A CHIP TYPE UHF SENSOR APPLICABLE TO FIND THE PD LOCATION IN GAS INSULATED TRANSFORMER

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Abstract: Different types of sensors working in Ultra-High-Frequency have been widely developed, since more than two decades, to detect the PD pulses occurring inside the Gas Insulated power apparatus. Some of them have been commercially used for Gas Insulated Transformer (GITr) and several advantages such as high sensitivity and less affected by external disturbances are attributed to them. In this work, a chip type UHF sensor has been designed with the smallest dimension for PD detection and then fabricated with a view to replacing the currently used patch type sensors. Its structure has been determined by 3-dimensional electro-magnetic simulation and then important characteristics such as gain, directivity and return loss have been evaluated in the working frequency ranges (0.3GHz-1.5GHz). In particular, the measured return loss of the prototype has been compared with that obtained by simulation. Moreover, laboratory tests have been carried out in order to investigate possibility to detect PD signals and also to find the PD source. For this work, 170kV GITr mock-up equipped with three inspection windows and the artificial defect have been used. Experimental investigation has been made for the PD pattern analysis by the conventional PRPD method respecting the IEC 60270 as well as finding PD location by “Trilateration method”. Ascribed to its high sensitivity detection below 10pC, PD location using artificial defect such as void has been realized at laboratory test.

1 INTRODUCTION

Over the past two decades, Partial Discharge (PD) detection technique at ultra-high frequency band(0.3 GHz - 3GHz) has been developed and then widely commercialized for preventing unexpected failures of Gas insulated substation attributed to its high noise discrimination and high sensitivity for monitoring insulation state. In this work, a new concept of the internal-type chip sensor is proposed and designed for detecting Ultra High Frequency (UHF) PD. Considering the irregular shape and obstacles in the structure of Gas Insulated Transformer (GITr), a detection technique is proposed for the diagnosis [1]. The analysis related to the self-designed structure of the sensor has been done using the 3-dimensional electromagnetic simulation and practical experimentation of fabricated prototype [2, 3]. The evaluation of the characteristics such as gain and sensitivity has been performed in the working frequency ranges (0.3GHz-3GHz). In particular, the measured return loss of the prototype has been compared with that obtained by the simulation analysis. Three UHF sensors are installed on the same surface of GITr Mockup (170kV-22.5kV level, D=900mm, down scaled to 1/3) where artificial defects are integrated as the PD source. Also the arrival time of PD signals to each of the sensors is identified and analyzed and then the PD source location is measured by applying two-dimensional Trilateration method [4].

2 TRILATERATION METHOD

In order to find the location of any object under consideration trilateration method is widely applied. It is based on three spheres of which the radius is determined respectively by three different lengths between the object and three referential points. The intersection of these surfaces makes the point which is assumed to be the location of the object under consideration. In this work, the time interval between the first detection (S1) of a PD signal and others, i.e. S2 and S3 are considered [5]. These intervals are multiplied by the light speed and then the results are taken as the basic radius of each sphere for S2 and S3 respectively. It should be pointed out that the radius of S1 could be zero at the beginning but usually an initial value is chosen. From these given values, the incremental increase of the radius is made gradually by use of software until three to make the larger sphere from S1, S2 and S3. Afterwards, three spheres reach to make an intersection, i.e. a point as the location of the unknown PD source under consideration.

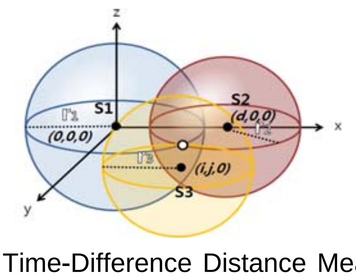


Figure 1: Time-Difference Distance Measurement and Trilateration Method

2.1 Location algorithm

Three UHF sensors are installed at S1, S2 and S3 to detect the PD from the void defects located inside GITr and the following two algorithms are applied in order to determine an intersection as the location of PD source [6, 7].

Time-difference distance measurement: Three UHF sensors (S1, S2, and S3) were connected to the oscilloscope respectively through the cables of which the lengths are same. Thus, it is assumed that there is no time delay of receiving PD signals due to the cable length. Therefore, it is allowed to consider only the arrival time of the signal from PD source to each sensor resulting in calculation of time interval between sensors. For example, the time interval between S1 and S2 is represented as t_{12} which will be multiplied by the propagation speed to obtain a length as the base radius of the sphere for S2. In the same way, the base radius is obtained from the time difference between S1 and S3, i.e., t_{13}. This process can be represented by use of following equations (1) & (2).

$$\Delta\ t_{12} \bullet V = r_1 - r_2 \quad (1)$$

$$\Delta\ t_{13} \bullet V = r_1 - r_3 \quad (2)$$

Trilateration method: This method enables to determine the location of anything of which the position is unknown in 3D space by tracing three spheres from 3 given points respectively through simulation until the intersection of their surfaces makes a point.

In Figure 1, assuming that S1 is located at the center of the given coordinate (0, 0, 0) with radius r_1 and other two spheres S2 and S3 with radius r_2 and r_3 are located at (d, 0, 0) and (i, j, 0), each radius of three spheres is expressed as the following equations.

$$r_1^2 = x^2 + y^2 + z^2 \quad (3)$$

$$r_2^2 = (x-d)^2 + y^2 + z^2 \quad (4)$$

$$r_3^2 = (x-i)^2 + (y-j)^2 + z^2 \quad (5)$$

Using the equations, the coordinate of intersection point for the three spheres (x, y, z) is calculated as below.

$$x = \frac{r_1^2 - r_2^2 + d^2}{2d} \quad (6)$$

$$y = \frac{r_1^2 - r_3^2 - x^2 + (x-i)^2 + j^2}{2j} \quad (7)$$

$$z = \sqrt{r_1^2 - x^2 - y^2} \quad (8)$$

3 EXPERIMENTS

3.1 Self designed UHF sensor

Structure: In order to reduce the physical dimension of the inspection window, a modified helical type antenna is chosen as shown in Figure 2. Such internal coupler is the active sensing part which consists of five parts such as a helical antenna, metallic ground, insulator, substrate and a connector. It is also designed to achieve optimum operational properties in the range of working frequency.

Main characteristics: The main characteristics of the sensor such as return loss, directivity and gain have been investigated. The first one is represented in terms of S-parameters, in particular S11, the ratio of the reflective wave to the incident wave which is the most important factor. It has been measured in the frequency ranges from 0.1GHz to 3.0GHz by use of Network analyzer (HP 8720C, 50MHz-20GHz). The evolution of dBm power as a function of frequency has been obtained by measurement as well as by simulation and then displayed in Figure 3 respectively. This shows the difference between them within the observed frequency range. Also 3 resonances are observed at 0.5GHz, 1.48GHz and 2.26GHz. When the return loss is cut off at-5dB, the sensor has been proved to have two different bandwidths such as 100MHz and 600MHz. The last two factors have been calculated by simulator and then represented in terms of Antenna Gain Pattern (AGP) and Antenna Directivity Pattern (ADP) and then the results are described in Figure 4 for above 3 frequencies. Considering the AGP, this sensor could receive the maximum energy through helical antenna since it is generally required to have the main lobe direction at 90 degrees of sensor. Regarding ADP, it could be pointed out as follows: below 1GHz, the directivity is oriented to the limited direction; however, it becomes wider as the frequency is increased. These results enable us to determine the position of the sensor to be fixed in the forward direction facing inner side of GITr. ADP and AGP are summarized in table 1 and table 2.

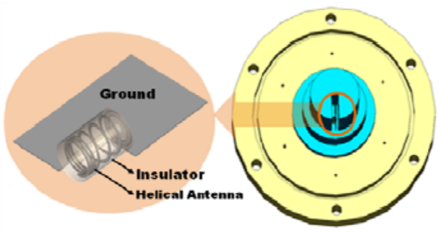


Figure 2: Structure of the chip sensor

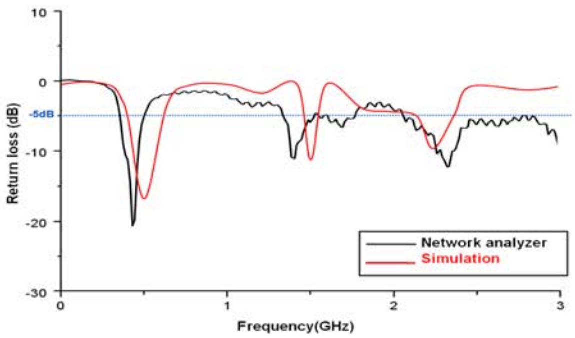


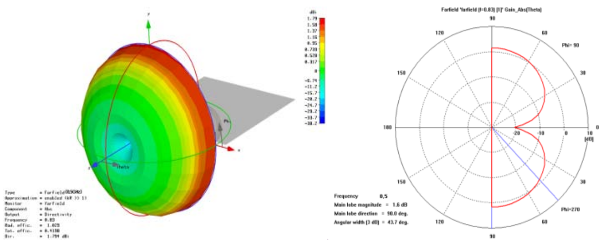
Figure 3: Return loss (S11) of the network analyzer and simulation

Table 1: ADP (antenna directivity patterns) [dBi]

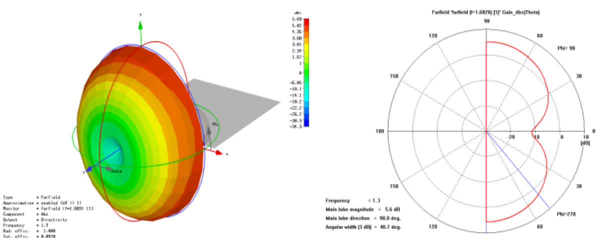
0.5GHz	1.48GHz	2.26GHz
1.749	5,694	6.514

Table 2: AGP (antenna gain patterns) [dB]

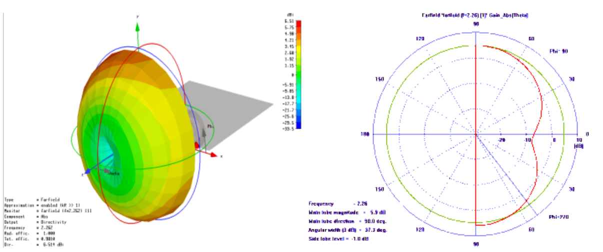
0.5GHz	1.48GHz	2.26GHz
1.6	5.6	5.9



(a) Antenna directivity pattern and Gain at 0.5GHz



(b) Antenna directivity Pattern and Gain at 1.48GHz



(c) Antenna directivity Pattern and Gain at 2.26GHz

Figure 4: Antenna directivity pattern and Gain

3.2 PD detection

The experiment was constructed in order to locate the position of the defects inside GITr as illustrated in Figure 5. Using HVAC Tester (Hipotronics, AC 100kV, 60Hz), voltage was applied to an artificial defect integrated into GITr as the PD source. And in order to obtain an equivalent signal transmission time, same length measuring cables (RG-214) were connected between each sensor and oscilloscope (LeCroy, 1GHz, Quad: 10GS/s). The acquired data through oscilloscope are analyzed by our data-analysis application developed in LabView. They enable us to estimate the arrival time of each PD signal to each sensor.

Three internal-type Chip sensors with identical pattern and characteristics are installed on the surface of GITr forming an equiangular-triangle shape (120 degrees apart in space) as in Figure 6(b). And in order to apply "2-D Trilateration method", A void defect as a PD source has been integrated into GITr in 4 different ways: ① Near the center of the circle shown in Figure 6(c) ② Three positions near each sensor as shown in Figure 6(c). The coordinates of each sensor location are summarized in Table 3.

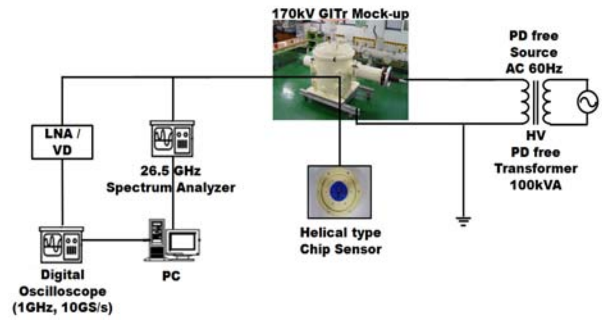
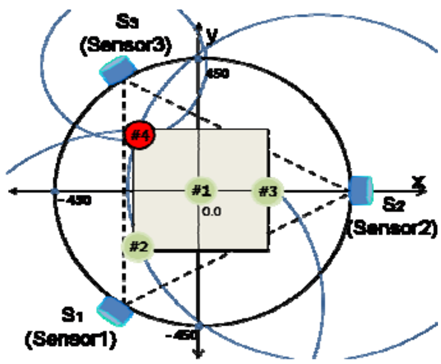


Figure 5: Block diagram of experimental set up

(a)

(b)



(c)

Figure 6:
(a) Void Defect (Diameter of 102mm, Thickness of 46mm)
(b) Helical-type Chip Antenna
(c) Locations of Sensors S1, S2, and S3 and Location of Defects #1, #2, #3, #4

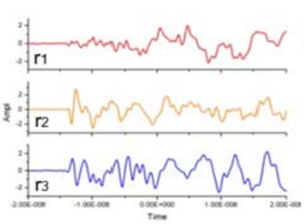
Table 3: Location Coordinates for Each Sensor and Defect

Sensor	Coordinate (mm)	Defect	Coordinate (mm)
S1	(-225, -389.71)	#1	(0, 0)
S2	(450, 0)	#2	(-127.37, -124.21)
S3	(-225, 389.71)	#3	(69, 0)
		#4	(-127.37, 124.21)

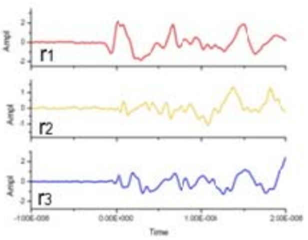
* Origin Point: Center of Mockup

4 RESULTS AND DISCUSSION

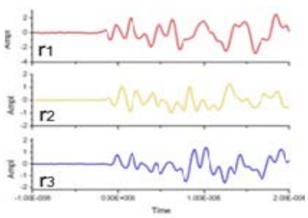
It is supposed that z is fixed at any value and only x-y plane is considered where PD source is assumed to be located. Thus, the time intervals of receiving PD signals between reference and other two sensors are considered. For this work, PDs are generated from 4 different locations of the defects as shown in Figure 6 (Table 3) and the distances are calculated between sensors and defects respectively. Figure 7 (a), (b), (c) and (d) show the PD signals with respect to each defect location obtained from the oscilloscope. Table 4 shows the time differences, distance differences and estimated locations of PD sources which were measured through input waveform according to defect locations. Comparing the defect locations in Table 3 and the estimated PD source locations in Table 4, It was possible to determine the location of defect within the range of 2% error. For example, in case an artificial defect was located at (#4), a defect location was precisely determined. Estimated PD source location (E_L) and actual defect location (A_L) were presented in Figure 8.



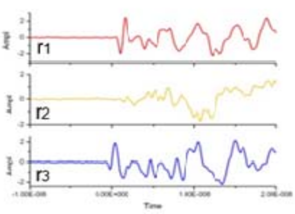
(a) Position #1



(b) Position #2



(c) Position #3



(d) Position #4

Figure 7: Wave Form Measured with Oscilloscope based on Defect Locations

Table 4: Time Interval, Distance Differences and Expectation Defect Locations

Defect	Reference	Time interval (ns)		Distance (mm)		Location
#1	S3	Δt_{31}	Δt_{32}	ΔR_{31}	ΔR_{32}	(-9.06, -20.48)
		0.101	0.114	30.3	34.2	
#2	S1	Δt_{12}	Δt_{13}	ΔR_{12}	ΔR_{13}	(-90.08, -112.51)
		0.667	0.769	200.0	230.6	
#3	S2	Δt_{21}	Δt_{23}	ΔR_{21}	ΔR_{23}	(97.65, -18.6)
		0.439	0.531	131.6	159.1	
#4	S3	Δt_{31}	Δt_{32}	ΔR_{31}	ΔR_{32}	(-92.28, 107.56)
		0.639	0.762	191.6	228.5	

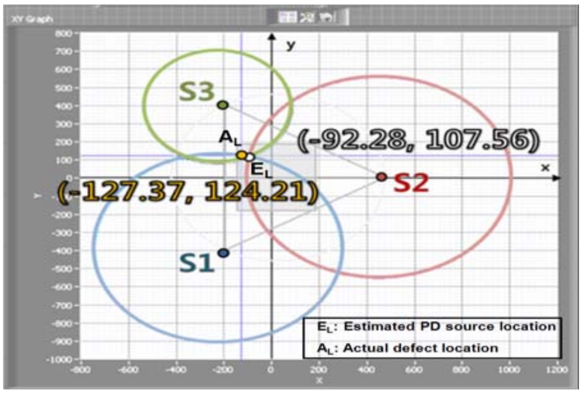


Figure 8: Estimated PD Source Location (E_L) and Actual Defect Location (A_L) in Case of Defect at #4

5 CONCLUSION

In this paper, a chip sensor was designed and developed for detecting the PD pulses occurring inside gas insulated transformer. In order to find the PD source location, two-dimensional Trilateration method has been applied. The results are summarized as follows:

1. The sensor is designed with sufficiently reduced dimension to be introduced into GITr, by which external noises could be avoided.
2. Throughout the working frequency ranges (0.3 GHz~3GHz), 3 resonances were observed with narrow bandwidth such as 100MHz and 600MHz.
3. Below 1GHz, the directivity is oriented to the limited direction; however, it becomes wider as the frequency is increased.
4. The location of artificial void defect was calculated within the 2% range of error on the plane formed by three sensors.

6 ACKNOWLEDGEMENTS

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