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Some Aspects of Location Identification of PD Source Using AE Signals by an Iterative Method

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Abstract: An acoustic Partial Discharge (PD) location problem modeled mathematically, gives system of sphere equations, which are non-linear. These equations are formed with known acoustic emission (AE) sensors co-ordinates, with PD locations co-ordinates as unknowns. Newton‘s method is implemented to locate the PD activity using the AE signals. This is an iterative method and the convergence depends on the initial guess. Different aspects such as initial guess, location of sensors (sensor co-ordinates) and tank orientation in space are studied in this paper by numerical experiments on the algorithm implemented using the experimental data published (available) in a literature. The published data considered for the study here uses 8 number of sensors (4 on the front and 4 on the back wall of the transformer tank; laboratory model). The method of locating acoustic emission partial discharge (AEPD) requires at most 4 sensors (three to identify the coordinates of the location and one for arrival time of AE signal). Hence, results of such 70 combinations (i.e. $^8C_4$) are studied using the algorithm implemented. The numerical test runs indicate that some combinations either do not lead to convergence or yield results with high errors. At least such 10 combinations (out of 70) are identified and analyzed.

Key Words: Acoustic Emission, Newton‘s method, PD location, Sensor location, Time of arrival.

INTRODUCTION

Condition monitoring of electrical equipments has gained interest in recent years as a part of the asset management. The PD measurement is one such tool for condition monitoring of the power transformers. There are electrical and acoustic methods to measure the PD. The electrical methods have some limitations. Unlike electrical PD measurement, the acoustic PD measurement is noninvasive and online monitoring technique. In large volume structures like power transformers not only the PD identification but its location is equally important and acoustic PD measurement enables to find the location of PD source inside the tank.[1-2]

The acoustic emission sensors made up of piezo - electric material such as quartz, are used. A number of sensors are mounted on the surface of the transformer tank from outside [3-4]. This model gives set of sphere equations such that the sensor is the centre of the sphere and the distance between the PD source and the sensor is the radius of the sphere. The radius of the sphere is given by the product of the velocity of sound in oil and the arrival time of the PD signal to the particular sensor. The velocity of sound in oil depends on many factors, such as temperature, viscosity, moisture content of the oil and also the frequency content of the signal [5]. These non linear sphere equations can be solved by direct method or by iterative method such as Newton‘s method to obtain the location of PD source inside the tank.

The ‗n‘ number of sensors are located on the tank as $S_1(x_{S1},y_{S1},z_{S1}),S_2(x_{S2},y_{S2},z_{S2}),S_3(x_{S3},y_{S3},z_{S3})\ldots S_n\ (x_{Sn}, y_{Sn}, z_{Sn})$ and (x, y, z) are PD location co-ordinates. The velocity of sound in oil is v and T_1 is the time of arrival of PD signal to the closest sensor (first detection). In the practical situation the absolute arrival time of the signal is not known as the signal trigger instant would be unknown. So the time difference approach is preferred. The sensor system gives the time delays between the instants the sensors are triggered with respect to the first sensor triggered [4,6]. $\tau_{12}, \tau_{13}, \ldots, \tau_{1n}$ ($\tau_{1n} = T_n - T_1$) are the respective time differences between the signal arrival time for the first sensor and the remaining sensors, respectively. The set of ‗n‘ equations (equation 1) of sphere using the variable described above are given by

$$
\begin{aligned}
(x-x_{s1})^2 + (y-y_{s1})^2 + (z-z_{s1})^2 &= (v\,T_1)^2 \\
(x-x_{s2})^2 + (y-y_{s2})^2 + (z-z_{s2})^2 &= \{v\,(T_1+\tau_{12})\}^2 \\
(x-x_{s3})^2 + (y-y_{s3})^2 + (z-z_{s3})^2 &= \{v\,(T_1+\tau_{13})\}^2 \\
&\vdots \\
(x-x_{sn})^2 + (y-y_{sn})^2 + (z-z_{sn})^2 &= \{v\,(T_1+\tau_{1n})\}^2
\end{aligned}
\quad \ldots (1)
$$

In the above system of equations, x, y, z and T_1 are the four unknowns and can be found by solving four equations out of ‗n‘ equations [7]. These non linear equations can be solved by using iterative methods.

DETAILS OF DATA ANALYZED

The experimental setup and related data is used from reference [8] and the details are as given in table 1. In the published data the origin of the three dimensional space was considered at one of the corners of the tank. In the present study the origin is shifted from the original position (one tank dimension away) so as to have all non-zero sensor coordinates. This helps in simulation process, implemented. Figure 1 shows the orientation of tank with origin shifted, and the new sensor coordinates are as given in table 2.

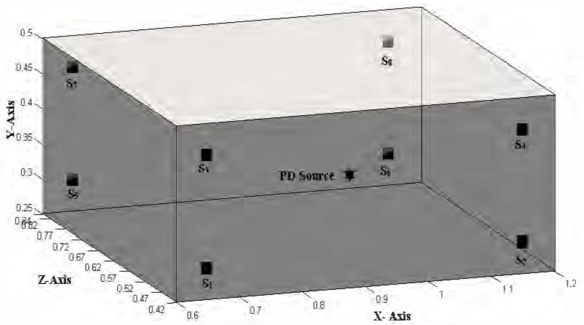

Figure 1 Tank orientation and arrangement of sensors for laboratory simulated PD source [8].

In the experimental tank (laboratory model), the simulated PD source location is at the coordinates (0.950 m, 0.360 m, 0.570 m), with the origin shift for the purpose of simulation. The distances of the sensors from PD point for each sensor in the ascending order of their time of arrival of the PD signal are calculated.

ITERATIVE METHOD IMPLEMENTED

Consider a set of 70 combinations (n=70) and using the 4 non linear equations with 4 unknowns (x, y, z, T_1) at a time, the detailed implementation of Newton‘s method is explained through a flow chart given in figure 2 [9]. In each combination, the sensors are to be arranged in ascending order of their arrival times and the time delays between the first and the remaining sensors in that particular combination are calculated. The computer code developed also sequences the sensors.

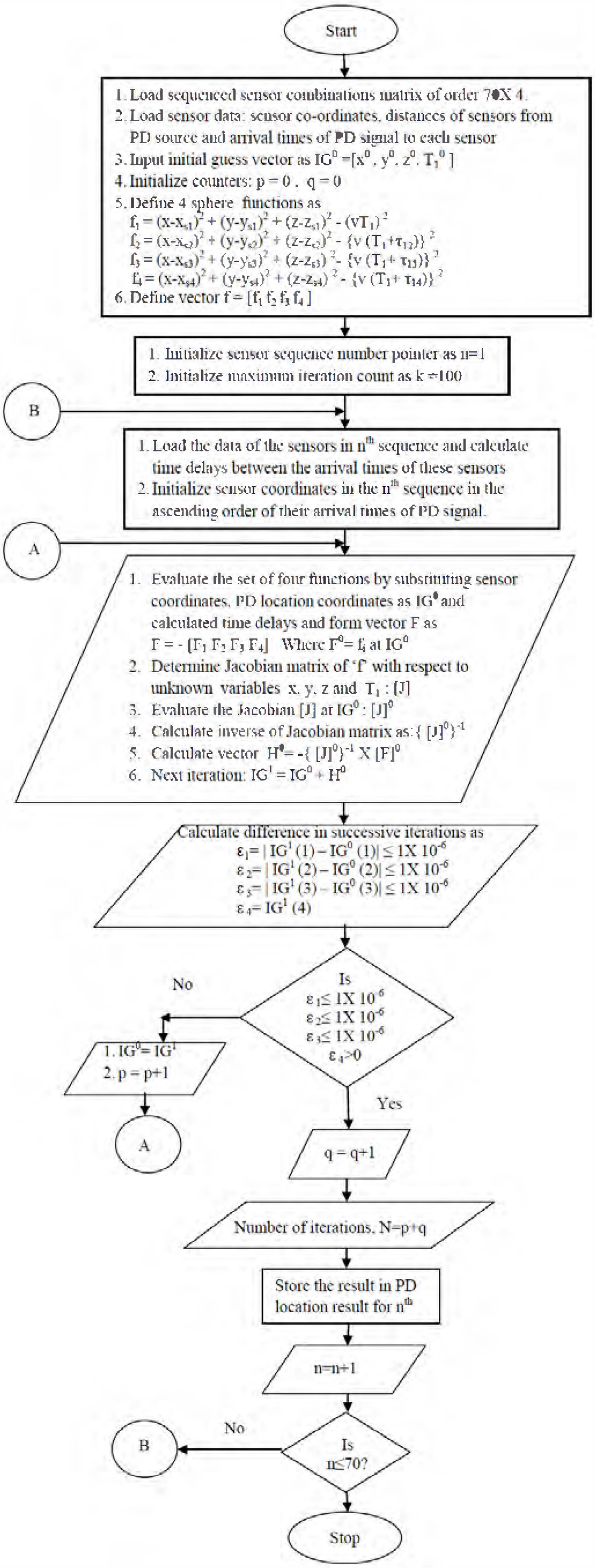

Figure 2 Flow chart for Newton’s method

Table 1 Data for the simulated model of AEPD location [8].

Sr. No	Quantity	Description
1	Tank Dimension	0.600m X 0.250m X 0.420m
2	PD Source location (with one of the tank corners as origin)	(0.350 m, 0.110 m, 0.150m)
3	PD Source location (with origin shifted)	(0.950 m, 0.360 m, 0.570 m)
4	Average velocity of sound in oil	1250 m/s
5	Number of AE sensors	8
6	PD source	Identical stainless steel needles of tip radius 150 μm
7	Applied voltage to the needle electrode	18 kV
8	Type of sensors	Piezo-electric

Table 2 Coordinates of the sensor locations [8].

Sensor Sr. No.	X (m)	Y (m)	Z (m)
S_1	0.648	0.295	0.420
S_2	1.148	0.295	0.420
S_3	0.648	0.455	0.420
S_4	1.148	0.455	0.420
S_5	0.648	0.295	0.840
S_6	1.148	0.295	0.840
S_7	0.648	0.455	0.840
S_8	1.148	0.455	0.840

RESULTS AND ANALYSIS

The Newton‛s method is implemented in MATLAB. Based on the time of arrival data, sensor coordinates (table 2) the location of the PD source in the experimental set (which is known; row 4 of table 1) is identified, using three randomly chosen initial guesses. Three different initial guesses (IG-1 to IG-3) chosen for the numerical experiments are given in table 3.

Table 3 Three initial guesses (randomly chosen) used for the study, with algorithm implemented.

Initial Guess no.	Co-ordinates of initial guess (x^0,y^0,z^0,T_1^0)
IG-1	(1.089 m,0.274m,0.486m,0.180ms)
IG-2	(1.144m,0.320,m0.828m,0.180ms)
IG-3	(0.676m,0.387m,0.822m,0.180ms)

The average values of the PD location coordinates and the percentage error in the average value (as the actual PD location in the laboratory model is known) is as given in table 4. The results given in table 4 include the average of all the 70 possible combinations for 3 randomly chosen initial guesses given in table 3.

Table 4 Results for the 3 initial guesses (of table 3)

		IG-1	IG-2	IG-3
Average Value	X	0.915	0.955	0.946
	Y	0.357	0.361	0.361
	Z	0.614	0.566	0.576
	V	1.643	1.291	1.292
% Error in Average Value	X	-3.716	0.521	-0.415
	Y	-0.783	0.292	0.240
	Z	7.641	-0.626	1.123
	V	31.462	3.311	3.358

From the table 4 it is observed that the errors are high in velocity and certain PD location coordinates. The errors depend on the initial guess as well. When such numerical experiments are conducted with a large number of initial guesses, on closer observation it is found that out of 70 combinations, there is a set of 10 combinations (of sensors), which showed either much higher errors or no convergence. Such a situation for sequence number 28 is shown in table 5. The typical plot showing no convergence of x coordinate estimates as a function of iteration number is as shown in figure 3 (this corresponds to sequence 28 with initial guess IG1; table 5; the expected convergence was at x=0.950 m). These 10 sets of sensor combinations in relation with the simulated PD location have certain symmetry, which resulted into near-equal distances (and near-equal times of arrival) with respect to PD location, resulting into higher errors. Hence such combinations need to be eliminated. But identification of such a set is difficult in actual practice as the location of PD is not known a prior. Hence, to eliminate such set standard deviation ‗σ‘ is made use of; in the present case the sensor combinations whose errors lie within a ‗σ‘ range only are taken for averaging. In such a situation these combinations (10 sequences) will get eliminated. The results of the average PD coordinates and errors in their estimation after eliminating these 10 sets for a typical initial guess are as shown in table 6. A typical convergence plot for one of the sequence obtained using the MATLAB code implemented is as shown in figure 4.

Table 5 Results for sensor sequences with high errors (% Error in mean values of X, Y, Z and V).

IG1 : (1.089,0.274,0.486,0.180)					
Sr. No.	Seq. No	% Error in PD coordinates and velocity			
		X	Y	Z	V
1	1	-0.200	0.200	-4.100	$1x10^{-6}$
2	18	0.000	-35.300	0.000	$1x10^{-6}$
3	25	5.300	-0.500	-1.200	$1x10^{-6}$
4	28	--	2.100	534.100	2202
5	32	-0.100	1.000	$1x10^{-6}$	$1x10^{-6}$
6	39	-1.100	-9.300	-0.100	$1x10^{-6}$
7	43	4.700	-1.000	9.000	$1x10^{-6}$
8	46	0.300	$1x10^{-6}$	0.100	$1x10^{-6}$
9	53	$1x10^{-6}$	-2.100	-0.100	$1x10^{-6}$
10	70	0.300	-0.200	-4.200	$1x10^{-6}$

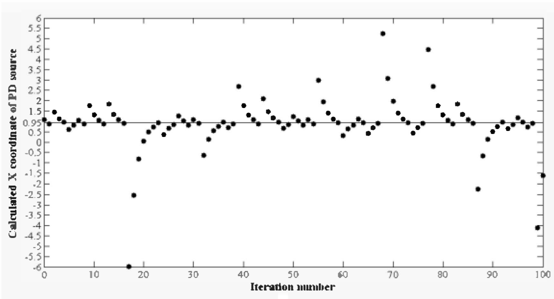

Figure 3 Computed X coordinate for sequence No.28 as a function of iteration number (showing no convergence).

Table 6 Results (Average, % Error in average values of X, Y, Z and V and standard deviation σ) for the remaining 60 sequences after eliminating those of higher errors.

	X	Y	Z	V
Average value	0.950	0.359	0.570	1.250
% Error	0.001	-0.176	0.021	$1x10^{-6}$
σ	$1x10^{-6}$	0.004	0.001	$1x10^{-6}$

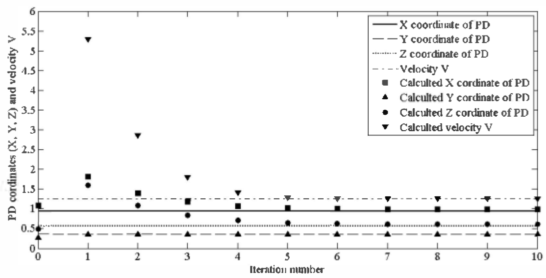

Figure 4 Convergence plot for a typical converging sequence.

CONCLUSIONS

1. The initial guess point (in general chosen randomly, within the tank dimensions) coordinates should not coincide with (or very close to) any of the sensors coordinates.
2. The errors are enormously high in the cases where minimum two sensors in that particular group have at least one coordinate common. Such 10 combinations in this specific case were identified with high errors (or with no solutions).
3. By eliminating those 10 sequences and taking remaining sequences the error can be reduced to below 1 %.
4. Although 4 sensors data is sufficient for PD location identification, data with a large number of sensors (more than 4), post processed by statistical means can eliminate some of the sequences which can lead to higher errors.

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