The Journal of CPRI
Vol. 1, No.1, September 2004, pp. 33–37

3D Location of Multiple Partial Discharge Sources

H.N. Nagamani* and Channakeshava*

1.0 PRINCIPLE OF AE SOURCE LOCATION

The ability to locate Acoustic Emission (AE) sources is one of the most important features of the multi-channel AE detection system. An array of AE sensors is necessary to locate an AE source. When the AE signals are transient in nature, measurement of time of signal arrival at different AE sensors is generally employed for source location. AE source is located by measuring the time delay between two or more AE sensors in the array. Location of AE source requires the knowledge of the velocity of AE signals in the medium under study, which can be obtained by simulating the AE sources at known locations within the medium.

In the present study, a multi channel AE system has been employed for detection and location of partial discharge (PD) or corona sources. PD sources were simulated in transformer insulation medium by energizing sharp metallic needles positioned at known locations. Velocity of AE PD signals in transformer oil medium was determined from the value of time delay in receiving AE PD signals by different sensors. The (x, y, z) co-ordinates of the PD source, i.e. the needle tip, were estimated with the help of 3D location software. The estimated co-ordinates of the PD source were compared with the actual coordinates to verify the accuracy of estimation. This paper discusses the methodology for estimating the propagation velocity of AE PD signals in transformer oil medium and 3D location of single and three sources simulated in transformer oil medium. The accuracy of location results is also discussed.

Attempts are being made to standardize the methodology for location of defects in power transformers, employing AE technique. A case study on a power transformer of rating 230 kV/110 kV installed in a 230 kV Substation has been presented in this paper.

2.0 SIMULATION OF PD SOURCES

For detection of acoustic emissions due to PD in transformer oil, the guidelines as per IEEE C57.127-2000 were generally followed. The laboratory experiments have been performed at the prevailing ambient temperature of 30°C ± 5°C. An AE system consisting of the following components was employed for detection and location of PD sources.

- AE sensors integrated with the preamplifier, model No. R15I
- An 16-channel AE system for acquiring and processing AE data
- Suitable software for detection and 3D location of AE sources.

PD source was simulated in transformer oil medium by applying suitable voltage to stainless steel needle with tip radius of 150 μm. The oil container made out of mild steel was grounded. The left bottom corner of the oil container was considered as the reference point for calculating the coordinates. The needle was positioned at pre-determined location within the oil medium and energized to a voltage above PD (or corona) inception voltage. Velocity of AE PD signals in transformer oil medium was determined from the value of time delay in receiving AE PD signals by different sensors. The (x, y, z)

*Central Power Research Institute, Sadashivanagar, Bangalore 560 080, India

Reprint: 2004 International conference of Doble clients, March 21–26, Boston, USA.

co-ordinates of the PD source, i.e. the needle tip, were estimated with the help of 3D location software. The estimated co-ordinates of the PD source were compared with the actual coordinates to verify the accuracy of estimation. Velocity of AE PD signals in transformer oil medium was estimated as outlined in Section 2.1.

2.1 Estimation of Propagation Velocity of AE Signals in Transformer Oil

A PD source emits AE signals in all directions. As soon as the wave reaches any one of the sensors, the AE system resets and the counter starts. As soon as the wave reaches the second sensor, the time counter stops and the time delay is determined. Knowing the distance between the sensors and the time delay, velocity ("V") of AE signals can be calculated from the formula,

$$V = \frac{(x - 2d_1)}{\Delta t_1} \quad (1)$$

where, Δt_1 is the time delay in receiving AE signals at the second sensor with reference to the first sensor and d_1 is the distance between the PD source and the reference sensor and "x" is the distance between the sensors, as shown in Figure 1.

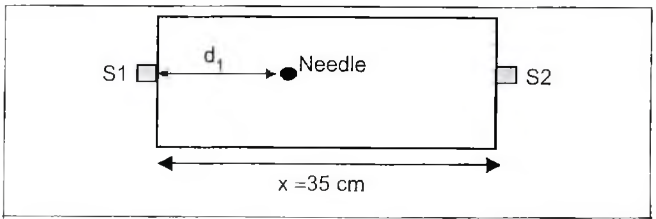


FIG. 1. ARRANGEMENT FOR ESTIMATING WAVE VELOCITY

A stainless steel needle was positioned on the line joining the two AE sensors fixed on the opposite sides of the metallic (mild steel) container. The needle was energized to a voltage higher than PD inception voltage and AE PD signals were acquired.

From the AE system, time delay and the distance from the reference sensor are obtained. Time delays recorded for 5 trials at 10 kV are tabulated in Table 1 along with the estimated wave velocity.

Therefore, 1250 m/s was taken as the value of velocity of AE PD signals in the transformer oil used in the present study. Similarly, estimation of velocity of AE PD signals in other insulating materials of power transformer like, paper, press board, etc., is under progress which will help in location of defective sites in transformer.

TABLE 1

WAVE VELOCITY IN TRANSFORMER OIL

Trial	Actual Distance from reference sensor, d_1, (cm)	AE system data Distance from reference sensor, d_1, (cm)	Time delay Δt_1, (μs)	Wave velocity, V, (m/s)	Average V(m/s)
1	9.0	9.09	135	1246	1250
2	9.0	8.92	137	1252	
3	9.0	8.92	137	1252	
4	9.0	9.00	136	1250	
5	9.0	9.00	136	1250	

TABLE 2

EXPERIMENTAL ARRANGEMENT FOR PD SIMULATION

PD sources	Identical stainless steel needles of tip radius 150 μm.
Number of AE sensors used	8
Sensor mounting	Sensors 1 to 4 on container surface ABCD and sensors 5 to 8 on container surface EFGH.
AE Sensor coordinates, in meters.	
	S5: (0.0475, 0.0450, 0.420) S6: (0.5475, 0.0450, 0.420) S7: (0.0475, 0.2050, 0.420) S8: (0.5475, 0.2050, 0.420) S1: (0.0475, 0.0450, 0.000) S2: (0.5475, 0.0450, 0.000) S3: (0.0475, 0.2050, 0.000) S4: (0.5475, 0.2050, 0.000)
Threshold for AE system	30 dB
AE wave velocity	1250 m/s

2.2 Location of Simulated PD Sources

For conducting experiments on simulation of PD sources, the following arrangement as shown in Figure 2 was used.

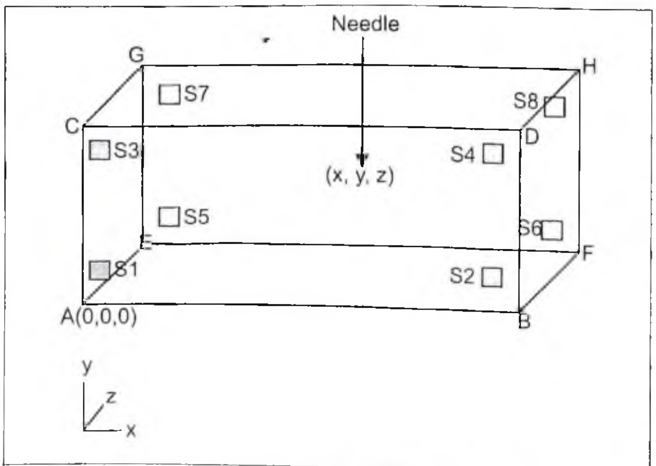


FIG. 2. ARRANGEMENT FOR SIMULATING PD SOURCE

2.2.1 *Location of Single PD Source*

The needle, N1, was positioned at (0.35, 0.11, 0.15 m) and energized to 18 kV, which was higher than PD inception voltage. AE PD signals were acquired and needle tip coordinates were estimated. Figure 3(a) shows the amplitude of AE PD signals received by AE sensors due to PD activity occurring at N1 and Figure 3(b) gives the 3D location chart. Table 3 compares the source location estimated from AE system with actual coordinates of the needle. Error in estimated coordinates are also tabulated separately for individual coordinates.

Figure 3(c) gives the waveforms of AE PD signals, sequence of AE sensors receiving AE PD signals, time delay (dT) in receiving AE PD signals by AE sensors, estimated (x, y, z) co-ordinates estimated by AE system from the above dT.

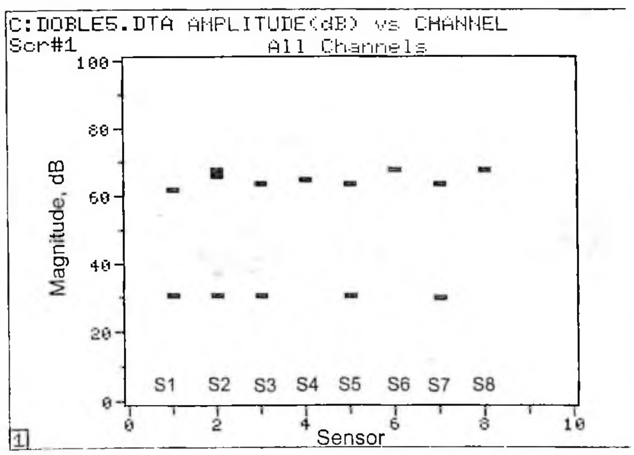
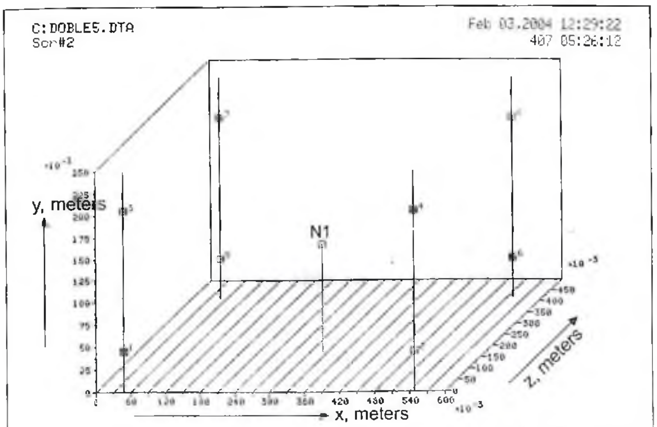
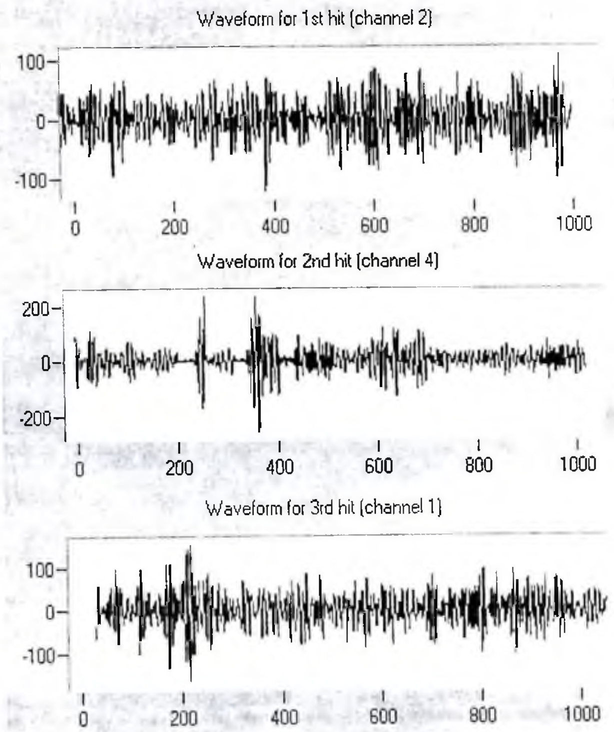


FIG. 3a. MAGNITUDE OF AE SIGNALS DUE TO PD AT N1



Red box: AE sensors & Green box: Needle position located by AE system

FIG. 3b. LOCATION CHART OF N1 AS OBTAINED FROM AE SYSTEM



Gp# 1[2,4,1,3,6,8,7,5]: Sequence of sensors in which AE PD signals were received.
Estimated coordinates: x = 0.3373, y = 0.1062, z = 0.1489
Time delays: dT[20, 53, 53, 63, 71, 122, 125]
Maximum magnitude = 66.0, dB

FIG. 3c. WAVEFORMS RECORDED BY AE SYSTEM ALONG WITH TIME DELAY AND SENSOR ORDER FOR ESTIMATING PD SOURCE COORDINATES

TABLE 3
RESULTS OF SINGLE SOURCE LOCATION

Co-ordinates of the needle, (x, y, z) meters		Error (%) in estimated co-ordinates		
Actual	Estimated from AE system	x	y	z
N1: (0.350, 0.110, 0.150)	(0.337, 0.106, 0.148)	3.7	3.6	1.3

2.2.2 *Location of Multiple PD Sources*

Three needles P1, P2 & P3 were positioned at different predetermined positions and were simultaneously energized to 19 kV, which is higher than PD inception voltage. AE PD signals were acquired and processed to locate the needles. Figure 4(a) shows the amplitude of AE PD signals due to PD activity occurring simultaneously at P1, P2 and P3 as received by all the 8 AE sensors and Figure 4(b) gives the 3D location chart. Table 4 compares the multiple source location from AE system with actual coordinates of the needles. Error in estimated coordinates are also tabulated separately for individual coordinates.

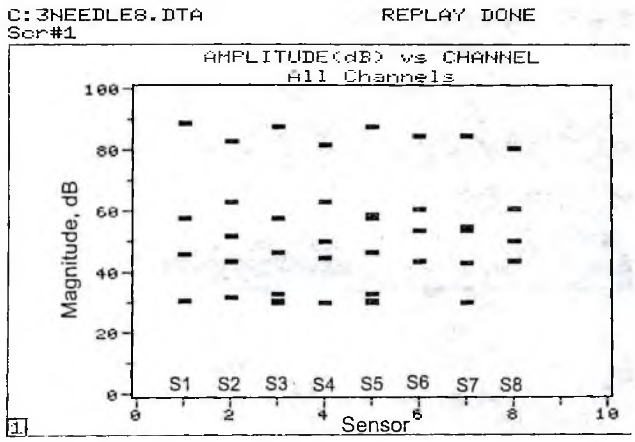
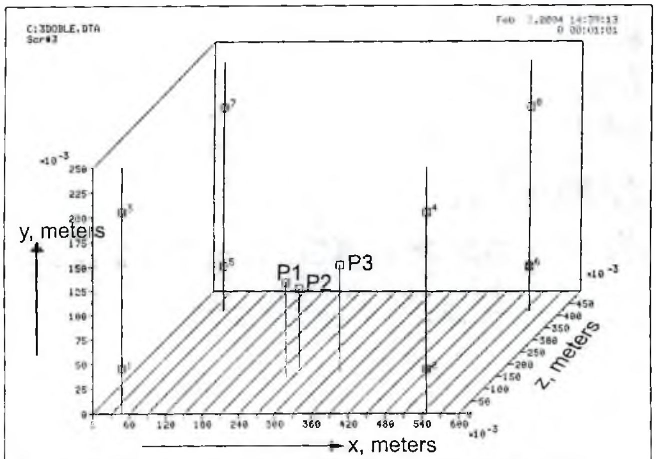


FIG. 4a. MAGNITUDE OF AE SIGNALS DUE TO SIMULTANEOUS PD AT P1, P2 & P3



Red box: AE sensors & Green box: Needle position located by AE system

FIG. 4b. LOCATION CHART OF NEEDLES P1, P2 & P3 AS OBTAINED FROM AE SYSTEM

3.0 FIELD TESTING OF POWER TRANSFORMERS

Measurement of partial discharges is one of the important diagnostic techniques for assessing the condition of power equipment. The conventional electrical method for PD detection is well established and is generally undertaken with adequate electromagnetic shielding. The limitations of electrical method of PD detection for equipment in service, has resulted in the development of alternative techniques. More recently, PD detection based on Acoustic Emission (AE) technique is gaining

TABLE 4

RESULTS OF MULTIPLE SOURCE LOCATION

Co-ordinates of the needles, (x, y, z) meters		Error (%) in estimated co-ordinates		
Actual	Estimated from AE system	x	y	z
P1: (0.250, 0.100, 0.140)	(0.259, 0.097, 0.143)	−3.6	3.0	−2.1
P2: (0.270, 0.080, 0.180)	(0.266, 0.080, 0.185)	1.5	0.0	2.8
P3: (0.340, 0.120, 0.175)	(0.330, 0.110, 0.171)	2.9	8.3	2.3

importance. The main advantage of AE detection method is that it is non-destructive and non-invasive. CPRI, Bangalore is attempting to apply AE technique for on-line testing of power transformer employing a multi channel AE system.

Recently, a 100 MVA, 230 kV/110 kV transformer installed in a 230 kV Substation was tested employing AE technique. The main objectives of the study were as follows:

- Measurement of AE signals which will become the reference value for further measurement.
- Establish a relation, if any, with DGA result.
- Locate the defective sites, if any, in the transformer.

In view of the above, the transformer was tested employing a 16-channel AE system. 16 numbers of AE sensors were mounted on the outer surface of the transformer container. S1 to S4 were mounted towards HV winding and S9 to S12 towards the LV winding. A view of the 100 MVA, 230 kV/110 kV transformer installed in a 230 kV Substation tested for AE is shown in Figure 5(a). AE PD signals were

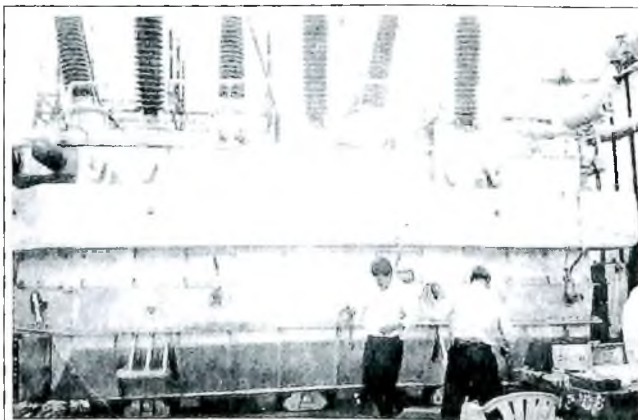


FIG. 5a. A VIEW OF TESTING OF 220 kV/110 kV, 100 MVA TRANSFORMER AT 220 kV SUBSTATION

monitored during normal operating condition of the transformer. Magnitudes of AE signals received by all the 16 sensors are shown in Figure 5(b). The 3D location chart is shown in Figure 5(c). The DGA test results are summarized in Figure 6.

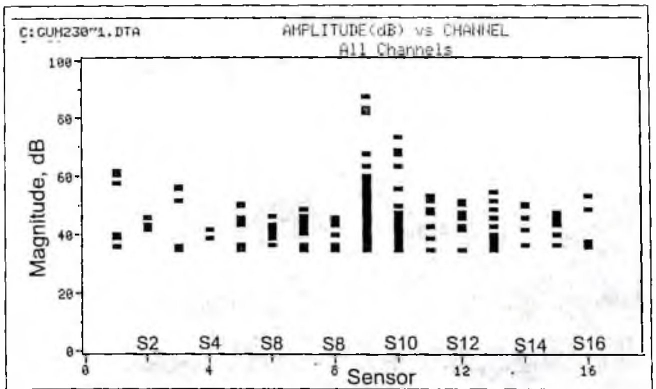
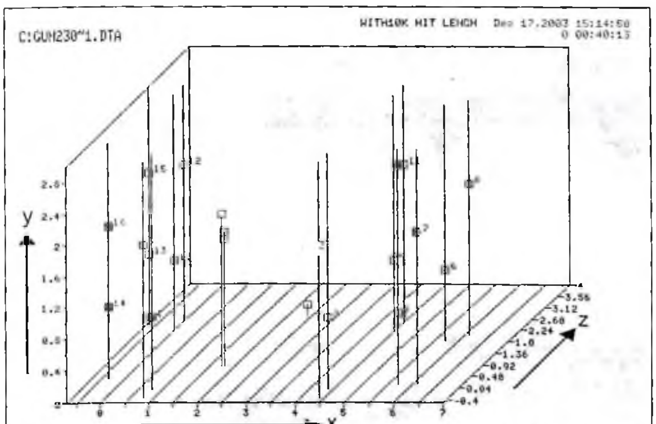


FIG. 5b. MAGNITUDE OF AE SIGNALS FROM THE TRANSFORMER AS RECEIVED BY 16 SENSORS



Red box: AE sensors & Green box: Defects located by AE system

FIG. 5c. LOCATION CHART OF AE SOURCES IN POWER TRANSFORMER AS OBTAINED FROM AE SYSTEM

The maximum magnitude of AE signals from the transformer is 85 dB as shown in Figure 5(b). Based on the AE data available with CPRI for more than 50 transformers in service, 85 dB appears to be on the higher side. Also, an increasing trend has been observed in gas level as illustrated in Figure 6.

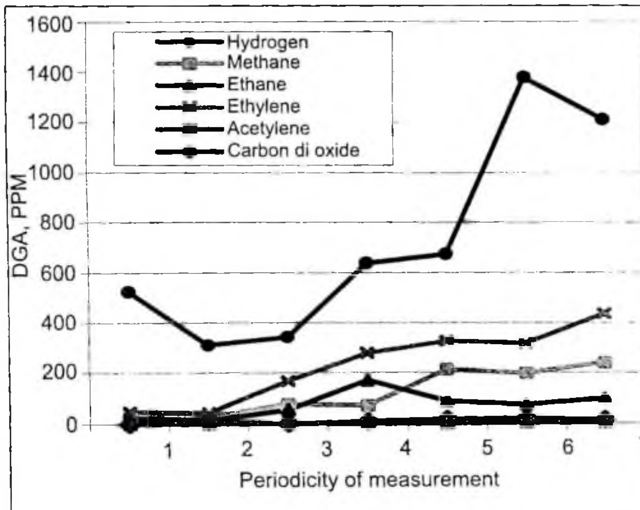


FIG. 6. RESULTS OF DGA FOR THE 220 kV/110 kV TRANSFORMER

Fault location chart obtained from AE system (Figure 5(c)) indicates that faults are towards HV winding and LV side.

However, verification of results regarding location of defects will be taken up after receiving necessary information. Also, the results are being analyzed to check any possible relation between DGA and AE signals.

4.0 CONCLUSION

3D location results of three case studies viz., (i) Single PD source, (ii) Multiple PD sources (three sources) and (iii) On-line testing of 220 kV/110 kV transformer at site, are considered in the present study. Results of location experiments as summarized in Tables 3 & 4 indicate that the coordinates of single and multiple PD sources estimated from AE system match fairly close with actual coordinates. The error encountered in the present study is in the range of 0% to 9%. Therefore, a suitable methodology has been arrived at for locating multiple sources employing AE technique. CPRI is attempting to apply AE technique for transformers at site for detection and location of defects.