Research on Detection and Positioning Technology of UHV GIS Based on Multi-Sensor Fusion and Chaotic Cuckoo Algorithm

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Uhv gas-insulated switchgear (GIS) plays an important role in power system, but its UHF partial discharge may cause equipment failure and threaten the safe and stable operation of power system. In this paper, a multi-sensor fusion based UHV GIS UHF local discharge detection and positioning technology is studied. The technology uses multiple sensors to collect the relevant data of UHV GIS equipment, and then through data fusion and analysis, complete the positioning solution under the mixed-team cuckoo algorithm, obtain the accurate location of the local amplifier, and realize the detection and positioning of the UHF local amplifier. In order to test the feasibility of this technology, a case application is also carried out at the end. The result shows that in the UHF test, the signal collected by sensor B is about 7ns ahead of sensor C, and the difference of signal transmission distance is 2.1m, which is consistent with the sensor layout spacing. The signal source is judged to be located on the left side of sensor B. The signal collected by sensor A is about 5ns lower than that of sensor B. It can be determined that the high-frequency signal source is between sensor A and sensor B. At the same time, the coordinate of the local release source is (0.52, 0.12, 0.45), which is the support insulator in the GIS. The abnormal signal is determined to be C-phase internal insulation discharge of T0511 tool brake. The results show that multi-sensor fusion is feasible in GIS location detection, which can effectively prevent equipment failure and improve the reliability of power system.

Povzetek: Raziskava predstavi večsenzorsko fuzijo in algoritem kaotične kukavice za UHV GIS zaznavanje in pozicioniranje, kar izboljša natančnost ter zmanjšuje tveganje za okvare in motnje sistema.

1 Introduction

Uhv GIS is an important transmission equipment in power system, and its safety, reliability and stability are crucial to the operation of power system [1-2]. However, UHF partial discharge may occur during the operation of UHV GIS equipment, which may cause damage to the insulation materials inside the equipment, thereby causing equipment failure and affecting the operation of the power system [3-5]. Therefore, detecting and locating UHF partial discharge of UHV GIS equipment is of great significance to prevent equipment failure and ensure the safe and stable operation of power system. Scholars Zhang et al. conducted a study on the diagnosis and location of GIS equipment defects with the help of X-ray imaging detection technology and local release technology, and found that the combination of these two technologies can complete the diagnosis and location of GIS equipment defects and anomalies, and has a relatively considerable detection rate and accuracy, which improves the quality of GIS equipment detection [6]. Chen et al. fully analyzed the phenomenon and measurement principle of GIS partial discharge, and tested the local discharge positioning technology through case detection, obtained the UHF local discharge detection results and ultrasonic local discharge detection results, and found that under the action of ultrasonic and UHF local discharge detection methods, more real and objective detection results could be obtained. The feasibility of its application in practical projects is confirmed [7]. Zhang et al. tested the ultrasonic local discharge detection technology of GIS equipment through case application. In order to carry out the demonstration better, they first analyzed the detection principle, then set the monitoring process, and finally applied the technology to the operating state diagnosis of GIS equipment in 66kv substation. The results confirmed the feasibility of the method. It has promoted the development of GIS equipment detection [8]. It is not difficult to find that many scholars have joined in the research on GIS equipment office discharge detection, but few scholars have used multi-sensor research on office discharge positioning, which may lead to certain result errors, which is unfavorable to GIS UHV office discharge detection and positioning. In order to improve the effect of GIS UHF office discharge detection and positioning, this paper will use multi-sensor fusion to carry out the study of office discharge detection and positioning, and collect the relevant information of UHV GIS equipment through the sensor. Through data fusion and analysis, the detection and location of UHF local amplifier are realized, so as to effectively prevent equipment failures and improve the reliability of the power system.

2 UHV GIS UHF office discharge detection and positioning simulation based on multi-sensor fusion

2.1 Definitions of GIS UHF office discharge detection and positioning

The location of local discharge power supply is the focus of GIS equipment local discharge detection. Since the structure size and related design of UHV GIS equipment are obviously different from that of conventional GIS equipment, in order to further study the UHV GIS office release location technology, the UHV GIS UHV office release detection and location analysis of house shows is conducted to test the correspondence between the time difference between UHV signals at different locations and the actual field detection. In order to study the propagation characteristics of the internal discharge signal in UHV GIS, the UHF positioning method is proved to be applicable to the field location. The simplified 3D GIS model is constructed, the boundary of the model is selected as the gas boundary, the electric field simulation is carried out, and the UHF positioning simulation is carried out for UHV GIS equipment. Considering the complexity of GIS main body structure, the internal materials can be divided into conductive materials and non-conductive materials according to different material properties during simulation, and the insulating devices and gases inside GIS equipment can be uniformly processed. Nowadays, the structure of UHV GIS equipment includes long straight bus bars, simple T-shaped and L-shaped structures, as well as complex structures such as isolation switches. The following will take complex structures as an example to carry out positioning simulation experiments. The UHF simulation of UHV GIS needs to conform to the actual signal propagation rules in the field, and the mathematical model of UHV signal must meet the requirement of the actual propagation gauge. Therefore, on the setting of the square power supply, a double exponential oscillation attenuation function is suspended to simulate the propagation of UHF electromagnetic waves. Among them, the time-domain form of the double exponential type oscillation attenuation function [9] is shown in formula 1.

$$s(t) = G\left(e^{\frac{1.3(t-t_0)}{\tau}} - e^{\frac{2.2(t-t_0)}{\tau}}\right)\sin(2\pi f_c t) \quad (1)$$

In the formula, the amplitude of the local release signal is represented by G; The attenuation constant is represented by τ; The central oscillation frequency is represented by f_c; The start time is represented by t_0. The UHF double exponential attenuation oscillation waveform is shown in Figure 1.

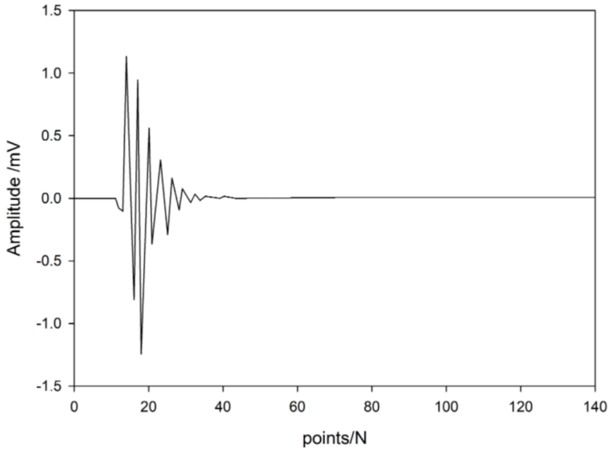

Figure 1: UHF double exponential attenuation oscillation waveform

2.2 Multi-sensor fusion UHV GIS UHF office discharge detection and positioning simulation

The 3D simplified model of GIS is built according to the structure of an isolation switch in a 1000kV UHV substation. The model is mainly divided into four parts, namely, the conductive part of the isolation switch, the basin insulator, the support insulator and the GIS shell. In order to simulate the situation that the static and static contacts are in alignment during the operation of the isolation switchgear, the simulation model sets the contact contacts to the connected state. Due to the addition of the isolation switch in the internal structure, the discharge point may appear in various positions of the isolation switch, rather than only on the central axis. Therefore, it is not only necessary to judge from the vertical and horizontal, but also to judge the distance before and after. 3D positioning requires 4 detection points to determine the three delay differences. During the propagation period, the electromagnetic wave will propagate along the conductive part of the tool brake, the GIS gas part, and the support insulator part, but the propagation speed of each other is different. The electromagnetic wave first reaches the entire shell along the conductive part, and the supporting insulator is relatively close to the discharge point, but the speed is slightly slower. Electromagnetic waves in different media speed differences are relatively not obvious, so quickly uniform coverage throughout the three-dimensional model. According to this feature, the applicability of the 3D model to UHF simulation can be verified, and the electromagnetic wave amplitude of the GIS shell at different times can be statistically obtained, as shown in Table 1.

Table 1: Performance of electromagnetic wave amplitude of the shell at different times.

Time	**0ns**	**2ns**	**4ns**	**6ns**	**8ns**	**10ns**

Amplitude /mV	1±1	3±1	6±1	9±1	12±1	15±1

During the operation of the equipment, most of the internal local discharge problems are generated on high-potential conductors. In the simulation, the discharge point is selected on the conductive part of the space, that is, (0.5, 0,1.2), and four sensors are installed on the upper and lower parts of the basin insulators on both sides, as shown in Figure 2.

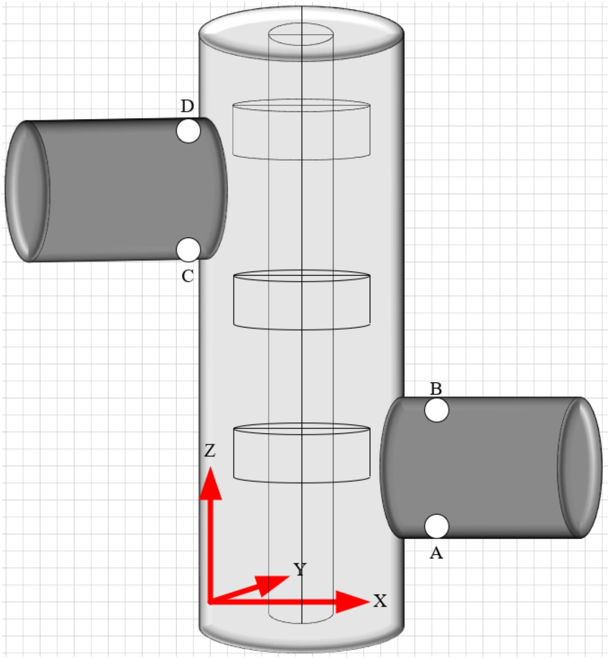

Figure 2: Schematic diagram of sensor layout.

In the 3D modeling model, there are four observation point sensors, and the acquired UHF signal along the situation is shown in Figure 3.

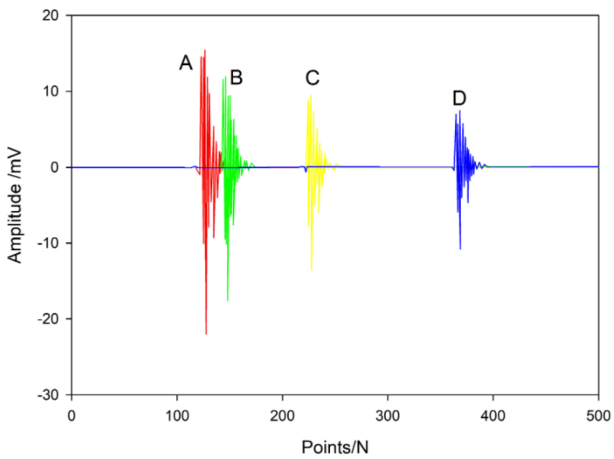

Figure 3: Time delay of three-watt high frequency signal.

In MATLAB, the delay difference of the simulation results is 8.2ns, 22ns and 24ns, respectively, and the locations of four observation points A, B, C and D are known to be PD1(0.8,0,0.6), PD2 (0.8, 0,0.9), PD3(0.2, 0,1.4), PD4 (0.2,0,0, etc. 1), the only solution is (0.49, 0.02, 1.212), and the three coordinate errors are 1.4%, 2%, and 1%, respectively, meeting the relevant requirements.

3 Local discharge location solution

Based on the above positioning simulation analysis, it is necessary to use multiple UHF sensors to adopt the spatial positioning method for local release positioning, so as to meet the positioning error requirements. The spatial positioning method based on multiple UHF sensors is no longer a simple linear equation solution, but involves the solution of nonlinear equations, so the intelligent search algorithm is chosen to solve the local discharge source [10]. Based on the principle of energy product, the starting point of UHF signal is determined. When the initial moment of sensor signal is $t_i(i = 1,\cdots,N)$, N is the number of sensors. Then, let the transmission speed of the power supply signal be v, and the difference between the start time of the first sensor signal and the start time of the i sensor be $t_{Ii} = (i = 2,\cdots,N), t_{Ii} = t_I - t_i$. Based on the space geometry, formula 2 can be obtained.

$$\begin{cases} vt_{I2} = d_I - d_2 \\ \cdots \\ vt_{Ii} = d_I - d_i \\ \cdots \\ vt_{IN} = d_I - d_N \end{cases} \quad (2)$$

The distance between the local emission source and the sensor is represented by d_i. The calculation formula in the three-dimensional space coordinate system is shown in formula 3.

$$d_i = \sqrt{(x_i - x_s)^2 + (y_i - y_s)^2 + (z_i - z_s)^2} \quad (3)$$

By combining formula 2 and formula 3, a nonlinear system of equations with local emission source as the solution can be obtained. How to solve these equations is the key to judge the location of the local discharge source. Therefore, the chaotic Cuckoo algorithm is applied to this solution to obtain the location of the local release source [11].

3.1 Chaotic Cuckoo algorithm

The chaotic Cuckoo algorithm is a swarm intelligence algorithm that simulates the process of finding other brooding birds, and has a strong search ability. At the same time, it can also show superior convergence in specific places [12-13]. The specific algorithm flow is as follows: first, N bird nests $Nest_i(x_1, x_2, \cdots x_D), 1 \leq i \leq N$ are set, and the location of bird nests is randomly set in D-dimensional space. $f(Nest_i)$ $1 \leq i \leq N$ represents the fitness value of each bird nest under the selected humidity function, and the bird nest with the highest fitness is selected. Second, let x_i^t represent the position in the t iteration of the i bird nest, and let $Levy(\lambda)$ represent the search path chosen by the algorithm, then the algorithm bird nest position update mode can be calculated by formula 5.

$$x_i^{t+1} = x_i^{(t)} + \alpha \oplus levy(\lambda)(i = 1,2,\cdots,n) \quad (5)$$

Where, the search step is represented by α; $\oplus$ is point multiplication. Third, assuming that the probability of finding foreign bird eggs is P, the uniformly distributed random number γ is $[0, 1]$, and if $\gamma > P$, then the nest position is iterated, and vice versa. During the iteration of the algorithm, the convergence speed and solving accuracy will not remain unchanged, but will change. In order to reduce the influence of this aspect, the hybrid idea will be used to intervene. Logisic mapping is a one-dimensional discrete chaotic system with fast operation speed. Repeated iteration of equations can produce a better chaotic sequence, and the resulting chaotic sequence is extremely sensitive to the initial state and system parameters. Therefore, Logistic equation is used. The chaos variable is shown in formula 6.

$$y_{n+1} = 4y_n(1 - y_n) \quad (6)$$

Where, $n = 1,2,\cdots,n$, y_n is A chaotic variable and y_n is $[0,1]$. When the output value of the solution of the algorithm for consecutive iterations k is unchanged, it is considered to be trapped in a local solution. According to the optimization calculation of the above formula, the current optimal solution is converted according to formula 7.

$$y_1^k = \frac{x_{best} - x_{min}^k}{x_{max}^k - x_{min}^k} \quad (7)$$

If y_1^k is iterated T times by $y_{n+1}^k = 4y_k^n(1 - y_k^n)(n = 1,2,\cdots,n)$, the chaotic sequence $y^k = \left(y_1^k, y_2^k, \cdots, y_T^k\right)$ can be obtained. Inversely map the solution value according to Formula 6:

$$x_{best}^{*k} = x_{min}^k + \left(x_{max}^k - x_{min}^k\right)y_m^k, m = 1,2,\cdots,T \quad (8)$$

In the formula, x_{best}^{*k} is the calculated optimal solution position, and the chaotic Cuckoo algorithm flow is shown in Figure 4.

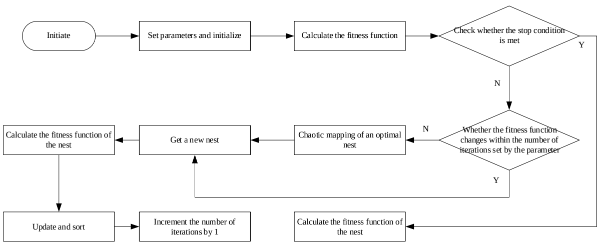

Figure 4: Flow of chaotic Cuckoo algorithm.

3.2 Local emission source solution based on chaotic cuckoo

Today's UHV GIS equipment tank diameter is large, in order to ensure the local discharge positioning accuracy, need to use multiple UHF sensors detection and positioning. When the multi-channel ultra-high frequency signal is obtained, it is solved according to formula 2 and formula 3. When the chaotic Cuckoo algorithm is used to solve the location of the local release source, it is necessary to establish a spatial marking system according to the specific situation of GIS equipment. Usually, the GIS components are installed on both sides of the basin formula and other references to determine the coordinate origin. When the chaotic Cuckoo algorithm is used to solve the location of local discharge source, the determining element of the UHF sensor in the outermost position is calculated, and the approximate cylinder boundary determined by the GIS tank in the search range is solved. The chaotic Cuckoo algorithm is applied in the field of local source solving, with emphasis on the construction of fitness function. The cumulative sum of squares function is constructed to calculate the fitness value of local discharge search. The process of solving local discharge source is to find the solution with the smallest difference between each known position. In the set coordinate system, $u_i(x_i, y_i, z_i,)$ represents the position of the i-th sensor, and the required location is $V\left(V_x, V_y, V_z\right)$. The fitness function is constructed as shown in Formula 9.

$$K_{sum} = \sum_{t=2}^{N}(2V - u_1 - u_i - vt_{li})^2 \quad (9)$$

In the algorithm search solution place is to find K_{sum}^{min}, which is also the minimum value in each local. The global K_{sum}^{min} in the boundary specification is solved by Levy flight path. After setting the calculation coordinates, solving the boundary, accurately reading the time difference and constructing the humidity function according to the steps above, the chaotic Cuckoo algorithm can be used to calculate and accurately solve the local release source position within the boundary range. In this paper, a single UHV GIS is taken as an example, and the cuckoo algorithm is used to solve the local discharge. In general, GIS positioning monitoring needs to use four UHF sensors. In equivalent calculation, GIS can approximate the cylinder and use the surface equation description algorithm of the cylinder to solve the boundary. With the center of the bottom surface of the cylinder as the origin, the three-dimensional space coordinate system is established, then the position of the four sensors can be given according to the actual situation, and the position of the local discharge source is unchanged. Based on the given process above, output the location of the office release source, that is, complete the office release detection and positioning work.

4 Case tests

This paper carries out feasibility analysis through case study, that is, taking A UHV AC substation as an empirical study. Historical data pointed out that on December 28, 2022, the 1000kV GIS equipment of the power station exceeded the limit alarm, the alarm sensor was located in the 1000kV#1 bus 18#C phase gas chamber, and the UHF local discharge detection was carried out with the long-rail instrument, and the detection signal peak value of the built-in sensor was about 600mV. The UHF signal can also be detected at the basin insulators on both sides of the T0511C phase cutter gate, with a peak value of about 160mV, which is the local release phase characteristic of the UHF abnormal signal at that time. For further analysis, external interference signals need to be excluded. In this link, the instrument with automatic time difference analysis function is used to detect UHF local discharge, and the local discharge signal with discharge characteristics can be detected. In order tocheck the accuracy of interference signal recognition, an oscilloscope is also used to connect one signal to the built-in sensor and another signal to the external sensor. If the external sensor moves in all directions, it can detect UHF signals. The UHF abnormal signals in the air background and the abnormal signals in the GIS are the same local signal source. According to the time difference lead principle, the GIS internal signal is always ahead of the signal of the external sensor. Therefore, it can be determined that the UHV abnormal signal originates from the GIS internal signal and needs to be located in the office release. That is, the position of the signal source is located by means of the multi-function office release positioning system PDS-G1500. Among them, the sensor A and B are arranged at the basin insulators on both sides of the C-phase of the T0511 tool brake, the distance is about 2.6m, and the signal peak is about 160mV; Sensor C is a built-in sensor with a signal peak value of about 600mV. The detection diagram is shown in Figure 5.

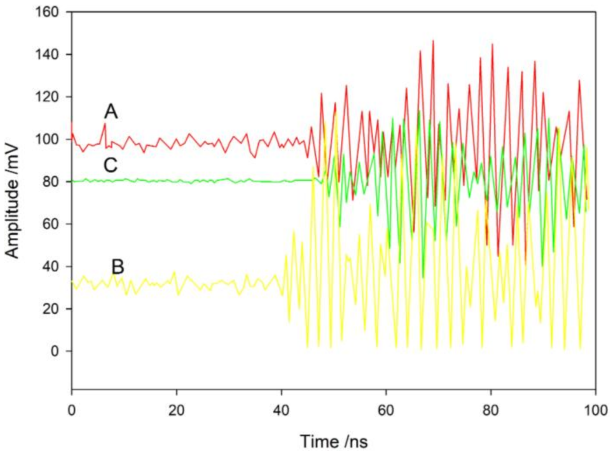

Figure 5: UHF detection map.

In the figure, the signal collected by sensor B is about 7ns ahead of sensor C, and the difference of signal transmission distance is 2.1m, which is consistent with the sensor layout spacing. It is judged that the signal source is located on the left side of sensor B. The signal collected by sensor A is lower than that of sensor B, about 5ns, so it can be judged that the high-frequency signal source is between sensor A and sensor B. In order to further locate the local location accurately, the UHF spatiotemporal difference spatial positioning method is used to further locate the local location. Two UHF sensors are arranged at the basin-type insulators on both sides of the tool brake, and the sensors on each basin-type insulator are respectively located at the top surface and the lowest surface of the basin-type insulator, as shown in Figure 2. The time difference between the sensor and the sensor is shown in Table 2.

Table 2: Time difference of UHF sensors.

sensor	**The time difference compared to sensor A**
A	0
B	0.8
C	2.9
D	4.8

After many measurements, the time difference of the signals collected by the four sensors tends to be stable. A group of data waveforms with stable time difference are selected to read the time difference values between the other three groups of UHF signals and the 1# sensor respectively, and the corresponding coordinates and time difference values are obtained. After full calculation, the coordinates of the local release source (0.52, 0.12, 0.45) are obtained, which are the support insulators in the GIS. The abnormal signal is determined to be C-phase internal insulation discharge of T0511 tool brake. The signal source is located at the bottom support insulation, which may cause partial discharge due to defects such as internal cracking and air gap of the solid insulation pad at the bottom of the brake.

5 Conclusions

To sum up, this paper first proposed the GIS UHF mean square detection and positioning method, and built a GIS simplified model. Through simulation analysis, the GIS location method was obtained, and the positioning error was calculated to verify the accuracy of the method. The conclusions are as follows: First, for UHV GIS equipment with long straight pipe, when the distance between sensors is less than 2.1m, the two-point linear time difference positioning method can not be successfully positioned. Second, for GIS equipment with complex structures such as circuit breakers and spacing switches, sensors still need to be further increased in order to accurately position the office discharge. At the same time, for the time difference location of multi-channel signals, the chaotic Cuckoo algorithm is applied to the solution of UHF local discharge location, and it is verified by a practical case. It is found that with the support of the algorithm, the use of multiple sensors can complete the location of local discharge source, which can provide some reference for the development of practical projects. Although the research has made some achievements, due to the limitations of resources, knowledge, time and other aspects, there are certain shortcomings in the research society, such as the failure to detect and analyze abnormal office release signals in UHV GIS by manual methods. In the future, on the basis of this research, the UHV GIS equipment detection database will be continuously improved, the anomaly map diagnosis and analysis will be integrated, the backend system data will be connected with the field detection terminal with the help of 5G technology, the intelligent research and judgment will be realized through big data, and the application research of edge technology and cloud computing in GIS equipment detection will be further carried out.

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