohms as the coaxial impedance value.

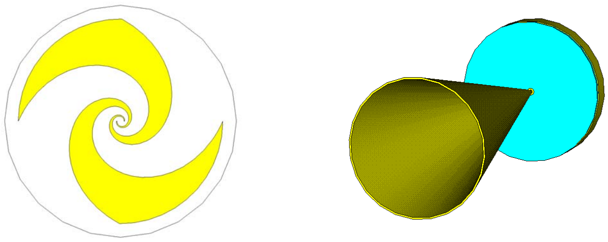


Figure 2: Log-spiral and conical sensor shape.

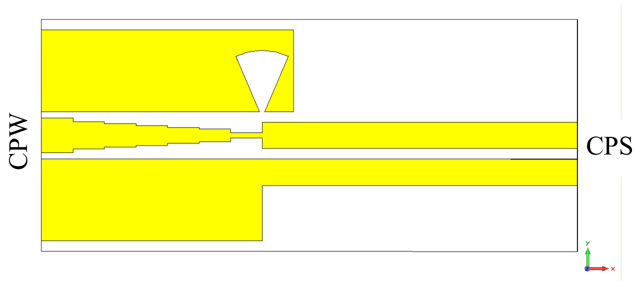
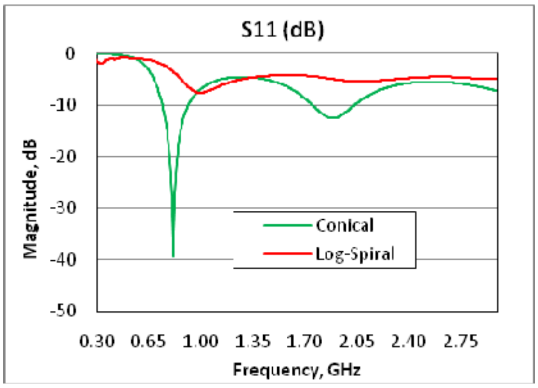
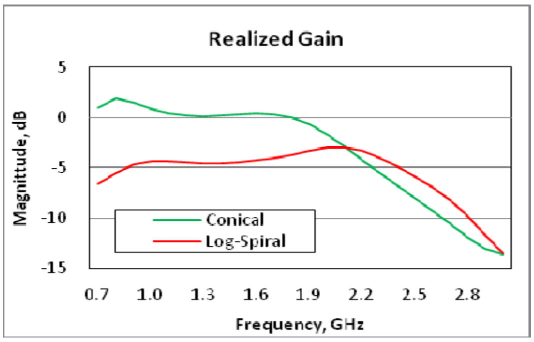


Figure 3: The five stage balun.

Both sensors were designed using the CST Microwave Studio software package. The chosen criteria are the S11 parameter and the Realized Gain. A good sensor should have the S11 value as constant as possible within its working frequency range. A good sensor also should have a realized gain as high as possible and also as flat as possible. The log-spiral sensor has an almost flat S11 response although it is uneven at frequency below 700 MHz. The conical sensor, on the other hand, has a significant variation of S11 over short frequency intervals at around 800 MHz and 1900 MHz. It has higher realized gain although it slightly decreases for frequencies above 1900 MHz. Meanwhile, the log-spiral sensor has a more consistent realized gain parameter value for the UHF frequency range but also decreases for frequencies above 2200 MHz. The realized gain of the log-spiral sensor is lower than that of the conical sensor for frequencies below 2200 MHz. Also, due to the addition of a balun for the log-spiral sensor, its realized gain is further reduced. However, the addition of a balun is also useful as this balun will act as a band pass filter with a passband frequency range of 300 ~ 3000 MHz.



(a)



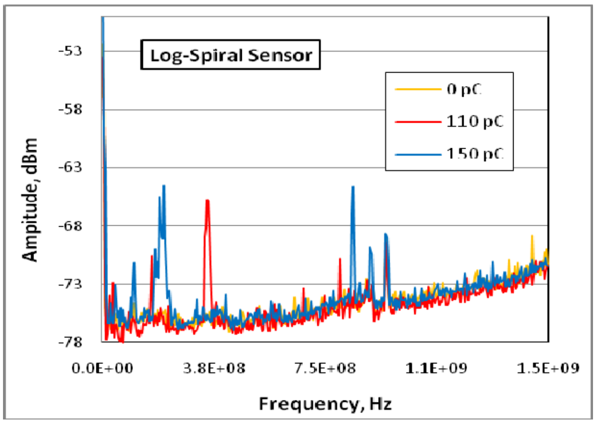
(b)

Figure 4: Sensor parameters: (a) S11 and (b) Realized gain.

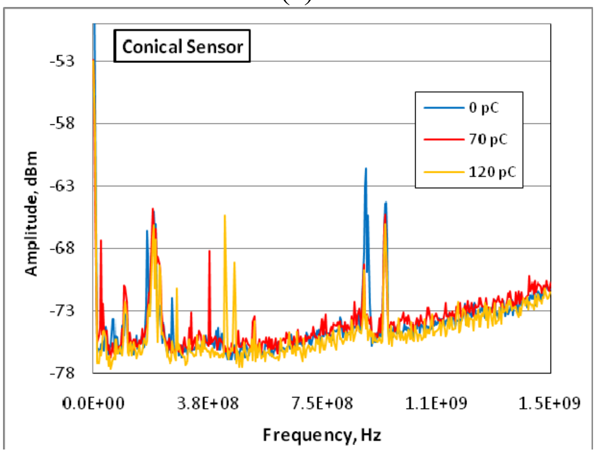
IV. Result and Discussion

In the experiment, both the conventional PD measurement system and the UHF system were used concurrently and with the same measurement period of 3 minutes to detect the partial discharge. The conventional system was used as the reference to measure the apparent PD magnitude in terms of pC. Also, the PRPD results from both measuring systems were compared to verify that the actual PD is indeed captured by the UHF detection system.

Figure 5 shows results of wide band measurement of the background noise (i.e. in the absence of PDs) for both conical and log-spiral sensors. The results show two areas of significant interference: (i) at around 100 – 200 MHz from digital radio and DVB-T transmissions, and (ii) at around 850 MHz and 900 MHz from mobile phone transmissions. The figure also shows measurement results when the PD source was energised. It can be seen that the PD spectra mostly occur in the frequency range 300 to 500 MHz. Both sensors are capable of detecting PDs if the level is above 30 pC. In addition, the PD signal also appears at above 1000 MHz and detectable if the PD level exceeds 200 pC.



(a)



(b)

Figure 5: Wide span plots for void PD defect picked up by (a) log-spiral sensor and (b) conical sensor.

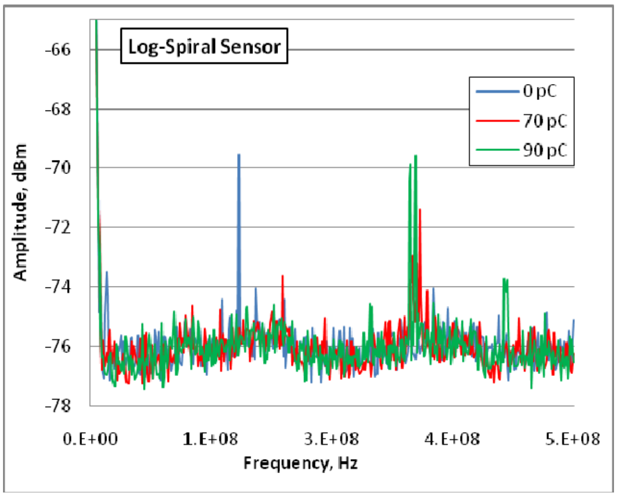
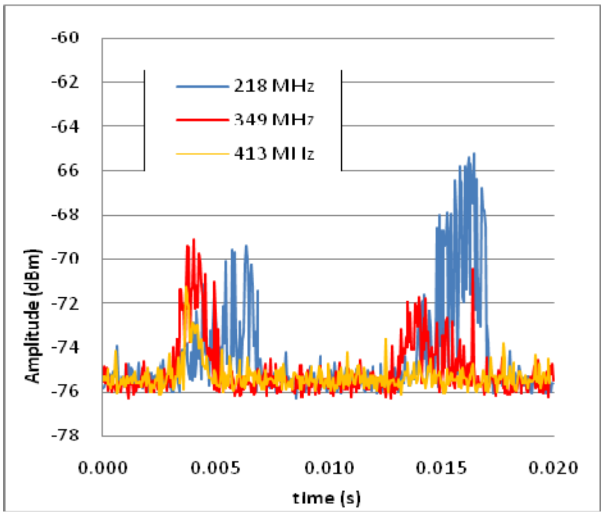
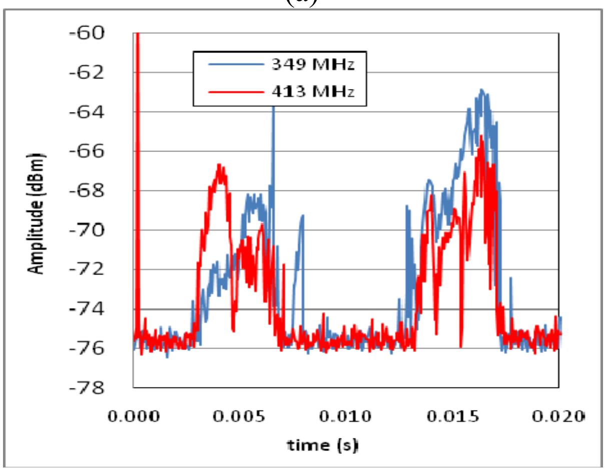


Figure 6: Narrow span plots picked up by log-spiral sensor, measured at frequency up to 525 MHz.

By using the wide band method and comparing the background noise pattern against the patterns obtained with the PD source energized, a coarse frequency range that contains detectable PD signal can be found. Then by further using the narrow band method within this coarse range, a more specific range where the PD signal lies well above the background noise can be identified. By using the above mentioned procedure, frequencies of 218, 349 and 413 MHz (Figure 6) were chosen to detect the PD signals using the zero span method (Figures 7-9). For PD above 200 pC, the PD signal well above the background noise also occurs at 1110 MHz for the case of surface discharge source.



(a)



(b)

Figure 7: Zero span plots of surface discharge using (a) log-spiral sensor and (b) conical sensor.

The zero span method is employed to capture the signal within one AC cycle (50 Hz), so the sweep time is set to 20 ms. This produces the so-called phase resolved partial discharge (PRPD) patterns. The test results show the PRPD using SA has similar shape to that obtained using the conventional PD measurement system. However, the SA results only show the envelope of the PD activity without giving information about the quantity of PD pulses that occur at different phase positions within the cycle. Figures 7 - 9 show the PRPD patterns for void and surface discharges. Both discharge types give quite similar shape. Thus it is not possible to distinguish the different PD types based on the PRPD results.

From Figures 7 – 9, it can be seen that the signals at higher frequency tend to have lower magnitude. This could be because the higher frequency signals suffer rapid attenuation along the propagation path [5] inside the transformer tank. Both types of artificial PD defect generated similar PRPD patterns but surface discharge produces higher frequency signal. For both samples, the dominant PD occurs in the frequency range 300 MHz to 500 MHz. Higher frequencies PD at around 1100 MHz is also detectable for surface discharge (Figure 6).

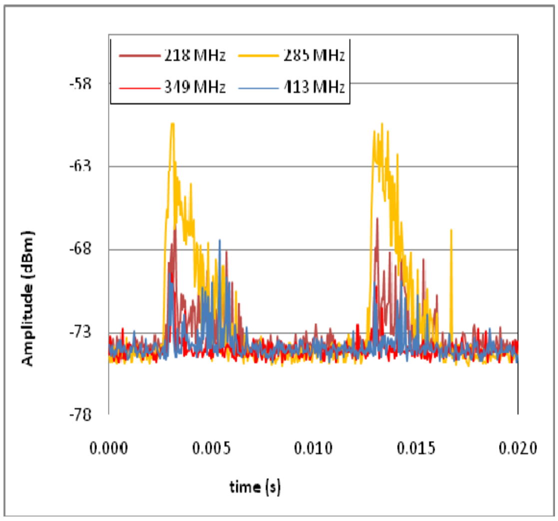


Figure 8: Zero span plots of 300pC void discharge, measured at various frequencies using the log-spiral sensor.

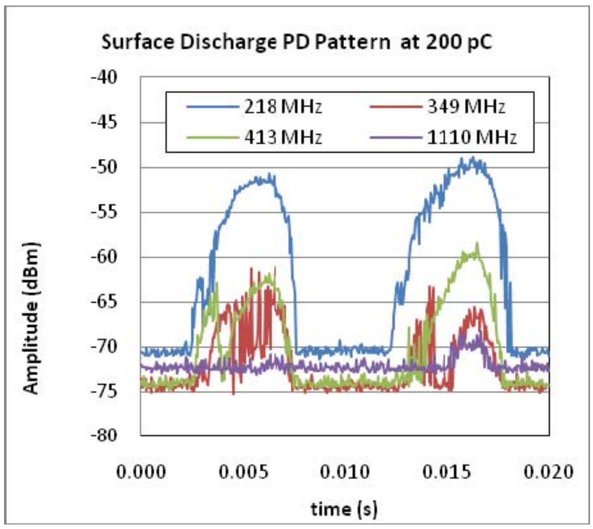


Figure 9: Zero span plots captured by the conical sensor.

Except for frequencies below 200 MHz, the signals captured by both sensors have similar patterns. The log-spiral sensor used in the experiment has a balun which functions as a connector between the sensor and the coaxial cable. This balun was designed to work at frequency between 300 to 3000 MHz. Any signal outside this frequency band will be significantly attenuated. As can be seen in Figure 6, the interference from digital radio and DVB-T transmissions at around 150-200 MHz is much reduced. However, this balun also attenuates signals in the range 300-3000 MHz although much less compared to the attenuation at below 300 MHz or above 3000 MHz. Thus, the magnitude of the PD signal is lower than that captured by the conical sensor. Nevertheless, both sensors show their ability to detect PD and the captured PRPD patterns are similar to those obtained with the conventional PD measurement system. Thus both sensors could be used to detect PD in transformers.

V. CONCLUSION

The experiment conducted demonstrates the viability of the UHF partial discharge detection method. This method was implemented by using two types of UHF sensor: conical and log-spiral. Testing was carried out with two different artificial defects to simulate surface discharge and void discharge. The system is able to capture the PD signal and the minimum detectable PD level is 30 pC. The phase resolved partial discharge (PRPD) patterns are similar to those obtained using the conventional PD measurement system. The conical sensor has higher sensitivity compared to the log-spiral sensor but the latter provides better noise rejection at low frequency. Both sensors show ability to detect PD signal inside the transformer tank using either the wide band or narrow band method.

REFERENCES

[1] K. Raja and T. Floribert, Comparative Investigations on UHF and Acoustic PD Detection Sensitivity in Transformers, ISEI, Boston, MA USA, April 7-10, 2002.

[2] Martin D. Judd, Li Yang and Ian B. B. Hunter; Partial Discharge Monitoring for Power Transformers Using UHF Sensors Part 2: Field Experience, IEEE Electrical Insulation Magazine, pp: 5- 13, Vol. 21, No. 3, May/June 2005.

[3] J. Lopez-Roldan, T. Tang and M. Gaskin.; Optimization of a Sensor for Onsite Detection of Partial Discharges in Power Transformers by the UHF Method; IEEE Trans. on Dielectrics and Electrical Insulation Vol. 15, No. 6; December 2008; pp : 1634- 1639.

[4] Rengarajan, S.; Parmar, R.N.; Bhoomaiah, A.; Kuntia, J.S.; Development of an UHF detection system for partial discharge measurement in transformer insulation; ISEI 2008, pp:100 – 103, 9-12 June 2008.

[5] Denis Denissov, Wolfgang Köhler, Stefan Tenbohlen, Ruben Grund, Thomas Klein; Wide and narrow band PD detection in plug-in cable connectors in the UHF range; ICCMD, Beijing, China, April 21-24, 2008

[6] Yanzhou Sun, Hua Yin, Qiaogen Zhang, Fashan Yu, Hui Wang and Yuchang Qiu; Partial Discharge Detection for GIS Using Narrow Band Ultra-High-Frequency (UHF) Method, ISEI, Kitakyushu, Japan, June 5-9, 2005.

[7] D.M. Pozar, Microwave Engineering, Second Edition, John Wiley & Sons, 1998.