Application of Artificial Intelligent Technique for Partial Discharges Localization in Oil Insulating Transformer

ANANT OONSIVILAI and BOONRUANG MARUNGSRI
Alternative and Sustainable Energy Research Unit, Power and Control Research Group
School of Electrical Engineering, Institute of Engineering, Suranaree University of Technology
Muang District, Nakhon Ratchasima, 30000, THAILAND
Email: anant@sut.ac.th, bmshvee@sut.ac.th

Abstract: - Partial discharges in a power transformer are often a predecessor of serious fault, as Power transformers are fundamental apparatuses in electrical power system network. Thus, partial discharge measurement are a significant diagnostic tool to supervise the insulation state of a power transformer, as elementry Partial Discharges (PD) detection is not adequate to make a decision about intervening, so the localization is required to evaluate the risk and to plan rectification actions. Acoustic signals collected by piezoelectric sensors established outside of the transformer, supply the accurate position of PD as parameters. Conclusion demonstrates the efficacious of suggested solution for PD source localization in oil insulating power transformers using Adaptive Tabu Search (ATS).

Key-Words: - Artificial Intelligent Technique, Partial Discharge, Localization, Oil Insulating Transformer, Acoustic Signal, Adaptive Tabu Search

1 Introduction

Generally, power transformers are one of the most important components in electrical power system networks. In addition, power transformers are very expensive and form a high percentage of investment of a power system. It is well-known that all service life of power transformer the dielectric strength of its insulation system is decreased due to the cumulative effect of the thermal, electrical and mechanical stresses. Insulation failure of a power transformer can cause disruptions and result in very expensive losses in power system. Most insulation failures of a power transformer are caused by partial discharges (PD), that are localized electrical discharges within a void of an insulation system. Although only a small amount of energy is involved, the PD can cause the progressive deterioration of the insulation that may lead to a disruptive breakdown.

Extending transformer life as long as possible is not only economically valuable, but also prevents lost revenues when power outages occur. Statistical studies have shown that failures of bushings, winding insulation, and online tap changers are the main causes for long duration outages of transformers [1]. As result, the instrument for supervising the conditions of power transformer unit has to be in special interest and development. An on-line continuous insulation monitoring diagnostic system helps prevent power interruptions and costly damage caused by insulation failure.

In general, PDs inside the power transformer can be detected by three approaches of detection including (i) electrical, (ii) chemical and (ii) acoustic methods [2]. (i) The electrical method can provide accurate recordings of PDs under laboratory conditions, but it is difficult to be applied in the field on in-service power transformers because of the high environmental noise level and lack of accurate calibrations. (ii) The current chemical approach detects PDs in power transformers by taking gas or oil samples from the transformer. Each type of dissolved gas which measured from insulating oil indicates PDs inside in-service power transformer. Problems associated with chemical methods are the fact that there can be a long time delay between the initiation of a PD source and the evolution of enough gas to be detectable. For the electrical and chemical methods, a further limitation of them is that it is generally not possible to allocate the exact location of a detected PD source. (iii) Generally speaking, a PD results in a localized, nearly instantaneous release of energy. It produces acoustic waves propagating through the insulate medium. By placing a suitable sensor, the acoustic wave can be detected to generate information relevant to the PDs. One obvious advantage of the acoustic methods is that the site of a PD can be located by studying the phase delay or the amplitude attenuation of the acoustic waves.

Furthermore, acoustic methods have the potential advantage of better noise immunity for on-line PD detection applications. Acoustic PD detection can be realized by mounting acoustic sensors externally on the walls of the power transformer, and very often a suitable coupling is used to ensure good transmission of the acoustic waves. The externally mounted acoustic sensor method offers the advantage of easy installation and replacement. However, the acoustic sensor suffers from corruption of the signal from environmental noises such as electro-magnetic interference [3].

The acoustic method is based in the fact that when a PD occurs, an acoustic wave is emitted. Therefore, it can be detected by one or more sensors spread on the walls outside the isolated oil transformer. Acoustic partial discharge detection apparatus is very simple, consisting of a sensor, filter, preamplifier, and some type of data acquisition instrument (e.g., storage oscilloscope), as shown in Fig. 1[4].

The detected sign shall be processed to extract useful parameters for the flaw diagnosis. Among these parameters, there is the instant in which the front of the wave reaches the sensor when going through a straight line between it and the origin of the emission, needed to perform the localization, which is essential for the estimation of the flaw risk, as well as to plan the repairs.

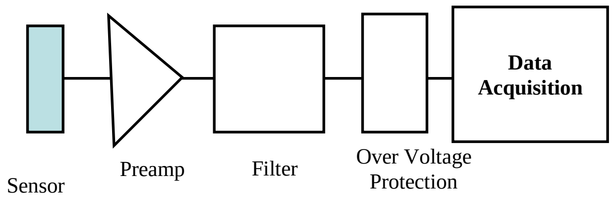

Fig. 1 Acoustic partial discharge detection circuit

The possibility of PD location is one of the major features of acoustic discharge detection. Location can be based on either measurement of the time of signal arrival at a sensor or on measurement of signal level, as shown in Fig. 2. In practical situations, a location based on a time-of-flight measurement requires two or more simultaneous measurements in order to facilitate triangulation to determine the source location. The simplest approach is to measure the electrical signal simultaneously with the acoustic signal. If the acoustic propagation velocity is known, then calculation of the source location becomes simple. However, the fact that different wave components travel along different paths in a structure is a complicating factor.

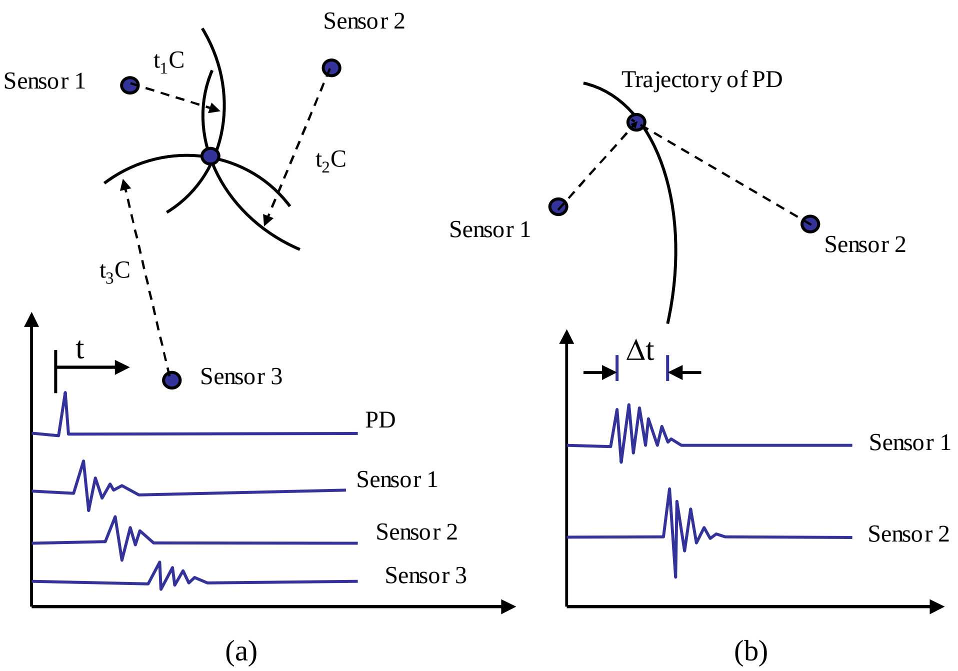

Fig. 2 Triangulation of source location based on time of flight measurements. (a) Based on measurement of both electric and acoustic signals; (b) based on only acoustic measurements

Up to now, artificial intelligent techniques have been adopted to many applications in electrical engineering field [5–11]. The objective of this work is to apply an artificial intelligent technique, Adaptive Tabu Search algorithm (ATS), to solve non-linear equation system for PD source localization in oil insulating power transformer. According to this purpose, the equations of the system are reformulated as an optimization problem and an optimal solution with the ATS is sought. Beyond that, a wide range of sensors can be used without any need to change the algorithm. This work does not approach the processing of the acoustic emission (AE) signal needed to obtain the parameters used by the ATS. The problem of the localization is initially turned into an equation and some strategies are presented to solve it. Therefore, this work does not approach the acoustic technique for the detection of partial discharges as a whole, but only the part referring to their localization.

2 Formation of Mathematical Model

PDs source localization by the use of acoustic signals can be modeled through a system of non-linear equations. As already known, to numerically solve a non-linear system is not simple, and normally it depends on a deep knowledge of the problem to get to an algorithm able to rapidly converge into a solution [12 – 16].

A procedure for turning the problem into an equation of PD source localization is illustrated in the Fig. 3. Four acoustic sensors are spread on the walls of the tank, which adopts any point as the origin of a rectangular coordinates system in three dimensions.

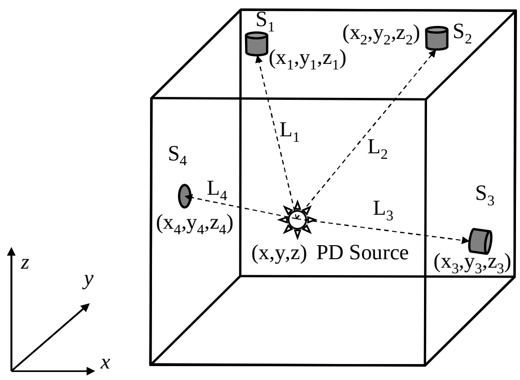

Fig. 3 Scheme for turning the problem into an equation

Fig. 3 shows that the acoustic signal emitted from PD source at any given point $P(x, y, z)$ in the oil propagates to all acoustic signal sensors. Assuming the propagation time of acoustic signal to the acoustic sensor S_1 is T and the distance (L) from the PD source to the four acoustic sensors is then given by the following formulas:

$$L_1 = v_s T_1 = v_s T \quad (1)$$

$$L_2 = v_s T_2 = v_s \left(T + \tau_{12}\right) \quad (2)$$

$$L_3 = v_s T_3 = v_s \left(T + \tau_{13}\right) \quad (3)$$

$$L_4 = v_s T_4 = v_s \left(T + \tau_{14}\right) \quad (4)$$

where T_n is the propagation time from the PD source to the sensor S_n, τ_{1n} is the time delay between the acoustic sensor S_1 and S_n and v_s is the propagation velocity in the oil.

Non-linear equations system for PD source localization can be obtained considering each sensor as the center of a sphere whose radius is the distance between the acoustic sensors to the PD source, as shown in Fig. 4.

As shown in Fig. 4, radius of the sphere not only given in term of propagation speed v_s of the acoustic signal in the oil and in terms of the time T_n in which it took to reach the point where the sensor is, as shown in equation (1) – (4). But the equation of the sphere radius can be given in the following way:

$$(x-x_n)^2 + (y-y_n)^2 + (z-z_n)^2 = (v_s \cdot T_n)^2 = L_n^2 \quad (5)$$

where (x_n, y_n, z_n) are the coordinates of the sensor S_n.

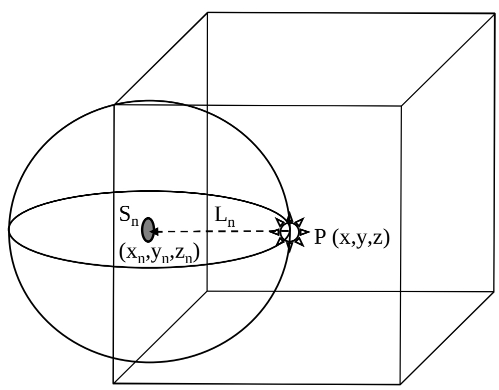

Fig. 4 Sphere with the center in the sensor to turn into an equation the problem of the localization of the AE source.

However, the time intervals in which the acoustic signal takes to reach the acoustic sensors can not be directly obtained without the simultaneous electric detection. Therefore, a scheme with many acoustic sensors shall be used to monitor the transformer when an acoustic emission occurs due to a PD, in case the only method used is the acoustic one. Differences of time in relation to the first sensor that detected the acoustic signal were recorded. Stated that, the unknown factors of the problem shall be the time interval *T* between the occurrence of the PD and the detection of the acoustic signal by the nearest acoustic sensor and the rectangular coordinates(*x*, *y*, *z*) of the position of the acoustic emission source, that is, the position of the PD. Therefore, a nonlinear system with four equations is obtained:

$$(x-x_1)^2+(y-y_1)^2+(z-z_1)^2=(v_s\cdot T_1)^2 \qquad (6)$$

$$(x-x_2)^2+(y-y_2)^2+(z-z_2)^2=\left(v_s\cdot T_2\right)^2 \qquad (7)$$

$$(x-x_3)^2+(y-y_3)^2+(z-z_3)^2=\left(v_s\cdot T_3\right)^2 \qquad (8)$$

$$(x-x_4)^2+(y-y_4)^2+(z-z_4)^2=\left(v_s\cdot T_4\right)^2 \qquad (9)$$

3 Adaptive Tabu Search Algorithm

The tabu search (TS) algorithm is an iterative search that starts from some initial feasible solution and attempts to determine a better solution in the manner of a hill-climbing algorithm. TS is commonly developed for solving local optimization problem. The algorithm keeps historical local optima for leading to the near-global optimum fast and efficiently. The local optima are kept in Tabu List (TL) for making sure that there will be no same local optimum happening again in the process. Another powerful tool in TS is called backtracking. Backtracking process starts from stepping back to some local optimum in TL and then searching a new optimum in different directions. Backtracking is performed when the backtracking criterion (BC) is encountered.

The TS algorithm has a flexible memory in which to maintain the information about the past step of the search and uses it to create and exploit the better solutions. The main two components of the TS algorithm are the tabu list (TL) restrictions and the aspiration criterion (AC). Before TS procedure explanation, the following Tabu components must be defined.

Solution, Search Space, Move and Neighborhood : A solution is an output from a process in the algorithm. Search space is a domain containing all possible solutions. A move is a process creating a new solution from the current solution within search space. Neighborhood is a set of all possible moves from the current solution.

Cost and Objective Function: Cost is a value for judging what solution is better than the others. Objective function returns the solution cost.

Tabu Criterion (TC): To prevent cycling search, some moves should be forbidden under a condition known as TC. Normally, TC will ban local optimal solutions, which are recorded in TL.

BC: In opposition to TC, this condition allows a solution in TC to be a new solution. This usually happens when moving under TC gets stuck in a local optimum.

In applying the TS algorithm, to solve a combinatorial optimization problem, the basic idea is to choose a feasible solution at random and then obtain a neighbor to this solution. A move to this neighbor is performed if either it does not belong to the TL or, in case of being in the TL it passes the AC test. During these search procedures the best solution is always updated and stored aside until the stopping criterion is satisfied [6,10].

Well description and detail of adaptive tabu search (ATS) can be found in [17-19]. The following notations are used through the description of the ATS algorithm for a general combinatorial optimization problem:

X : the set of feasible solutions.
x : the current solution, $x \in X$
x_b : the best solution reached.
x_{nb} : the best solution among trial solutions.
$E(x)$: the objective function of solution x
$N(x)$: the set of neighborhood of $x \in X$
TL : tabu list
AL : aspiration level
J : the objective function

The procedure of the ATS algorithm is as follow:

Step 0: Set TL as empty and AC as zero.

Step 1: Set iteration counter k = 0. Select an initial solution $x \in X$, and set $x_b = x$.

Step 2: Generate a set of trial solutions in the neighborhood of x. Let x_{nb} be the best trial solution.

Step 3: If $E(x_{nb}) > E(x_b)$, go to **Step 4**, otherwise set the best solution $x_b = x_{nb}$ and go to **Step 4**.

Step 4: Perform the tabu test. If x_{nb} is NOT in the TL, then accept it as a current solution, set $x = x_{nb}$, and update the TL and AC and go to **Step 6**, otherwise go to **Step 5**.

Step 5: Perform the AC test. If satisfied, then override the tabu state, set $x = x_{nb}$, and update the AC.

Step 6: Perform the termination test. If the stopping criterion is satisfied then stop, otherwise set $k = k + 1$ and go to **Step 2**.

Based on ATS algorithm, solution of non-linear problems can be identified using the flow chart show in Fig. 5.

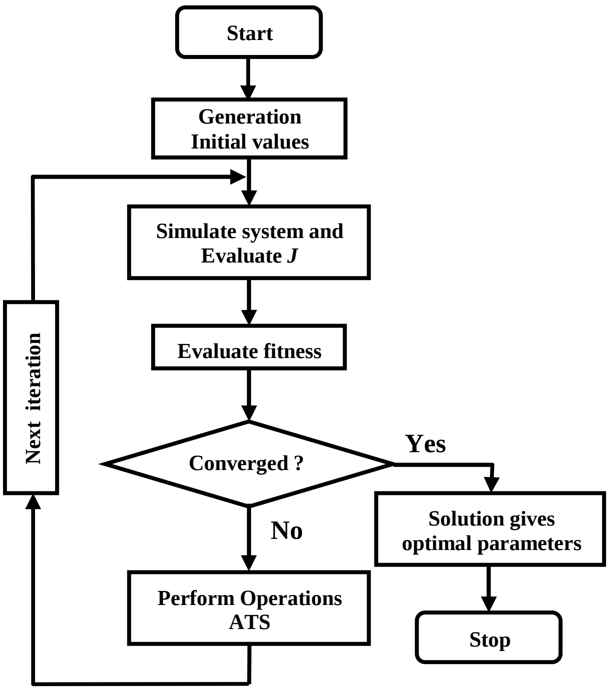

Fig. 5 Flow chart for the ATS process

4 Solution Through ATS Algorithm

Rectangular coordination (x, y, z) of PD source and propagation time of acoustic signal to the nearest acoustic sensor are the system variables. Taking the expressions from (6) to (9), the following functions are obtained:

$$\left[(x-x_1)^2+(y-y_1)^2+(z-z_1)^2\right]/v_s^2 = T_1^2 \quad (10)$$

$$\left[(x-x_2)^2+(y-y_2)^2+(z-z_2)^2\right]/v_s^2 = T_2^2 \quad (11)$$

$$\left[(x-x_3)^2+(y-y_3)^2+(z-z_3)^2\right]/v_s^2 = T_3^2 \quad (12)$$

$$\left[(x-x_4)^2+(y-y_4)^2+(z-z_4)^2\right]/v_s^2 = T_4^2 \quad (13)$$

Let, T_{mn} is measuring time delay of acoustic signal propagation from PD source (PDS_m) to acoustic sensor S_n and $T_{mn,et}$ is estimating time delay of acoustic signal propagation from PD source (PDS_m) to acoustic sensor S_n. Then, non-linear equations from (14) to (16), the fitness function is obtained.

$$\left[(x_m-x_n)^2+(y_m-y_n)^2+(z_m-z_n)^2\right]/v_s^2 = T_{mn}^2 \quad (14)$$

$$\left[(x_{m,et}-x_n)^2+(y_{m,et}-y_n)^2+(z_{m,et}-z_n)^2\right]/v_s^2 = T_{mn,et}^2 \quad (15)$$

$$J_{mn} = T_{mn,et}^2 - T_{mn}^2 \quad (16)$$

The solution of a non-linear equation system to localize PD source can be obtained with ATS Algorithm. The variable J_{mn} is the fitness function and the square root of the sum of J_{mn} is the objective function. Applying the ATS to (15) , (16) and taking the square root of the sum of J_{mn}, optimal solution arrival when the minimum value obtained from the objective function (the ideal is that it is reduced to zero).

5 Simulation Results and Discussions

In order to test the effectiveness of ATS algorithm for the PD localization in oil insulating type power transformers, computer-simulated data based on [16], initially, were used. The dimension of fictitious tank is 800×1200×500mm^3. Five locations of PD source are illustrated in Table 1. However, in the next stage, situations of partial discharges simulated in an oil filled tank shall be performed, followed of field experiences, in real cases.

Four acoustic sensors were used to measure acoustic signal from PD source. Each senor placed outside the fictitious tank. Two set of acoustic sensor having different position were used to elucidate the purpose technique.

Table 1. Testing point of PD sources

PD Source	Position (mm)
PDS_1	$x=$ 585 $y=$ 610 $z=$ 240
PDS_2	$x=$ 595 $y=$ 570 $z=$ 230
PDS_3	$x=$ 635 $y=$ 580 $z=$ 170
PDS_4	$x=$ 630 $y=$ 580 $z=$ 60
PDS5	$x=$ 570 $y=$ 700 $z=$ 465

Four different positions of the first set of acoustic sensor are given for the simulation, which appear in the Table 2. Fig. 6 illustrated the first set of acoustic sensors for PD localization. The origin of the coordinates system was placed in one of the corners of the tank.

Speed of acoustic signal in the oil is 1400m/s. The example of acoustic signal from PD source (PD_5) received by each acoustic sensor, are illustrated in Fig. 7, Fig. 8, Fig. 9 and Fig. 10, respectively.

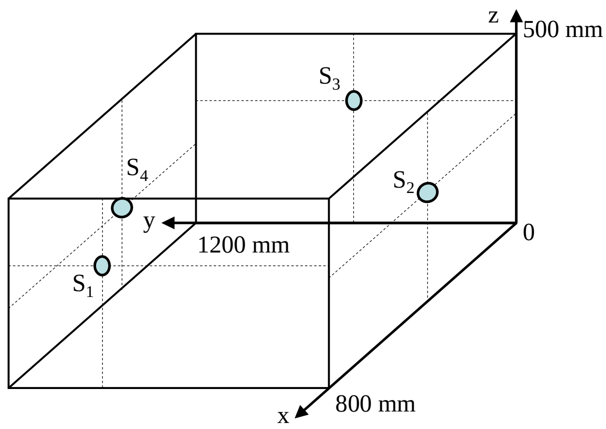

Fig. 6 The fictitious tank of 800×1200×500mm^3, and sensor positions

Table 2. Positions of the first set of acoustic sensors for the simulation

Sensor	Position (mm)
S_1	$x=$ 800 $y=$ 820 $z=$ 365
S_2	$x=$ 245 $y=$ 0 $z=$ 347
S_3	$x=$ 0 $y=$ 600 $z=$ 385
S_4	$x=$ 320 $y=$ 1200 $z=$ 230

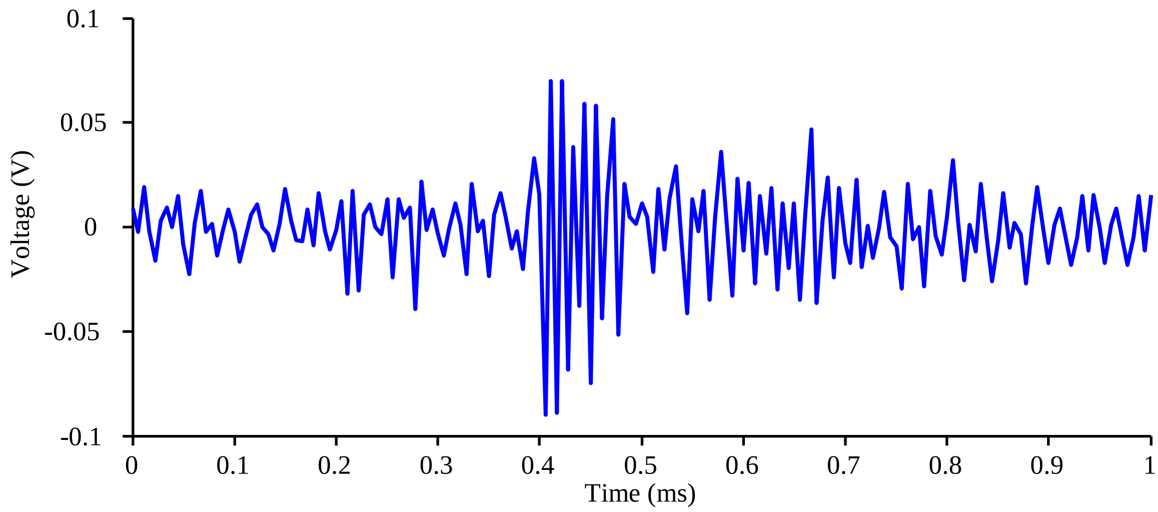

Fig. 7 Acoustic signal received by sensor S_1

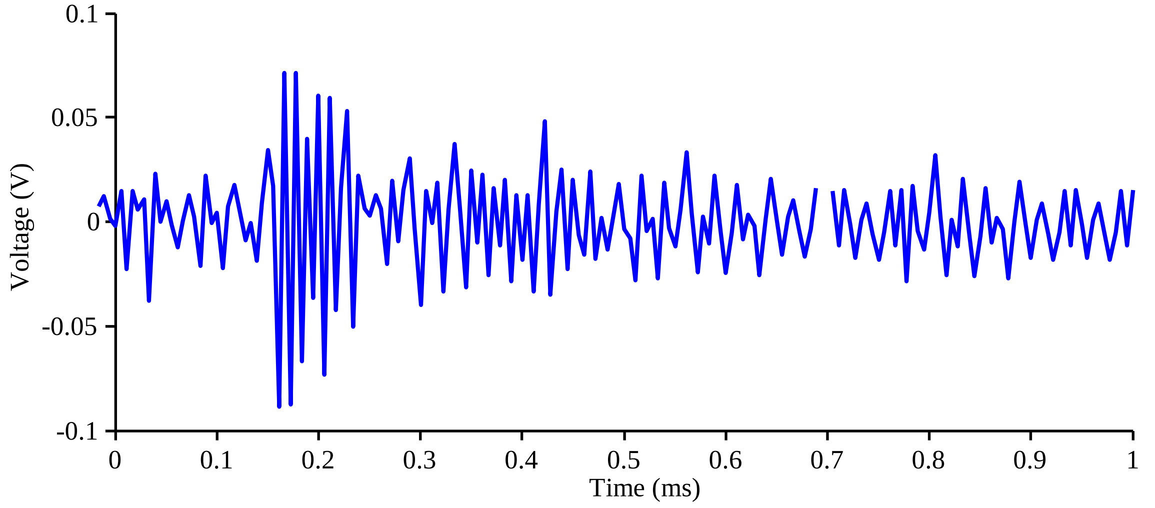

Fig. 8 Acoustic signal received by sensor S_2

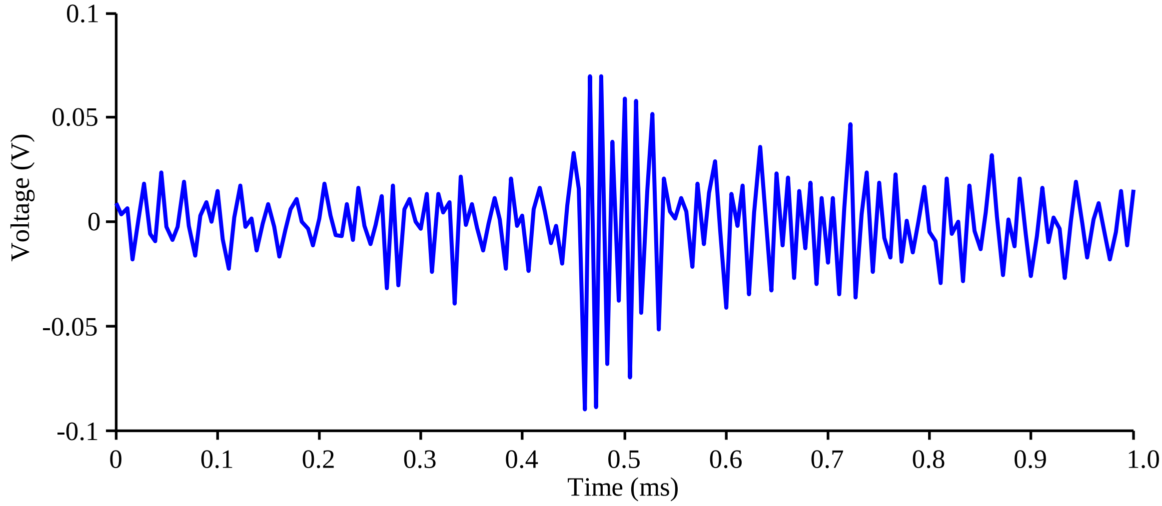

Fig. 9 Acoustic signal received by sensor S_3

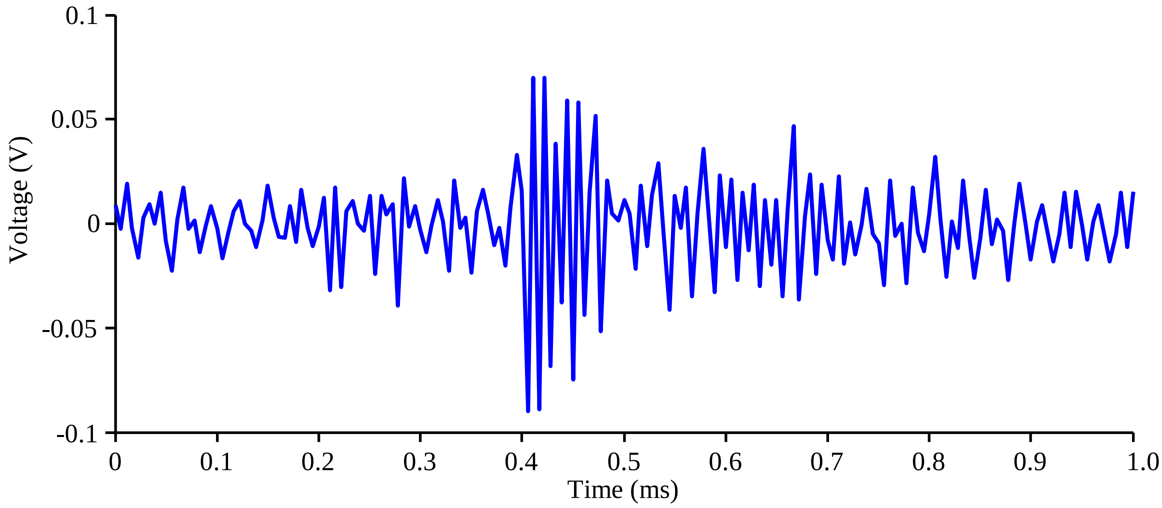

Fig. 10 Acoustic signal received by sensor S_4

Form PD occurrence source in Table 1, the arrival time of acoustic signals from PD source to acoustic sensor are given in Table 3 and used to localization PD source.

Table 3. Arrival delay time of PD signal measured at each sensor of the first set sensor

PD Sources	Time delay measured at Each Sensor
PDS1 : $x = 585$ $y = 610$ $z = 240$	S1 : $t_{delay,11} = 0.230$ *ms* S2 : $t_{delay,12} = 0.499$ *ms* S3 : $t_{delay,13} = 0.426$ *ms* S4 : $t_{delay,14} = 0.457$ *ms*
PDS2 : $x = 595$ $y = 570$ $z = 230$	S1 : $t_{delay,21} = 0.248$ *ms* S2 : $t_{delay,22} = 0.480$ *ms* S3 : $t_{delay,23} = 0.435$ *ms* S4 : $t_{delay,24} = 0.486$ *ms*
PDS3 : $x = 635$ $y = 580$ $z = 170$	S1 : $t_{delay,31} = 0.248$ *ms* S2 : $t_{delay,32} = 0.510$ *ms* S3 : $t_{delay,33} = 0.474$ *ms* S4 : $t_{delay,34} = 0.493$ *ms*
PDS4 : $x = 630$ $y = 580$ $z = 60$	S1 : $t_{delay,41} = 0.299$ *ms* S2 : $t_{delay,42} = 0.532$ *ms* S3 : $t_{delay,43} = 0.501$ *ms* S4 : $t_{delay,44} = 0.504$ *ms*
PDS5 : $x = 570$ $y = 700$ $z = 465$	S1 : $t_{delay,51} = 0.196$ *ms* S2 : $t_{delay,52} = 0.552$ *ms* S3 : $t_{delay,53} = 0.413$ *ms* S4 : $t_{delay,54} = 0.426$ *ms*

After apply ATS technique for PD source localization, the simulation results are obtained. As illustrated in Table 4, near the same position of PD sources were obtained when comparing the simulation results with the given data. Error from the simulation results less than 1%.

In order to clarify the effect of sensor position, the second set of acoustic sensor having different position comparing with the first set of acoustic sensor is given. Four different positions of the second set of acoustic sensor are given for the simulation, which appear in the Table 5. Fig. 6 illustrated the second set of acoustic sensors for PD localization.

Table 4. PD source localization results using Adaptive Tabu Search

PD Source	Position (mm)	Simulation Results (mm)	Error (%)
PDS1	$x = 585$ $y = 610$ $z = 240$	$x = 584.92$ $y = 609.85$ $z = 240.12$	0.01 0.02 0.05
PDS2	$x = 595$ $y = 570$ $z = 230$	$x = 594.90$ $y = 569.61$ $z = 229.34$	0.02 0.07 0.28
PDS3	$x = 635$ $y = 580$ $z = 170$	$x = 635.56$ $y = 579.79$ $z = 170.49$	0.09 0.04 0.30
PDS4	$x = 630$ $y = 580$ $z = 60$	$x = 630.56$ $y = 580.04$ $z = 59.47$	0.09 0.01 0.88
PDS5	$x = 570$ $y = 700$ $z = 465$	$x = 570.09$ $y = 699.98$ $z = 465.71$	0.02 0.002 0.15

Table 5. Positions of the second set acoustic sensors for the simulation

Sensor	Position (mm)
S_1	$x = 400$ $y = 0$ $z = 250$
S_2	$x = 800$ $y = 600$ $z = 400$
S_3	$x = 400$ $y = 1200$ $z = 500$
S_4	$x = 0$ $y = 700$ $z = 250$

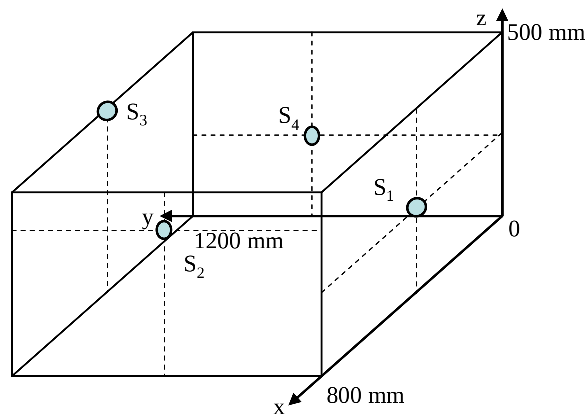

Fig. 11 The fictitious tank of 800×1200×500mm^3, and positions of the second set sensor

Form PD occurrence source in Table 1, the arrival time of acoustic signals from PD source to each acoustic sensor of the second set are given in Table 6 and used to localization PD source.

Table 6. Arrival delay time of PD signal measured at each acoustic sensor of the second set

PD Sources	Time delay measured at Each Sensor
PDS1 : $x = 585$ $y = 610$ $z = 240$	S1 : $t_{delay,31} = 0.451$ *ms* S2 : $t_{delay,32} = 0.190$ *ms* S3 : $t_{delay,33} = 0.474$ *ms* S4 : $t_{delay,34} = 0.418$ *ms*
PDS2 : $x = 595$ $y = 570$ $z = 230$	S1 : $t_{delay,21} = 0.430$ *ms* S2 : $t_{delay,22} = 0.189$ *ms* S3 : $t_{delay,23} = 0.504$ *ms* S4 : $t_{delay,24} = 0.431$ *ms*
PDS3 : $x = 635$ $y = 580$ $z = 170$	S1 : $t_{delay,31} = 0.446$ *ms* S2 : $t_{delay,32} = 0.201$ *ms* S3 : $t_{delay,33} = 0.523$ *ms* S4 : $t_{delay,34} = 0.460$ *ms*
PDS4 : $x = 630$ $y = 580$ $z = 60$	S1 : $t_{delay,41} = 0.461$ *ms* S2 : $t_{delay,42} = 0.269$ *ms* S3 : $t_{delay,43} = 0.561$ *ms* S4 : $t_{delay,44} = 0.473$ *ms*
PDS5 : $x = 570$ $y = 700$ $z = 465$	S1 : $t_{delay,51} = 0.531$ *ms* S2 : $t_{delay,52} = 0.183$ *ms* S3 : $t_{delay,53} = 0.374$ *ms* S4 : $t_{delay,54} = 0.431$ *ms*

After apply ATS technique for PD source localization, the simulation results are obtained. As illustrated in Table 7, near the same position of PD sources were obtained when comparing the simulation results with the given data. Error from the simulation results less than 1%. The position of a sensor have no effect on PD localization when using the purpose technique.

Table 7. PD source localization results using Adaptive Tabu Search

PD Source	Position (mm)	Simulation Results (mm)	Error (%)
PDS1	$x = 585$ $y = 610$ $z = 240$	$x = 585.20$ $y = 609.88$ $z = 239.34$	0.03 0.02 0.22
PDS2	$x = 595$ $y = 570$ $z = 230$	$x = 595.43$ $y = 570.34$ $z = 230.35$	0.07 0.06 0.15
PDS3	$x = 635$ $y = 580$ $z = 170$	$x = 634.65$ $y = 579.60$ $z = 170.13$	0.06 0.07 0.08
PDS4	$x = 630$ $y = 580$ $z = 60$	$x = 629.78$ $y = 580.03$ $z = 59.84$	0.03 0.01 0.27
PDS5	$x = 570$ $y = 700$ $z = 465$	$x = 569.59$ $y = 700.19$ $z = 464.14$	0.07 0.03 0.18

4 Conclusion

The effectiveness of purpose technique for PD source localization is confirmed. Near the same PD source locations was obtained from the simulation results using ATS technique comparing with the given data. Artificial intelligent technique, ATS, show enough potential for application in PD source localization.

References:

[1] A. Akbari, P. Werle, H. Borsi and E. Gockenbach, "*Transfer Function-Based Partial Discharge Localization in Power Transformers: A Feasibility Study*", IEEE Electrical Insulation Magazine, Vol. 18, No. 5, September/October 2002, pp. 22 – 32.

[2] A. Zargari and T. R. Blackburn, "*Application of Optical Fiber Sensor for Partial Discharge Detection in High-voltage power equipment*", IEEE Conf. on Electrical Insulation and Dielectric Phenomena, San Francisco, October 20-23, 1996, pp. 541 – 544.

[3] J. D Deng, H. Xiao , W. Huo , M. Luo, R. May , A. B. Wang and Y. L. Liu, "*Optical fiber sensor-based detection of partial discharges in power transformers*", J. of Optics & Laser Technology, Vol. 33 , 2001, pp. 305–311.

[4] L.E. Lundgaard, "*Partial Discharge - Part XIV: Acoustic Partial Discharge Detection - Practical Application*", IEEE Electrical

Insulation Magazine, Vo1.8, No.5, September /October 1992, pp. 34-43.

[5] B. Marungsri, N. Meeboon and A. Oonsivilai, "*Dynamic Model Identification of Induction Motors using Intelligent Search Techniques with taking Core Loss into Account*", WSEAS TRANSACTIONS on POWER SYSTEMS, Vol. 1, No. 8, August 2006, pp. 1438 – 1445.

[6] D. Puangdownreong, C. U-Thaiwasin and S. Sujitjorn, "*Optimized Performance of a 2-Mass Rotary System Using Adaptive Tabu Search*", WSEAS TRANSACTIONS on CIRCUITS and SYSTEMS, Issue 3, Volume 5, March 2006, pp. 339-345.

[7] A. Oonsivilai, R. Boonwutiwiwat, T. Kulworawanichpong, and P. Pao-La-Or, "*Artificial Neural Network Approach to Electric Field Approximation Around Overhead Power Transmission Lines*", Proc. of the 7th IASTED Int. Conf. on Power and Energy Systems, paper no. 582-052, Palma De Mallorca, Spain, 29 – 31 August 2007.

[8] A. Oonsivilai and M.E. El – Hawary, "*Power System Dynamic Modeling using Adaptive – Network Based Fuzzy Inference System*", Proc. of the 1999 IEEE Canadian Conf. on Electrical and Computer Engineering, Canada, 9 – 12 May 1999.

[9] A. Oonsivilai, and M. E. El-Hawary, "*Wavelet Neural Network Based Short-Term Load Forecasting of Electric Power System Commercial Load*", Proc. of IEEE Canadian Conf. on Electrical and Computer Engineering, pp. 1223 – 1228, 1999.

[10] A. Oonsivilai, and B. Marungsri, "*Optimal PID tuning for AGC system using adaptive Tabu search*", Proc. of the 7th WSEAS Int. Conf. on Power Systems, pp. 42-47, Beijing, China, September 2007.

[11] B. Marungsri and A. Oonsivilai, "*Multi-Objective Optimal Pricing Dispatch Using Particle Swarm Optimization Technique*", Proc. of the 2007 Int. Conf. on Electrical Engineering, paper no. ICEE-411, Hong Kong, July 2007.

[12] S. M. Markalous and K. Feser, "*All-Acoustic PD measurements of oil/paper-insulated transformers for PD-localization*", Proce. of Int. Conf. on Advances in Processing, Testing and Application of Dielectric Materials, Wroclaw, Poland, 2004.

[13] Giscard F. Cintra Veloso, L. E. Borges da Silva, G. Lambert-Torres and J.O.P. Pinto, "*Localization of Partial Discharges in Transformers by the Analysis of the Acoustic Emission*", IEEE Int. Sym. on Industrial Electronics, Montreal, Quebec, Canada, July 9-12, 2006, pp. 537 – 541.

[14] G. S. Kil, D. W. Park, I. K. Kim and S. Y. Choi, "*Analysis of Partial Discharge in Insulation Oil using Acoustic Signal Detection Method*", WSEAS TRANSACTIONS on POWER SYSTEMS, Issue 3, Volume 3, March 2008, pp. 90-94.

[15] Li Yanqing, Lu Fangcheng , Xie Hongling, Yin Ming, "Practical Location Method of Transformer Partial Discharge", Proc. of Int. Conf. on Power System Technology, Singapore, 21-24 November 2004, pp. 1371 – 1374.

[16] Y. Lu, X.Tan and X. Hu, "*PD detection and localisation by acoustic measurements in an oil filled transformer*", IEE Proce. on Sci. Meas. Technol., Vol. 147, No. 2, March 2000, pp. 81 – 85.

[17] K.-N. Areerak and S. Sujitjorn, "*Performance Comparision between Genetic Algorithms and Tabu Search*", Suranaree Journal of Science Technology, Vol. 9, No.1, 2002, pp. 61 – 68.(In Thai)

[18] N. Thatphitakkul and S. Kanokphara, " *HMM Parameter Optimization using Tabu Search*", International Symposium on Communication and Information Technology, October 2004, pp. 904-908.

[19] D. Puangdownreong, T. Kulworawanichpong and S. Sujitjorn, "*Convergence Analysis of Adaptive Tabu Search*", International Journal of ScienceAsia, Vol. 38, No.2, 2004, pp. 183-190.

Anant Oonsivilai, was born in Khon Kaen Province, Thailand, in 1963. He received his B. Eng. from Khon Kaen University, and M. Eng. from King Mongkut Institute of Technology North Bangkok, Thailand and PhD. from Dalhousie University, Canada, all in electrical Engineering, in 1986 , 1992 and 2000, respectively. Dr. Oonsivilai is currently an Assistant Professor in School of Electrical Engineering, Suranaree University of Technology, Thailand. His areas of interest are electrical power system, stability, control technology, advance alternative, and sustainable energy.

Boonruang Marungsri, was born in Nakhon Ratchasima Province, Thailand, in 1973. He received his B. Eng. and M. Eng. from Chulalongkorn University, Thailand in 1996 and 1999 and D. Eng. from Chubu University, Kasugai, Aichi, Japan in 2006, all in electrical engineering, respectively. Dr. Marungsri is currently a lecturer in School of Electrical Engineering, Suranaree University of Technology, Thailand. His areas of interest are electrical power system and high voltage insulation technologies.