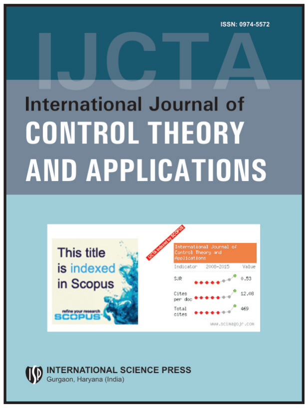

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An Adaptive Ant Lion Optimizer for Partial Discharge Localization using Acoustic Emission Technique

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Abstract: Partial Discharge (PD) occurring in the insulation systems of transformer are an important indicator of their deterioration. Insulation degradation is a well-known source of power transformer failure. Many methods have been realized to measure PD, including electrical, chemical, acoustic and UHF methods. A survey of current research reveals the continued interest in the application of advanced techniques like acoustic for partial discharge diagnostic in transformer. This paper proposed Ant Lion Optimization technique for localization of PD source using acoustic detection technique. The acoustic localization technique using adaptive ALO is easy to implement and gives improved result in comparison to other optimization techniques.

Keywords: Partial discharge, Acoustic, Ant lion Optimization.

1. INTRODUCTION

The term "Partial Discharge (PD)" is defined by International Electro technical Commission (IEC) 60270 (Partial Discharge Measurements) as a localized electrical discharge that only partially bridges the insulation between conductors and which may or may not occur adjacent to a conductor [1]. Transformer is key elements in power system which represents the largest portion of capital investment in power system. Reliability of transformer affects economical operation of utility. Normally, faults in power transformers are caused by the decreasing of dielectric strength and dielectric breakdown during operation due to the cumulative effect of the thermal, electrical and mechanical stresses [2]. Regular Partial Discharge (PD) analysis and bushing monitoring give an accurate indication of the status of the deterioration process. So it is possible to foretell developing fault condition by online monitoring and precautionary tests. It is very much essential to have information of PD level and location to plan maintenance of electrical equipment.

It is well known that the occurrence of discharge results in discharge current or voltage pulse, electromagnetic impulse radiation, ultrasonic impulse radiation and visible or ultraviolet light emission. Accordingly, there are several detection methods that have been developed to measure those phenomena respectively. Electrical [3], chemical [4], acoustic [5] and UHF [6] are four main PD detection methods. Electrical technique is predominantly an offline method. It is also vulnerable to electrical disturbances and noise during onsite measurement. In chemical technique gassing characteristic is highly dependent on size and structure of transformer as well as loading and history of maintenance. So there is no uniformity in analysis of health of transformer. Advantage of the acoustic method is that it can locate the site of a PD by studying the phase delay or the amplitude attenuation of the acoustic waves. The acoustic response of PD inside a transformer is typically measured by piezo-electrical sensors. Using the different arrival times of the acoustic PD signal at multiple sensors, algorithms can compute the location of the PD source. Algorithm used for localization will decide the accuracy of PD source location in acoustic PD detection technique. No algorithm is perfect due to its own limitation. In present context implementation of new algorithm is needed to overcome limitation of existing algorithm. In this paper adaptive ALO algorithm is implemented and final localization results are being compared with existing algorithm to show improvement.

2. PD SIGNAL PROPAGATION

Acoustic technique can be used for estimating location of PD source. PD generates acoustic waves in range of 20 kHz to 1 MHz. The acoustic wave propagates through insulation media enclosing the region of emission, before reaching the enclosure of the electrical equipment. Wall mounted acoustic emission sensors senses vibrations and convert it into electrical signals. Captured signals are analyzed for further study. Captured signals depends on detection equipments, source and propagation media.

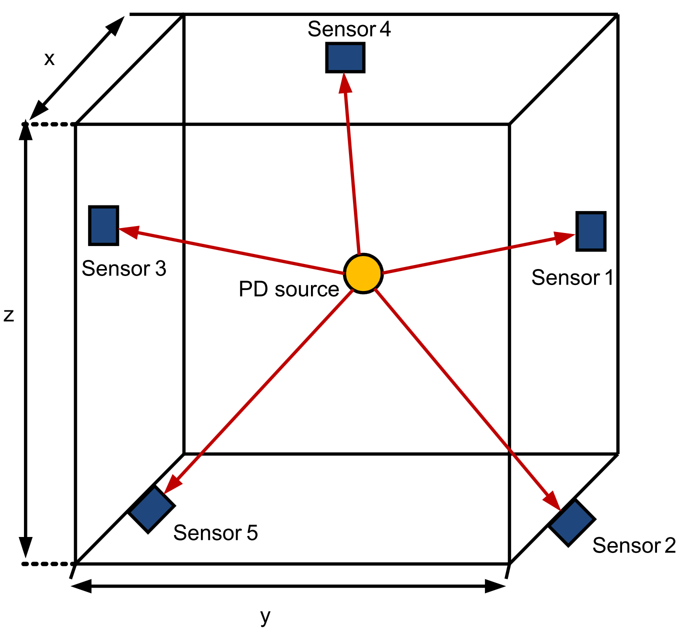

Figure 1: Setup for acoustic emission technique

A prototype transformer tank of 50 cm × 30 cm × 40 cm is shown in Figure 1.

A main objective is to determine the position of the PD source based on signals captured by sensor array inside the transformer tank as shown in Figure 1. Each sensor will capture acoustic signals at different time as shown in Figure 2. Time Difference of Arrival (TDOA) algorithm has been implemented to find location of partial discharge source.

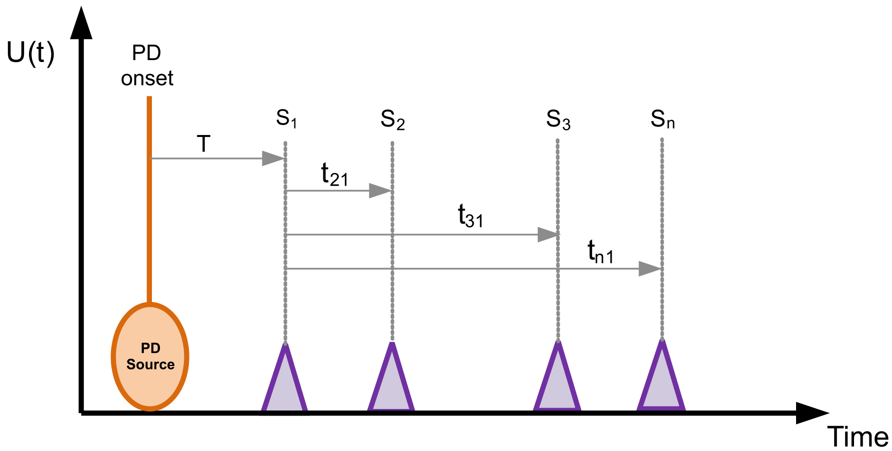

Figure 2: Schematic of time difference of arrival in acoustic signals

PDE equation in homogeneous medium for propagation of acoustic wave:

$$\frac{\partial^2 P}{\partial t^2} = v^2 \nabla^2 P = v^2 \left(\frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2} + \frac{\partial^2 P}{\partial z^2} \right)$$

where, P (*x, y, z, t*) pressure wave field; *v* is acoustic wave velocity (m/s).

It is very difficult to get perfect location of PD source by solving non linear equation governing acoustic source and sensors. So we can always try to get optimal solution of the problem. Some smart algorithms are preferred for the solution.

3. ANT LION OPTIMIZATION (ALO)

A novel bio-inspired optimization algorithm based on the hunting process of Ant Lions in nature is known as the Ant Lion optimizer (ALO). The ALO technique proposed by Seyedali Mirjalili [7] that reflects the intellectual activities of antlions in hunting ants in environment. To model such interfaces, ants have to travel over the exploration space, and antlions are permitted to pursuit them and become fitter using traps [1].

3.1. Operators of ALO Algorithm

As ants travel randomly in nature when searching for food, a random walk is selected for demonstrating ants' movement and it is given by following equation:

$$X(t) = \left[0, \text{cumsum}\left(2r(t_1) - 1\right), \text{cumsum}\left(2r(t_2) - 1\right), \ldots, \text{cumsum}\left(2r(t_n) - 1\right)\right] \tag{1}$$

Where, *cumsum* computes the cumulative sum, *n* is the maximum number of iteration, *t* is the step of random walk (iteration), and *r*(*t*) is a stochastic function defined as follows:

$$r(t) = \begin{cases} 1 \rightarrow \text{rand} > 0.5 \\ 0 \rightarrow \text{rand} \leq 0.5 \end{cases}$$

Where, *t* is the step of random walk and rand represents a random number created by uniform distribution in the interval of [0, 1].

The location of ants are kept and used during optimization in the given matrix:

$$M_{Ant} = \begin{bmatrix} A_{11} & A_{12} & . & . & A_{1d} \\ A_{21} & A_{22} & . & . & A_{2d} \\ . & . & . & . & . \\ . & . & . & . & . \\ A_{n1} & A_{n2} & . & . & A_{nd} \end{bmatrix} \tag{2}$$

where, M_{Ant} = the matrix for storing the location of every ants, A_{ij} = the value for j^{th} variable (dimension) of i^{th} ant, n = the No. of ants and d = the total No. of variables.

For calculating individual ant, a fitness function is used in optimization and subsequent matrix saves the fitness value of each ants:

$$M_{OA} = \begin{bmatrix} f\left(\left[A_{11}, A_{12}, ..., A_{1d}\right]\right) \\ f\left(\left[A_{21}, A_{22}, ..., A_{2d}\right]\right) \\ \vdots \\ \vdots \\ f\left(\left[A_{n1}, A_{n2}, ..., A_{nd}\right]\right) \end{bmatrix} \tag{3}$$

where, M_{OA} = the matrix for storing the each ant fitness, A_{ij} = the value of j^{th} variable of i^{th} ant, n = the total No. of ants and f = the objective function.

So we suppose that ants as well as the antlions are hiding somewhere in the search area. So as to store their locations and fitness values, the following matrices are used:

$$M_{Antlion} = \begin{bmatrix} AL_{11} & AL_{12} & . & . & AL_{1d} \\ AL_{21} & AL_{22} & . & . & AL_{2d} \\ . & . & . & . & . \\ . & . & . & . & . \\ AL_{n1} & AL_{n2} & . & . & AL_{nd} \end{bmatrix} \tag{4}$$

where, $M_{Antlion}$ = the matrix for storing the location of individual antlion, A_{Lij} = the value of j^{th} variable of i^{th} antlion, n = No. of ants and d = the No. of variables.

$$M_{OAL} = \begin{bmatrix} f\left(\left[AL_{11}, AL_{12}, ..., AL_{1d}\right]\right) \\ f\left(\left[AL_{21}, AL_{22}, ..., AL_{2d}\right]\right) \\ \vdots \\ \vdots \\ f\left(\left[AL_{n1}, AL_{n2}, ..., AL_{nd}\right]\right) \end{bmatrix} \tag{5}$$

where, M_{OAL} = the matrix for storing the fitness of individual antlion, A_{Lij} = the value of j^{th} variable of i^{th} antlion, n = No. of ants and f = the objective function.

3.2. Random Walk of Ants

Each of the behaviors is mathematically modeled as:

$$x_i^t = \frac{(x_i^t - x_i) \times (d_i - c_i^t)}{(d_i^t - a_i)} + c_i \tag{6}$$

where, a_i = the minimal of random walk of i^{th} variable,

b_i = the Maximum of random walk in i^{th} variable.

The Random walks of ants is calculated from equation (6).

3.3. Trapping in Antlions pits

The Trapping in antlion's pits is calculated from following equation (7) and equation (8)

$$c_i^t = \text{Antlion}_j^t + c^t \tag{7}$$

$$d_i^t = \text{Antlion}_j^t + d^t \tag{8}$$

3.4. Sliding Ants towards Antlion

The Sliding ants towards ant lion calculated from equation (9) and equation (10)

$$c^t = \frac{c^t}{\text{I}} \tag{9}$$

$$d^t = \frac{d^t}{\text{I}} \tag{10}$$

where, I = ratio, c^t = the minimal of total variables at t^{th} iteration, and d^t = the vector containing the maximum of total variables at t^{th} iteration.

3.5. Catching Prey and Re-building the Pit

Catching prey and re-building the pits calculated from equation (11)

$$\text{Antlion}_j^t = \text{Ant}_i^t \text{ if } [f(\text{Ant}_i^t)] > f(\text{Antlion}_j^t) \tag{11}$$

where, t = the current iteration, Antlion_j^t = the location of chosen j^{th} antlion at t^{th} iteration, and Ant_i^t = the location of i^{th} ant at t^{th} iteration.

3.6. Elitism

Elitism of ant lion calculated using roulette wheel from equation (12)

$$\text{Ant}_i^t = \frac{\text{R}_\text{A}^t + \text{R}_\text{E}^t}{2} \tag{12}$$

where, R_A^t = the random walk nearby the antlion chosen by means of the roulette wheel at t^{th} iteration, R_E^t = the random walk nearby the elite at t^{th} iteration, Ant_i^t = the location of i^{th} ant at t^{th} iteration.

3.6. Adaptive ALO Algorithm

In the meta-heuristic algorithms, randomization play a very important role in both exploration and exploitation where more randomization techniques are Markov chains, Levy flights and Gaussian or normal distribution and new technique is adaptive technique. Adaptive technique used by Pauline Ong in Cuckoo Search Algorithm

(CSA) [8] and shows improvement in results of CSA algorithms. The Adaptive technique [9] includes best features like it consists of less parameter dependency, not required to define initial parameter and step size or position towards optimum solution is adaptively changes according to its functional fitness value over the course of iteration. So mete-heuristic algorithms on integrated with adaptive technique results in less computational time to reach optimum solution, local minima avoidance and faster convergence.

$$X_i^{t+1} = X_i^t + \text{randn} \times \left(\frac{1}{t}\right)^{\left|((\text{bestf}(t) - fi(t))/(\text{bestf}(t) - \text{worstf}(t)))\right|} \tag{13}$$

where, X^i_{t+1} new solution of i^{th} dimension in t^{th} iteration $f(t)$ is the fitness value

4. SIMULATION RESULT ANALYSIS

The Adaptive Ant Lion optimizer is used to solve the problem of PD source localization. Simulation parameter is quoted from reference paper [10] as given in Table 1.

Table 1
Simulation Parameter

Elements	*X-axis (mm)*	*Y-axis (mm)*	*Z-axis (mm)*
Transformer Dimension	5000	3000	4000
Actual PD source	4500	2600	3700
Sensor (S_1)	2500	0	2000
Sensor (S_2)	2500	1500	4000
Sensor (S_3)	5000	1500	2000
Sensor (S_4)	2500	3000	2000
Sensor (S_5)	0	1500	2000

$t_1 = 2600$ µsec is Reference time

Sensor S_1 is Reference sensor [11,12]

$$\tau_{i1}(\mu\text{ sec}) = [1600, 1500, 1900, 3524.69] - t_1, i = 2, 3, 4, 5$$

5.1. Problem Formulation

$$t_{21} = -1000 \times 10^{-03}, \tau_{31} = -1100 \times 10^{-03},$$

$$t_{41} = -700 \times 10^{-03}, \tau_{51} = -924.69 \times 10^{-03}, \tag{14}$$

$$P = \left[(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2\right]^{0.5} \tag{15}$$

$$a = \left[(x - x_2)^2 + (y - y_2)^2 + (z - z_2)^2\right]^{0.5} - P - \upsilon_e \tau_{21}; \tag{16}$$

$$b = \left[(x - x_3)^2 + (y - y_3)^2 + (z - z_3)^2\right]^{0.5} - P - \upsilon_e \tau_{31}; \tag{17}$$

$$c = \left[(x - x_4)^2 + (y - y_4)^2 + (z - z_4)^2\right]^{0.5} - P - \upsilon_e \tau_{41}; \tag{18}$$

$$d = \left[(x - x_5)^2 + (y - y_5)^2 + (z - z_5)^2\right]^{0.5} - P - \upsilon_e \tau_{51}; \tag{19}$$

$$\text{Min } \{D_f(x, y, z, \upsilon_e)\} = a^2 + b^2 + c^2 + d^2; \tag{20}$$

Subjected to,

$$\left.\begin{array}{l} 0 \le x \le x_{\max} \\ 0 \le y \le y_{\max} \\ 0 \le z \le z_{\max} \\ 1200 \le \upsilon_e \le 1500, (m/s) \end{array}\right\} \tag{21}$$

where, x_{max}, y_{max}, z_{max} are transformer tank dimension, v_e is equality sound velocity.

Calculated PD source is $P_c(x_c, y_c, z_c)$

Comprehensive distance error of it with actual PD source P(x, y, z) is

$$\Delta R = \left[(x - x_c)^2 + (y - y_c)^2 + (z - z_c)^2 \right]^{0.5} \tag{22}$$

Error of each coordinate is formulated as:

$$\in_r = \left| \frac{L_{act} - L_{cal}}{L_{act}} \right| \times 100\% \tag{23}$$

Maximum deviation D_{max} is:

$$D_{\max} = \max \left\{ \begin{array}{l} |x_{act} - x_{cal}| \\ |y_{act} - y_{cal}| \\ |z_{act} - z_{cal}| \end{array} \right\} \tag{24}$$

Figure 3 shows 3-Dimensional view of transformer geometry with PD source and sensor location along with calculated PD source location with AALO algorithm.

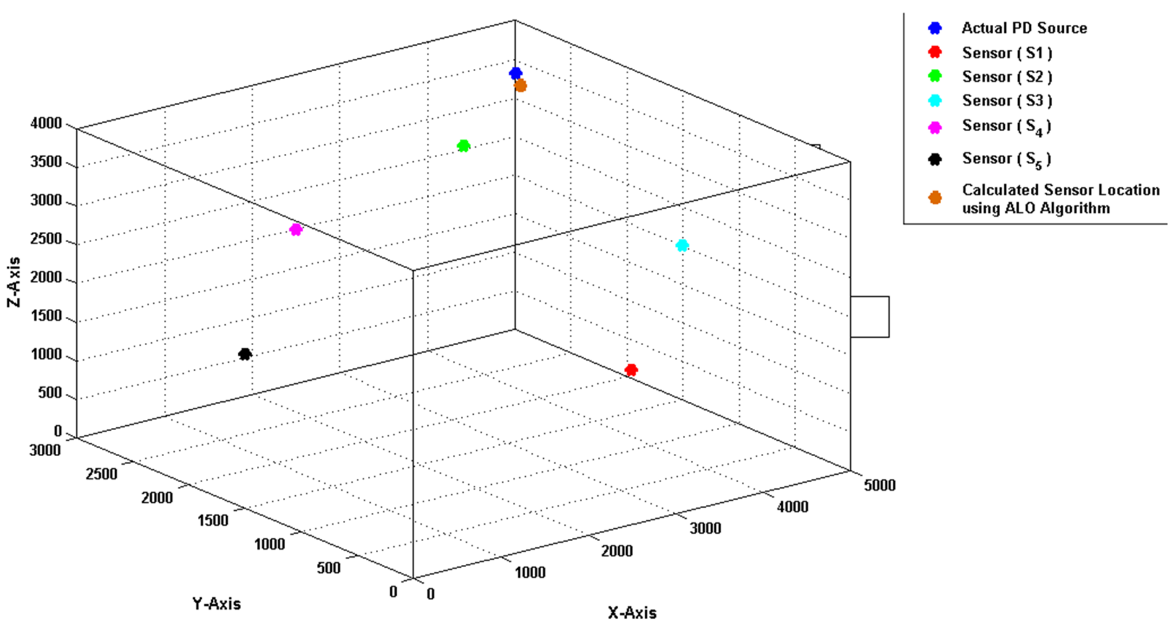

Figure 3: Prototype transformer with PD source and sensor location

Table 2
PD Localization result comparison

Coordinate (mm)	*Actual PD Source*	*ALO*	*AALO*	*GA [11]*
x	4500	4381.7459	4381.7465	4223.76
y	2600	2469.6026	2469.603	2391.71
z	3700	3647.4901	3647.4905	3503.04

Table 3
Error Analysis

Error	*ALO*	*AALO*	*GA [11]*
Error of x/%	2.627	2.627	6.14
Error of y/%	5.015	5.322	8.01
Error of z/%	1.419	1.419	5.32
D_{max}/mm	130.3974	130.397	276.24
Comprehensive Error (ΔR/mm)	183.6975	183.6968	398.10

Result of PD source location by different algorithm and error analysis is given in Table 2 and Table 3 respectively

Adaptive ALO algorithm is effective and gives more accurate PD source location coordinates in comparison to ALO and Genetic Algorithm (GA).

5. CONCLUSION

Ant Lion Optimizer has an ability to find out optimum solution with constrained handling which includes both equality and inequality constraints. While obtaining optimum solution constraint limits should not be violated. Randomization plays an important role in both exploration and exploitation. Adaptive technique causes faster convergence, randomness, and stochastic behavior for improving solutions. Adaptive technique also used for random walk in search space when no neighboring solution exits to converse towards optimal solution. Acoustic PD source localization method based on AALO algorithm is feasible and easy to implement. PD localization by AALO gives better result than ALO algorithm and also accurate in compare to GA. The ALO result of various unconstrained problems proves that it is also an effective method in solving challenging problems with unknown search space.

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