Characteristics of External Loop Sensor Located Near Bushing on Partial Discharge Induced Electromagnetic Wave Measurement

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Abstract: For transmitting a huge electrical energy, high voltage transmission systems are commonly operated. Due to high reliability and less space required, gas insulated substation (GIS) are widely used. In a defect experienced GIS, partial discharge (PD) usually takes place. Partial discharge (PD) monitoring technique using UHF method becomes more popular because of its higher signal to noise (S/N) ratio. Amongst novel sensors, loop sensor could be a candidate for PD detector to measure UHF signal emitted from PD source. This paper presents the experiment results on characteristics of loop sensors. The characteristics of three loop sensors with varying diameter were examined using a spectrum analyzer and a network analyzer to obtain frequency characteristic and optimum operating frequency (S11) parameter, respectively. Then, PD experiment was conducted on 66kV GIS model having floating electrode and free metallic particles as its PD source. The loop sensors were placed far external to GIS bushing to measure leaked PD signal from it. The influences of the sensor diameter and the sensor distance from GIS bushing on PD detection sensitivity were also examined. Based on IEC-60270 standard measurement, the highest sensitivity of 30 pC was obtained from this investigation. The result suggests that higher sensitivity could be achieved with proper shielding and suitable filter design against external noise.

Keywords: Partial discharge; loop sensor; frequency characteristic, gas-insulated substation; sensitivity; zero span modes.

1. Introduction

For transmitting a huge electrical energy, high voltage transmission systems are commonly operated. Due to high reliability and less space required, gas insulated substation (GIS) are widely used. During operation partial discharge (PD) may take place in GIS. The PD occurrence is an indication of GIS abnormality. Partial discharge (PD) detection is the most effective method to monitor and diagnose the insulation condition of high voltage apparatus[1-8]. PD detection method is of importance among the various diagnostic techniques, since it is non-destructive, non-intrusive and can qualitatively describe the integrity of insulation system.One of the promising PD diagnostic techniques is the ultrahigh frequency (UHF) electromagnetic wave detection method that has been widely used for measuring insulation performance in gas-insulated switchgear (GIS) due to its advantageous characteristics, such as high sensitivity, wide detection range and less external disturbances [9-19].

One of the most important part of PD measurement system is sensors. Sensors strongly influence the sensitivity of PD measurement system. Some experiments on detecting characteristics of various types antenna have already been conducted [10]. Loop sensor is one of PD detectors to measure UHF signal emitted from partial discharge source.

This paper presents the frequency characteristics and S11 parameter of loop sensor with varying the diameter. Then, the laboratory results on 66kV GIS model having floating electrode and free metallic particles as PD source will be shown afterwards. The loop sensors

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were placed far external to GIS busing to measure leaked PD signal from it. Based on IEC-60270 standard measurement, we verify the sensitivity of the sensors corresponding to apparent charge.

2. Loop Sensor and its Characteristics

An antenna in a radio application is needed for two main reasons: to transmit and to receive signal. A small loop coil could be functioned as both transmitting and receiving antenna utilizing near field magnetic induction coupling. However, in PD application, small loop sensor is needed only for receiving UHF signal. When time-varying magnetic field is passing through a coil, it induces voltage across a coil terminal. A loop sensor must be designed to maximize this induced voltage for the case of frequency resonance type. However, for PD sensor requiring flat frequency reponse, resonance frequency band should be avoided by adequate design process.

Based on Faraday's law, a time-varying magnetic field through a surface bounded by a closed path induces a voltage around the loop as expressed by equations (1) and (2).

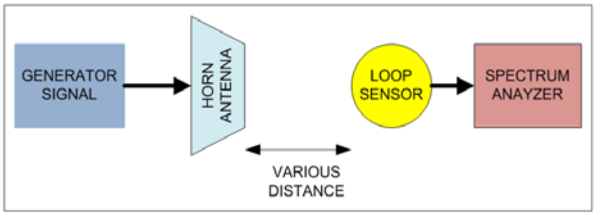
$$V_{ind} = -N\frac{d\Psi}{dt} \quad (1)$$

$$\Psi = \int B \, . \, dS \quad (2)$$

where : N = number of turns, Ψ = magnetic flux,
B = magnetic field, and S = surface area.

In this experiment, three loop sensors having diameter of 5cm, 8cm and 13 cm were examined using a spectrum analyzer and a network analyzer to obtain the distance and size effects of the sensors on sensitivity and S11 parameter, as shown in Figure 1.Using a network analyzer (Advantest R3765CG up to 3.8 GHz), S11 of three loop sensors were measured . The results are shown in Figure2. (a), (b), and (c).The result surely explains that the three loop sensors have their own resonance frequencies.

(a). S11 parameter measurement

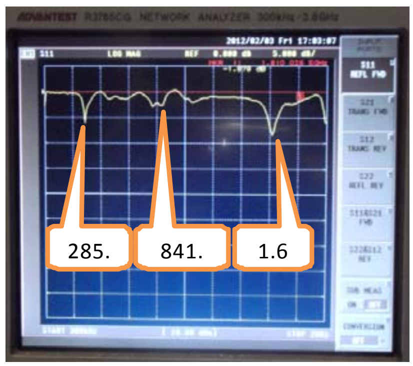


(b). Setup for distance and size effects measurement (500 MHz~3 GHz)

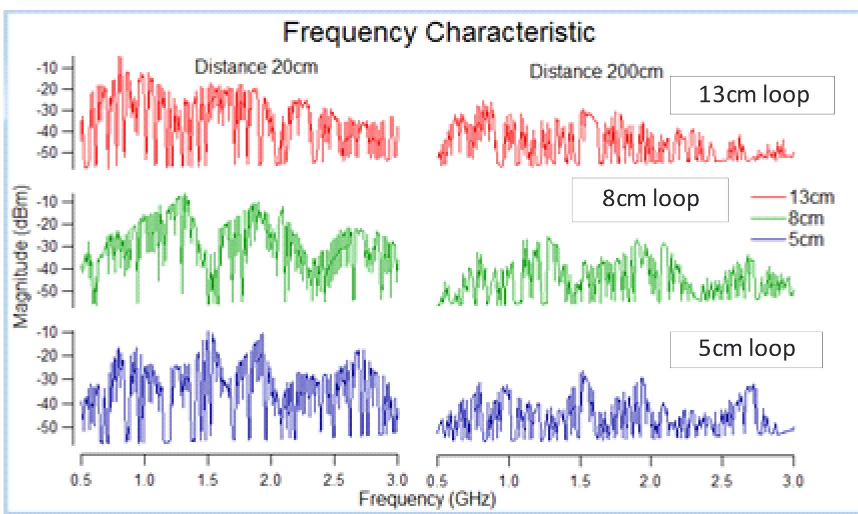
Figure 1. Setup for (a) S11 (b) distance and size effect measurement

(a)

(b)



(c)



(d)

Figure 2. S11 and frequency characteristics of three loop sensors (a) 13cm diameter (b) 8cm diameter (c) 5cm diameter and (d) detailed characteristics for 20 cm and 200 cm away from horn antenna (500MHz ~3GHz)

The experimental result of frequency characteristics are shown in Figure 2. (d).The three sensors exhibit the distinct distance effect of signal response attenuated by about 10 dBm per every meter. With 2 m away from the signal source, the detected signal was reduced by about 20 dBm. It is verified byS11 parameter tested with the same setup as in Figure 1. (b) that loop sensor of 5 cm diameter shows the highest frequency response around 1,600 MHz and loop sensors of 8cm and 13 cm in diameter indicate their peak response values around 1,300 MHz and around 800 MHz, respectively.

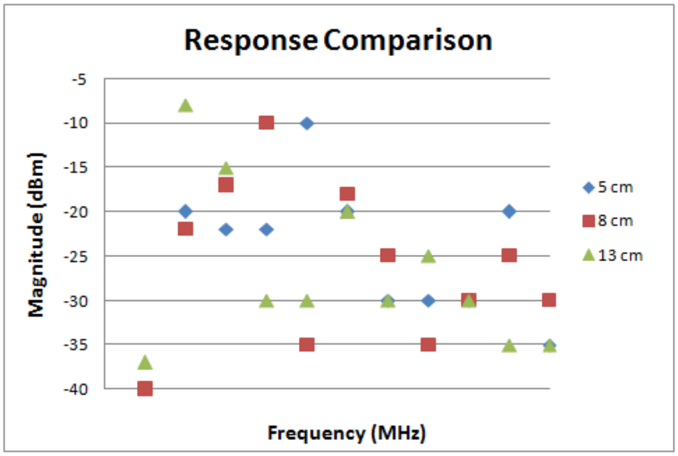
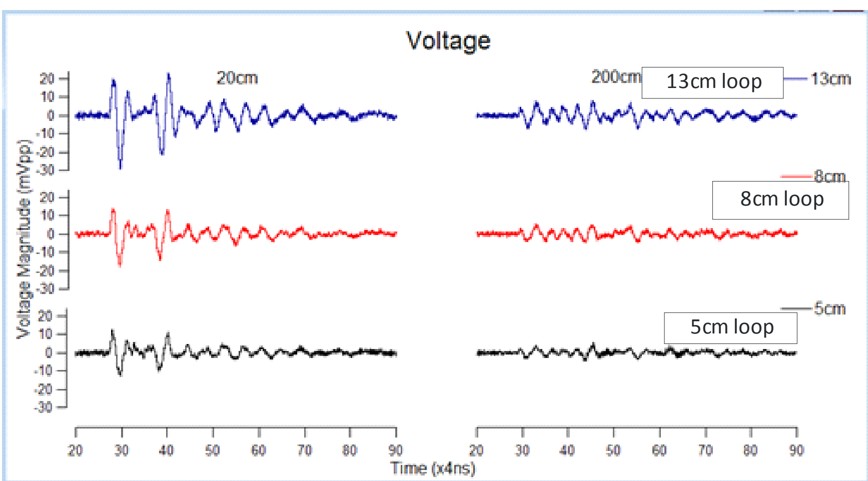


Figure 3. Relative response among three loop sensors with diameter of 5, 8 and 13 cm

Therefore, it would be said that as the sensor diameter increases from 5 cm to 13 cm, the resonance frequency (>-5 dB) decreased from 1,600 MHz to 800 MHz.

3. Experiment With Pulse Signal

In this experiment the loop sensors were subjected to a simulated PD pulses. The simulated PD pulse signal has 1 nano second rise time and 5V magnitude. The signal was injected to GIS conductor through 10 pF coupling capacitor. The signal level injected was corresponded to 50pC. The detected wave shapes are shown in figure 3.



Figue 3. Detected waveshapes by three loop sensors
(20 cm and 200cm away from GIS bushing)

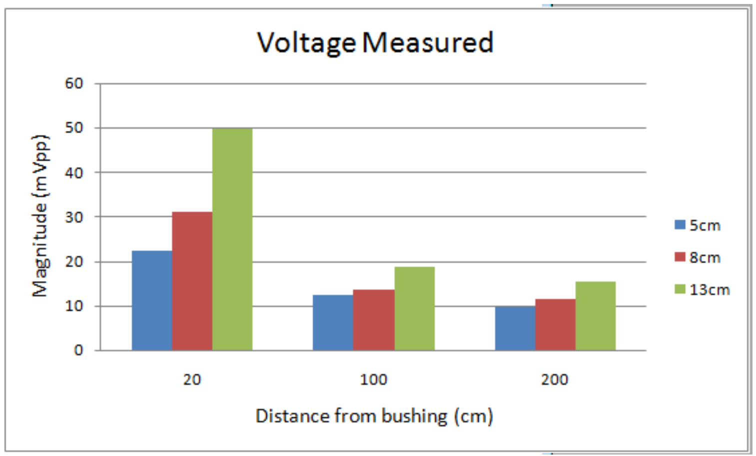


Figure 4. Signal attenuation v.s. distance from GIS bushing

The voltage measured for each antenna diameter as function of distance are shown in figure 4. The results indicated that the larger the diameter the higher the detected voltage.

4. Experimental setup for partial discharge measurements

In order to provide the basic data for on-site or on-line application of a loop sensor, experiments were conducted on 66kV GIS model (SF_6, 0.15 MPa). Experimental circuit is shown in Figure 5.

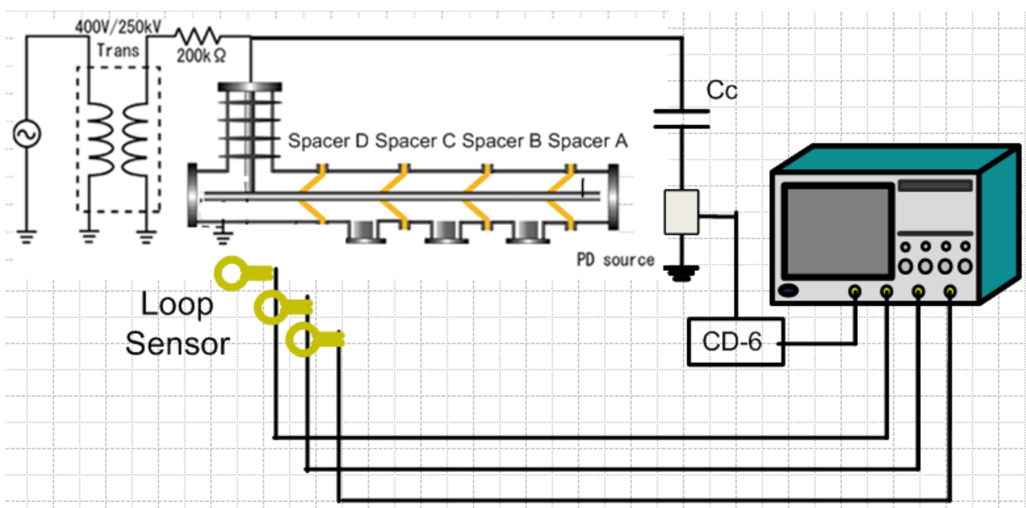


Figure 5. Experimental setup on 66 kV GIS model

The three loop sensors were used to measure PD signals leaked from GIS bushing, installed 20 cm, 100 cm and 200 cm away in sequence from the bushing as shown in Figure5. On the other hand, PD sources were installed at the opposite end of GIS enclosure about 5 m away from GIS bushing.UHF signals emitted from a PD source were detected by the loop sensors and those signals were transmitted to a digital oscilloscope (YokogawaDL9240, frequency band : 1.5GHz, sample rate: 10GS/s, record length: 6.25M) and a spectrum analyzer (Agilent E4404B up to 6.7GHz) for the further analysis of PD spectroscopy in time domain and in frequency domain, respectively.

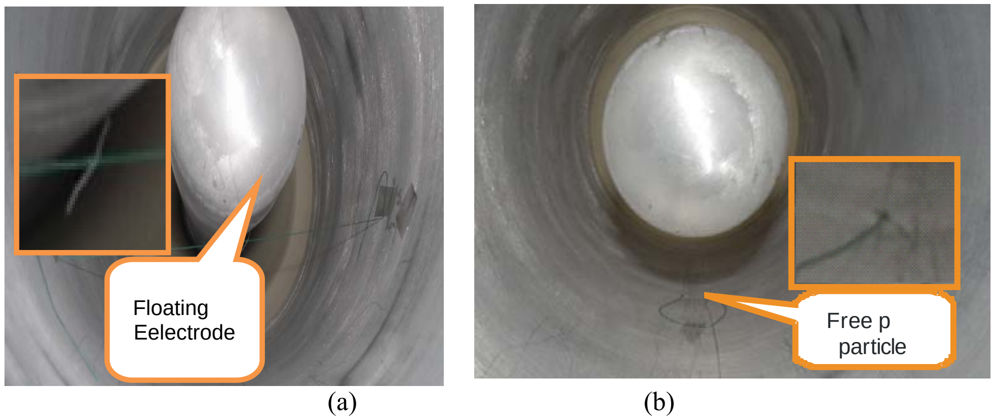


Figure 6. Installation view of PD source
(a)Floating metallic particle (b) Free metallic particles

At the first step, a floating metal electrode of 10 mm length was installed using isolated string floated 5 mm away from the high voltage conductor (Figure 6. (a)). PDIV recorded was around 32 kV. PD magnitude at 36 kV corresponded to about 60 pC. For the second experiment, we attached two free metallic particlesof 5mm length at each end of isolated string(Figure (b)). PDIV for this type of PD was around 35 kV. We applied voltage up to 40kV and clearly identified PD level corresponding to 30 pC measured 200 cm away from the GIS bushing.

5. Results and discussions

A. Floating metallic particle

Figure 7 shows frequency spectra of PD from this defect type. It is found that there are three dominant frequency bands such as 65~100 MHz (I), 300~340 MHz (II) and 750~800 MHz (III). Loop sensors shows higher sensitivity in lower dominant frequency bands (I) and (II). However, their sensitivity in 750 MHz~800 MHz (III)is rather lower than (I) and (II).

This result coincides with the waveshapes obtained from the oscilloscope as shown in Figure 8. Unfortunately, lower frequency bands (I) and (II) are more vulnerable to external noise than higher frequency band (III). Especially in the range of 50~200 MHz, external noise level is much higher than one of PD signals. The most useful frequency band having less external noise is suggested to be around 300 MHz for these type of the loop sensors.

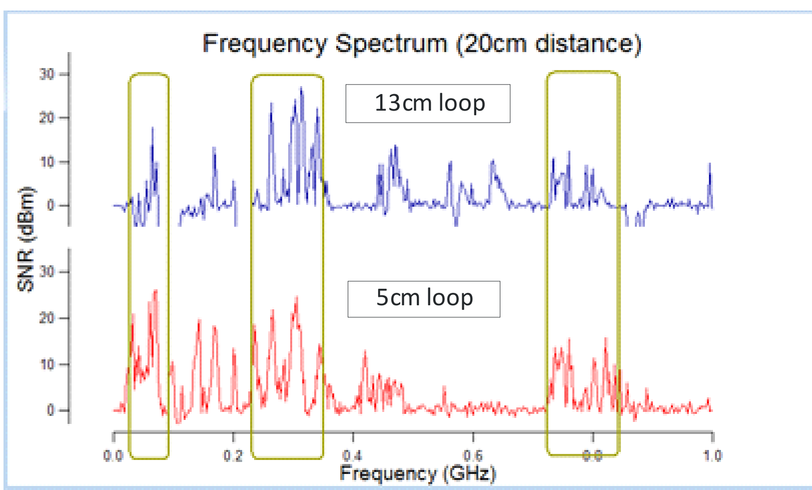


Figure 7. Frequency spectrum for floating metallic particle

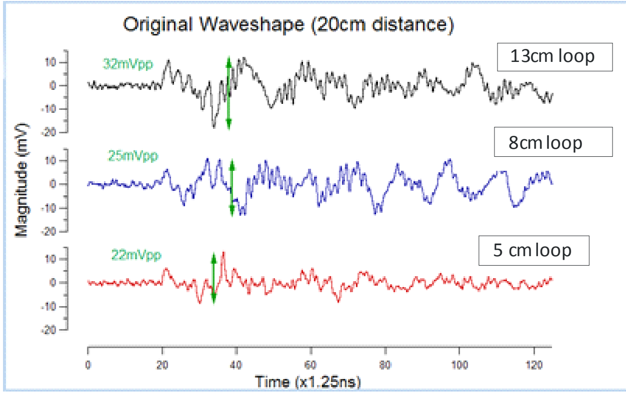
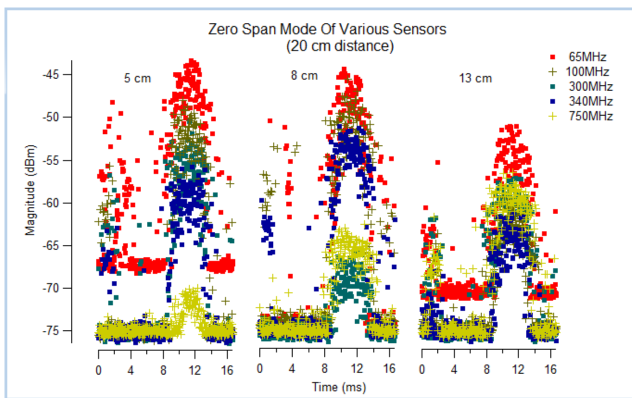


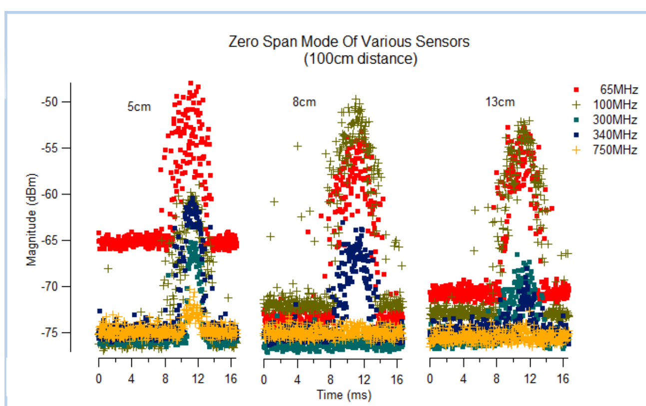
Figure 8. PD waveshapes for floating metallic particle

For more detail analysis, frequency spectrum analyzer exploiting zero span mode (3 MHz bandwidth, 16.67 ms sweep time synchronized to 60 Hz)was applied to obtain PRPD patterns.

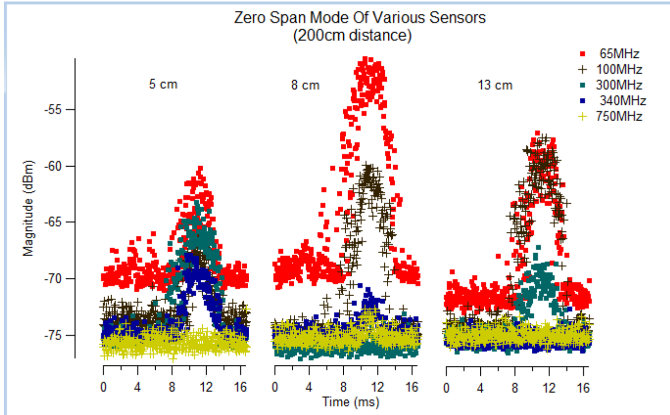
Figure 9 shows PRPD patterns of floating metallic particle for the three loop sensors collected in five frequency bands of 65, 100, 300, 340 and 750MHz. Amongst PRPD patterns measured around 750 MHz, loop sensor of 13 cm diameter shows higher sensitivity than the other loop sensors, which confirms higher S11 value (780 MHz, -21 dB) as illustrated in Figure2. (d). However, PRPD patterns in lower frequency bands (65 MHz and 100 MHz) revealed higher noise level due to VHF radio communication.



(a) 20cm distance from bushing



(b) 100cm distance from bushing



(c) 200cm distance from bushing

Figure 9. Zero span mode (PRPD) for floating metallic particle

B. Free metallic particle

Figure 10 shows frequency spectra of typical PD signalsobtained from free metallic particles. Several dominant frequency bands are also illustrated in 50~200 MHz (I), 300~350 MHz (II) and 750~800 MHz (III), which are similar to the previous resultsof the floating particle experiment.Leaked PD signals of 50~200MHz and 300~350MHz are in TEM mode that propagate along the high voltage conductor and then leaked from GIS bushing. PD signals in 750~800MHz propagate along GIS enclosure in TE mode. The sensitivity level of TEM mode signals in 50~200 MHz shows the highest but with the largest noise level.

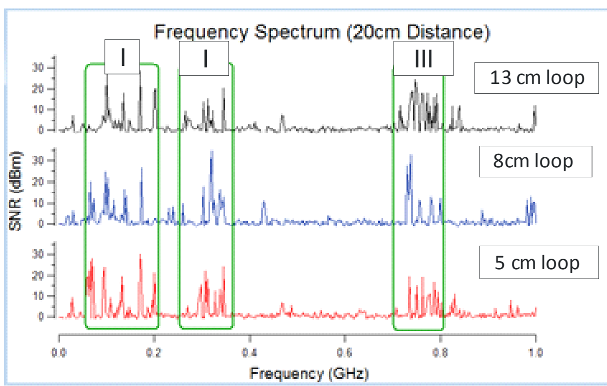


Figure 10. Frequency response for free metallic particle

However, Figure 11 shows that PD waveshapes from free particles experiment contain higher frequency components than one from the floating particle, which should be explained with further analysis.

As expected in Figure 12, PRPD patterns obtained from the free metallic particles experiment illustrate the scattered PD activities all over the phase angle. This typical PRPD pattern could be explained as sporadic movement of free particles.

According to the previous results, the loop sensors have sensitivity of 30 pC to detect leakage PD from the GIS bushing. With additional amplifier and proper filter, higher sensitivity may be achieved. According to the sensitivity test results, the loop sensors are also applicable for PD measurements on the transformers but not directly applicable without any amplifier for PD measurements on GIS.

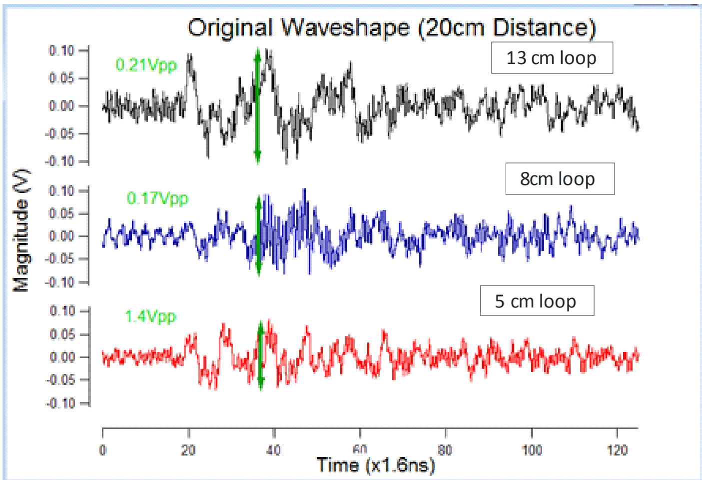
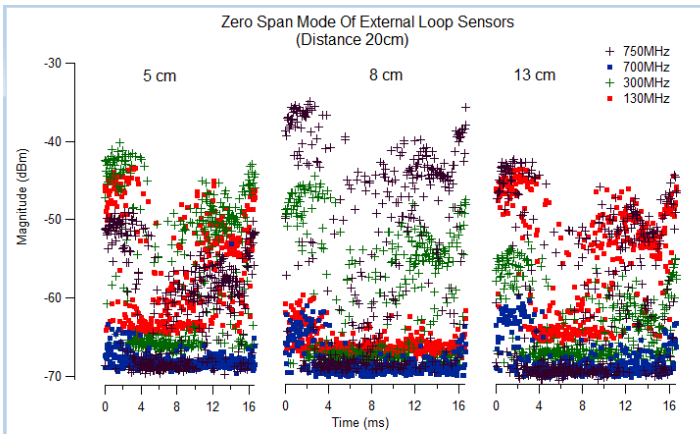
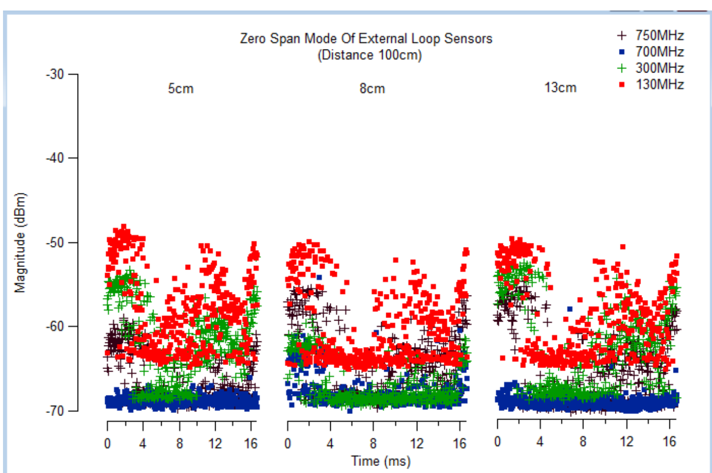


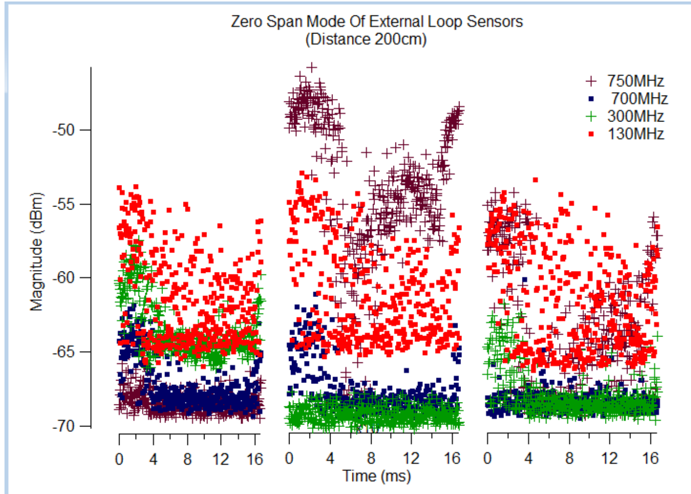
Figure 11. Original waveshapes for free metallic particle



(a) 20cm distance from bushing



(b) 100cm distance from bushing



(c) 200cm distance from bushing

Figure 12. Zero span mode (PRPD) for free metallic particle

5. Conclusion

From the characteristic test on the three loop sensors and their laboratory experiment on 66 kV GIS model, several conclusions are suggested as follows.

The loop sensor fabricated in laboratory tells us the distinct effect, which signal response was attenuated about 10 dB per meter.

For S11 experiment, as the loop sensor diameter increases from 5 cm to 13 cm, the resonance frequency (> - 5 dB) is decreased from 1,600 MHz to 800 MHz.

From simulated PD pulse injection experiment (1ns rising time), the center frequency of detected signal by the loop sensor was around 200 MHz, which propagated GIS conductor in TEM mode. The largest loop sensor of 13 cm diameter shows the highest response among three sensors.

The loop sensor shows PD sensitivity level corresponding to 30 pC measured 200 cm away from GIS bushing. The result suggests that higher sensitivity less than 10 pC could be achieved with proper shielding and suitable filter design.

The domain PD frequency bands obtained from two experiments (free particles and floating metalic particles) are similar in their ranges of 50-200 Mhz, 300-350 Mhz, and 750-800 MHz. Leaked PD signals of 50-200 MHz and 300-350 MHz are in TEM mode that propagate along the high voltage conductor and then leaked from GIS bushing. PD signals in 750-800 MHz propagate along GIS enclosure in TE mode. The sensitivity level of TEM mode signals in 50-200 MHz shows the highest but with the largest noise level.

Detection of leaked PD signal in TEM mode of 300~350 MHz frequency band are suggested to be the best option for PD diagnosis system due to its higher sensitivity with less external noise level.

This technique could be applied to PD detection system for high voltage power transformer.

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