Study on Partial Discharge Propagation in Power Transformer Based on the Ant System Algorithm

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***Abstract* - In this paper, the ant system algorithm is modified and used for localization of partial discharge (PD) source location in a power transformer. General localization assumes that EM wave propagates along the line of sight. However, EM wave in a power transformer randomly scattered due to internal structures of a power transformer. Therefore, a general ant system algorithm often used to solve TSP problem needs to be modified in order to calculate the shortest path and to reduce error of TDoA localization. By using the proposed modified ant algorithm, the accuracy of TDoA localization is improved from 16.86mm to 1.58mm.**

***Index Terms* — Ant system algorithm, partial discharge, localization, FDTD, TDoA Antennas, propagation, EM wave theory, AP-related topics.**

1. Introduction

A partial discharge (PD) problem is an important issue since it is potentially hazardous to proper functioning of a transformer. As the capacity of a power transformer keeps increasing, PD becomes a key issue to be identified [1]. Several researches have introduced interesting localization methods including ultrasonic sensing method, UHF sensing method, and optical method [2,3]. The PD localization using UHF sensing has better accuracy in detection and localization of PD than other methods due to its lower signal damping and low noise [2]. In addition, UHF sensing approach has been commonly used since UHF signal is generated within a few nano seconds when PD is occurred and the transformer is nearly isolated from external environment by a metallic case [2]. The UHF localization uses PD pulse propagation time. One of the UHF localization based method on the propagation time is the time difference of arrival (TDoA) method [4]. In TDoA localization, it is generally assumed that the electromagnetic signal propagates along the line of sight (LoS). However, the power transformers have many obstacles disturbing PD pulse propagation. Those obstacles can produce noticeable error in PD localization. In order to reduce the PD localization error, a statistical approach based on multiple simulation was proposed [5]. A PD localization optimization algorithm finding the shortest path between sensors and source was suggested in [1]. In this paper, PD pulse propagation path is explored based on the ant system algorithm [6] in two dimensions. The result using the proposed algorithm is compared to that of FDTD simulation.

```
Ant_system_algorithm
Begin()
Initialize simulation area, tabulist, number of ant
Do until (length of paths are converged)
    Do until (any ant reaches sensor or trapped)
    Select direction and travel
    Update local path
    Update tabulist
    End do
The ants trapped or reached relocates at source
Reset tabulists of the ants
Analyze tours
End do
```

Fig. 1. Pseudocode of modified ant system algorithm.

2. Ant System Algorithm

The ant system algorithm is a nature-inspired optimization method based on foraging behavior of ants [6]. Each ant emits pheromone along a path to food.

An elite ant, meaning an ant taking the shortest path in each round, can deliver food to his colony in the shortest time. After the delivery is iteratively conducted, the largest amount of pheromone will be accumulated on the shortest path. Then the other ant could follow the shortest path since ants reference the amount of pheromone when they select moving direction. The ant system algorithm is often applied to predict the shortest distance for travelling sales person (TSP) problem. However, finding shortest path in transformer problem has several different aspects comparing to general TSP problem.

Firstly, obstacle including core, winding wire, and supporting structures should be considered. And ants could be trapped by themselves when they select spiral-shaped path. Moreover, there is no city or colony, thus the ants need to find path by themselves.

In order to overcome the aforementioned issues, the general ant system algorithm for TSP problem needs to be modified as following

(1) Every ant starts from the source location and travels along the probabilistically selected direction by a certain distance, which defines resolution.
(2) Coordinates of the aforementioned obstacles are counted as tabulist.

In Fig. 1, pseudocode of the modified ant system algorithm is shown.

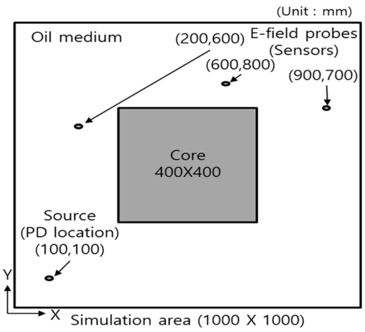

Fig. 2. Simulation setting

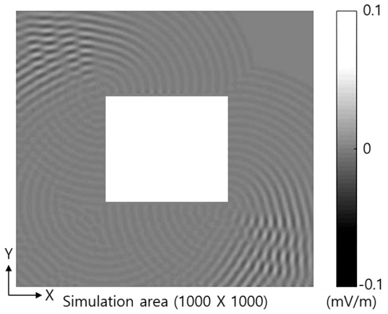

Fig. 3 E-field distribution inside modeled transformer.

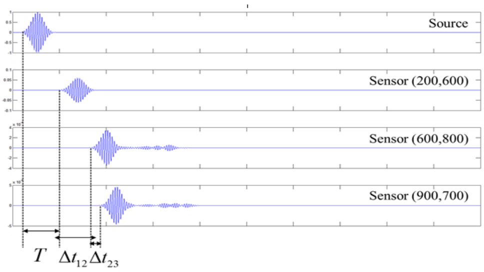

Fig. 4. The simulated waveform of UHF signal

TABLE I
Comparison of simulation results with and without the ant algorithm

	TDoA method without the algorithm	TDoA method with the algorithm
Source location	(100, 100)	
Calculated location	(116.5, 96.5)	(101.5, 99.5)
Error	16.86	1.58

3. Simulation

(1) Setting

For two dimensional simulation, the simulation area of 1000 mm × 1000 mm is modeled with a core size of 400 mm × 400 mm, and the medium is filled with insulation oil (ε_r=2). Sensors and source are arbitrarily located as shown in Fig. 2. Fig. 3 depicts E-field distribution inside the modeled transformer 212.13 μs after the impulse signal is engaged at the PD location using FDTD simulation. From the FDTD results, signal propagation time is converted to the distance between the source and the sensors.

(2) TDoA localization

Fig. 4 shows simulated waveform of PD signals. Sensors only knows received time when they received the signal. The time delay from source to sensor T is unknown value as there is no way to know when PD exactly occurs. Differences between received time at each sensor are denoted as Δt 12 or Δt 23. The received time differences at each sensor can be converted to differences of propagation paths from source to the sensors by multiplying propagation speed in oil medium. The modified ant system algorithm was used for calculation of the physical shortest paths between the source and the sensors. The shortest paths obtained from the modified ant system algorithm is utilized in TDoA localization algorithm. As a result, TDoA localization with the algorithm can account for the obstacle whilst general TDoA localization assumed EM signal propagate along LoS. The localization results with and without the modified ant algorithm are compared in table I. Residual of the TDoA localization with the ant algorithm is 1.58 mm whilst that without is 16.86 mm.

4. Conclusion

In this paper, the TDoA localization method using modified ant system algorithm in transformer was suggested. Since power transformer has several obstacles disturbing PD pulse propagation, a general TDoA localization based on LoS propagation can brings in recognizable error. Therefore, the modified ant algorithm figures out the shortest path avoiding the obstacles and it is implanted on the TDoA localization to predict the accurate PD location. As a result, the error of PD location caused by a general TDoA localization can be reduced substantially by utilizing the modified ant algorithm, suggested in this paper.

Acknowledgment

This research was supported by the MSIP(Ministry of Science, ICT and Future Planning), Korea, under the ITRC(Information Technology Research Center) support program(IITP-2016-H8601-16-1005)supervised by the IITP(Institute for Information & communications Technology Promotion).

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