Localization of Incipient Discharge in Power Transformer using UHF Sensor

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***Abstract*— Non-intrusive ultra high frequency detection method has been recognized as well established diagnostic tool for monitoring the condition of power transformers. This UHF method is considered as the best choice to sense the location of onsite partial discharges (PD's) in power transformer because of its good signal to noise ratio (SNR) and high sensitivity. The PD source location accuracy mainly rely on TDOA (Time differences of Arrival) of PD source and the individual four uhf sensors or sensor array placed around the transformer tank. The location of PD source is evaluated by using PSO algorithm with the set of TDOA measurements from the experiment.**

Keywords*— *partial discharges; time difference of arrival; ultra high frequency method.

I. INTRODUCTION

Partial discharge detection has been acknowledged as the diagnostic tool for insulation deterioration in power apparatus. Locating PD sources accurately not only helps to know about the defect in the insulation of that particular electrical apparatus but also secures the long term reliable operation by eliminating potential faults occurring on them. UHF technique has gained more importance because of its good signal to noise ratio and high sensitivity.

The detection sensitivity calibration for UHF PD source location is given by CIGRE [1]. A standard Gigahertz Transversal Electro Magnetic (GTEM) set up is established to check PD measurement sensitivity for different UHF sensors which are going to be installed on transformer and is recommend method for transformer monitoring & diagnostics.

The location of PD source by UHF method using TDOA signals was introduced in 2003[2]. Several researchers are employing shortest signal propagation path principle for locating PD source by UHF sensors TDOA signals till date. Most of the researchers worked different aspects like UHF Propagation, optimal placement of UHF sensors, arrival time recognition are carried out [3-5 &10].

Localization of PD source by UHF method involves two key steps, i.e. acquiring TDOA measurements and solving the non-linear TDOA equations. Three methods to quantify the TDOA measurements are first peak method, cross correlation and cumulative energy method adopted by UHF sensors in which utilized by many researches in this field. Sinaga et .al compared the three methods to calculate TDOA measurements captured by four UHF monopole sensors array and concluded that first peak method yielded best accuracy when compared to other methods[11].

Xu et al applied Finite difference time domain (FDTD) approach to study the UHF PD signal propagation characteristics in simulated transformer model and the simulation results showed that PD signal has different electric field intensity Shibuya et al developed the analysis of electromagnetic waves generated by PD measurement using rectangular patch antenna considering with and without active part elements[8].

Judd et .al addressed the problems like installation, practicability, capabilities of UHF sensors to power transformer and explained the PD source location procedure to the prototype transformer model with 0.3m accuracy[4,5]. In [4], the space grid search method was proposed to solve nonlinear TDOA equations to localize PD source but, it locates the PD source with more computational load and time. Tang et.al proposed energy accumulative based TDOA measurements in which a window is added to TDOA signal waveform in order to reduce error from PD reflected waveform there by located the PD source [7].

Shibuya *et al* developed the analysis of electromagnetic waves generated by PD measurement using rectangular patch antenna considering with and without active part elements[6].Robles et.al investigated experimental study on zigzag, log periodic and two monopole antenna of 5cm &10cm for different frequency response to detect PD and concluded that 5cm monopole antenna is simple & low cost and gains 60% UHF radiated energy signal which proves best choice for effective PD measurements [9,10].

The hyperboloid genetic algorithm , PSO algorithm and the semi definite relaxation approach was applied for non-linear TDOA equations using diamond shape sensor array and cross correlation method was utilized for TDOA measurements to locate PD source but the approximate location range is more. Different types of solution methods have been proposed by many researchers to enhance location accuracy using TDOA localization algorithms but the determined location range is more. The existing localization algorithms found in literature has

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mainly three drawbacks i.e., local convergence, sensitivity to TDOA error and takes more CPU time.

In this paper, tailor made uhf sensors are used for localization of a PD source and TDOA signals are used for determining the location of incipient discharge source using PSO algorithm with minimum location error from the actual source.

II. Mathematical Model of UHF PD Localization

Let 't' be the uhf signal propagation time travelling from PD source to the reference sensor S_1 , l be the light velocity which is equal to 3*10^8 m/s and τ_{12} ,τ_{13} , τ_{14} are the TDOA measurements of the uhf sensor signals from reference sensor S_1.The nonlinear equations are given in Eqn (1)

$$\left.\begin{aligned}(x-x_1)^2+(y-y_1)^2+(z-z_1)^2&=l^2*t^2\\(x-x_2)^2+(y-y_2)^2+(z-z_2)^2&=l^2(t+\tau_{12})^2\\(x-x_3)^2+(y-y_3)^2+(z-z_3)^2&=l^2(t+\tau_{13})^2\\(x-x_4)^2+(y-y_4)^2+(z-z_4)^2&=l^2(t+\tau_{14})^2\end{aligned}\right\} \quad (1)$$

After acquiring the UHF sensors TDOA measurements, the PD source location can be estimated by solving Eqn (1). But, these are nonlinear equations and it is very difficult to calculate directly like traditional approaches. The Eqn (1) can be converted as an optimization problem with constraints. Thus, Eqn (1) can be written shortly as

$$P_j=D_j-D_s=l*\tau_{12} \quad (2)$$

Where D_j is the distance of the PD source to the j^{th} sensor i.e.

$$D_j=\sqrt{(x-x_i)^2+(y-y_i)^2+(z-z_i)^2} \quad (3)$$

Unfortunately, 't' is unknown and it is required to quantify UHF sensors TDOA to estimate the PD source location.

The Eqn. (3) is then transformed to

$$P_{ji}=l(t_j-t_i)=\|D_j-D_s\|-\|D_i-D_s\| \quad (4a)$$

In the experiment set up, it is assumed that there are no obstacles (iron core, windings) and there is line of sight between PD source &four uhf sensors The exact calculation of TDOA, $(t_j - t_i)$ is important to locate accurate PD source position and even minute changes in this value can results a high uncertainty. Moreover, in practical approaches, TDOA measurement errors may included in the measurement of actual values. $P_j = l^* \tau_{12} = P_j + \Delta_j$, Δ_j is distance error induced by TDOA error.

Thus Eqn (4) can be expressed as

$$P'_{ji}-\|D_j-D_s\|+\|D_i-D_s\|=0 \quad (4b)$$

Where P'_{ji} is the distance including the error $\pm \Delta_j$.

$$\min F\left(x'y_z'\right)=\sum_{j=1}^{s-1}\sum_{i=j+1}^{s}\left(P_{ji}'-\|D_j-D_s'\|+\|D_i-D_S'\|\right) \quad (5)$$

Where s=4(number of sensors).

III. Experiment Set Up

The tailor made UHF sensors are used for incipient discharge localization in a free space. The laboratory experimental set up is developed as shown in Fig. 1. The tailor made log periodic antenna is used as UHF sensor. This sensor detects the PD signal in the range of (0.7-1) GHZ. The sensor is connected to mixed domain oscilloscope (MDO) through co axial cable. The UHF sensor output signal is displayed in MDO when incipient discharge occurred.

A test cell is designed for the occurrence of PD signal in a laboratory scenario, which consisting of a sphere and concave electrode with a 2 mm aluminum conducting spherical ball. The entire electrode system is filled with transformer oil and housing with Perspex tube. The test cell is energized by a100kV test transformer.

Fig.1. Experiment Model for localization of PD source.

IV. Result Analysis

The experiment is conducted for two different positions in the laboratory without any external noise. When the PD is initiated with the applied HV supply, the four UHF sensors will acquire the PD signals simultaneously and displayed in the MDO. This procedure is repeated for different positions of PD source and sensors. The recorded four UHF sensors signals for a particular incipient discharge are shown in Fig. 2.

Location Error can be determined by

$$\sqrt{(x_a - x_c)^2 + (y_a - y_c)^2 + (z_a - z_c)^2}$$

where x_a,y_a,z_a are actual coordinates and x_c,y_c,z_c are calculated co ordinates.The source and sensors co ordinates are presented in Table I .

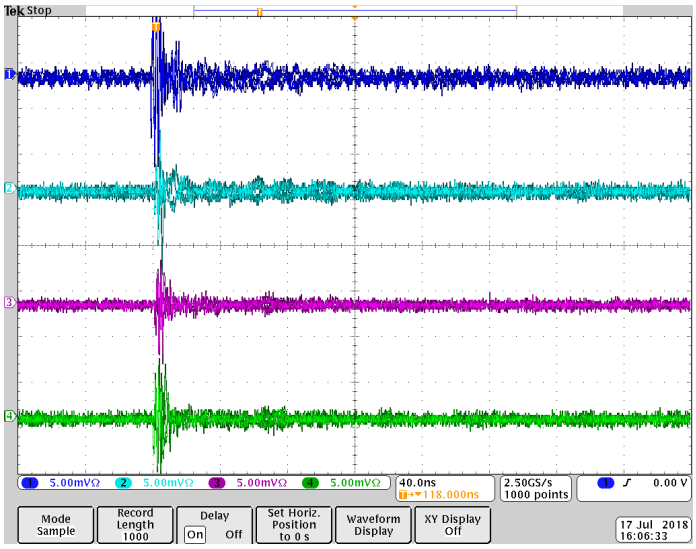

Fig.2. TDOA measurements of four UHF sensors for localization of PD source in laboratory scenario at 14.5kV.

TABLE I SENSORS CO -ORDINATES IN CM

Sensors	**Co ordinate (x,y,z) in cm**
Sensor 1	(47.5,0,0)
Sensor 2	(0,0,47.5)
Sensor 3	(47.5,0,100)
Sensor 4	(94,0,46)

TABLE II. LOCATION RESULTS OF ACTUAL AND CALCULATED PD SOURCE

S. No	**Actual PD source Position (cm)**	**Calculated PD Position by PSO(cm)**	**Location error (cm)**
1	(47.5,46.5,0)	(46.5,44.8,2)	2.8
2	(42.2,41.4,0)	(40.8,39.8,1)	2.35

The PSO algorithm is used for the PD source location with the measured 100 sets of TDOA measurements and an error of 3 cm is observed with the TDOA measurements from experiment conduction. The actual and calculated PD Position results are shown in the Table II.

V. Conclusion

The UHF PD signals are acquired by the incipient discharge like with the conducting particle movement in the transformer oil filled test electrode cell. The averaged TDOA measurements are considered for determination of the PD source using PSO algorithm. The obtained location error is almost 3 cm from the conducted experiment. This research may be very much helpful for utilities and manufacturers with low investment.

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