Fault Location for Multi-source Distribution Network Based on Improved Chaotic Jaya Algorithm

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Abstract. Due to the wide access of distributed energy in the distribution network, the structure of the distribution network becomes complex and diverse, and the power flow distribution is flexible and changeable. To optimize the fault location performance of the multi-source distribution network, this paper proposes a power grid fault location solution method based on the improved Jaya algorithm. By combining the chaos theory with the Jaya algorithm, the individual position iteration of the algorithm is optimized to improve the algorithm's global optimization capability and speed up the fault location. Through the example test and comparison with the traditional algorithm, the experimental results verify the effectiveness and superiority of this method.

1. Introduction

Due to the continuous improvement of the permeability of all kinds of distributed energy in the distribution network, it has changed from a single-source radial topology to a multi-source distribution network (MSDN). The difference of operation characteristics of heterogeneous distributed power supply changes the original topology and power flow direction of distribution network to a great extent. Moreover, with the increasing demand of social life for the reliability of power supply, the fault section of distribution network needs to be located and isolated more quickly and accurately, so as to reduce the scope of fault outage and improve the self-healing ability of power grid, and then improve the resilience of the power grid.

With the expansion of the scale of the power grid and the increasingly complex structure, the positioning ability of traditional methods is limited in practical application. In recent years, fault isolation technology using feeder terminal unit (FTU) has been developed, with shorter power outage time and more efficient fault handling [1]. This technology mainly relies on voltage and current information, and is based on matrix algorithms [2-3] or artificial intelligence algorithms and their optimization algorithms [4-8] to locate faults in the distribution network. Matrix algorithm is not widely used because of its poor fault tolerance; The fault location technology based on artificial intelligence algorithm has become a research hotspot because of its simple principle and high fault tolerance. In [3], in response to this problem of poor fault tolerance of matrix algorithm and slow positioning speed of optimization algorithm, a combinatorial optimization algorithm is proposed. In [5], a new method based on improved genetic algorithm is proposed, which improves the problem of premature and slow convergence of genetic algorithm. Yang [6] uses an immune binary firefly algorithm to locate the fault section of distribution network, and further improves the optimization ability by considering memory pool and immune algorithm. Although many researches are devoted to
improving the optimization ability of traditional intelligent algorithms, its search and optimization speed is limited by the high node dimension of multi-source distribution network, resulting in long computing time. In addition, the performance of algorithms largely depends on their own algorithm specific parameters. Improper adjustment of algorithm control parameters will lead to poor optimization results. To solve this problem, The Jaya algorithm proposed by Rao [9] has the characteristics of simple structure, weak dependence on algorithm parameter setting and fast convergence, and is more suitable for solving complex models.

In order to further improve the fault location speed of distribution network with multi types of distributed energy, a fault location method of distribution network based on improved chaotic Jaya algorithm is proposed in this paper. Firstly, the fault location model of MSDN is constructed and solved based on the improved Jaya algorithm; Secondly, the chaos theory and Jaya algorithm are integrated to optimize the setting of random numbers in the solving process, and the coding rules is modified, which promotes the global optimization ability of the algorithm and shortens the computing time of the solution. Finally, the experimental example is given to verify the performance of the method in fault location of MSDN.

2. Fault Location Model of MSDN

2.1. Fault Location of MSDN
The establishment of fault location model of MSDN mainly includes: (1) setting coding mode according to FTU monitoring current information. (2) setting switch function to realize the conversion between switching current information and fault section. (3) defining evaluation function to judge of location result.

2.2. Fault Current Information Coding
FTU can monitor the fault overcurrent information on the switch node. When the fault current information from the main power supply end of the system to the monitoring node is detected, it is recorded as 1; when the distributed power terminal to the monitoring node direction information is detected, it is recorded as -1; when no fault flow information is detected, it is recorded as 0. It is assumed that the direction from the system power supply point to the fault line is positive, so the switch status information detected is as follows.

\[
I_s = \begin{cases} 
1 & \text{The direction of fault current is positive} \\
0 & \text{Fault-free current} \\
-1 & \text{The direction of fault current is negative}
\end{cases}
\]  

(1)

2.3. Switching Function
According to the position of the switch, the distribution network can be divided into upstream and downstream areas, the line from the switch to the system power is the upstream area, and the line from the switch to the distributed power supply is the downstream area. The switching function of traditional single source network cannot analyze multi-directional current information and cannot meet the needs of multi-source distribution network. For the MSDN, the operation status of each power supply in the grid is represented by adding the distributed power coefficient to the traditional switching function, as shown in equation (2).

\[
I_j(S) = \left[ \sum_{n} K_{j,up} (1 - \sum_{m} x_{j,up}(m)) \right] \sum_{n} x_{j,down}(n) - \left[ \sum_{n} K_{j,down} (1 - \sum_{m} x_{j,down}(m)) \right] \sum_{m} x_{j,up}(m)
\]

(2)

Where, \( \sum = \) represents the logical OR operation. \( K_{j,up} \) and \( K_{j,down} \) are the power supply coefficients on the upstream and downstream of the \( j \)-th switch respectively. If it is in the state of grid-connected operation, the coefficient is 1, otherwise it is 0. \( x_{j,up} \) and \( x_{j,down} \) are the state values of the feeder
section experienced by the $j$-th switch to the upstream and downstream power supply paths, respectively. $x_{j,\text{up}}(m)$ and $x_{j,\text{down}}(n)$ are respectively the state value of each feeder section in the upstream and downstream area of the $j$-th switch. When the feeder fails, the value 1, otherwise it is 0. $M$ and $N$ are the total number of feeder sections in the upstream and downstream areas of the $j$-th switch.

### 2.4. Evaluation Function

According to the defined network switching function, an improvement is made on the basis of the traditional evaluation function, which allows the direction of fault current to be inconsistent when the front and back of the distributed generation connected to the grid fails. At the same time, considering that FTU is affected by external adverse factors, fault information upload distortion is easy to occur, resulting in location errors. Therefore, the evaluation function of fault section location model considering distributed energy switching and information distortion is constructed, as shown in equation (3).

$$
F = \sum_{j=1}^{P} |I_j - I_j^*| + \omega \sum_{j=1}^{Q} |S_a(j)|
$$

(3)

Where, $I_j$ is the status information value detected by FTU at switch $j$. $I_j^*$ is the expected value of the switching function of the $j$-th switch. $P$ is the total number of switches. $\omega$ is the weighting coefficient, the value interval is from 0 to 1, in this paper, $\omega$ is taken as 0.5. $S_a$ indicates section status. $Q$ is the number of feeder sections in the distribution network.

### 3. Improved Jaya Algorithm Based on Chaos Theory

#### 3.1. Jaya Algorithm

Jaya algorithm [9] is a new heuristic optimization algorithm. Its core idea is the individual location update strategy, which requires that the change of candidate solutions should approach the optimal solution and stay away from the worst solution. Unlike most heuristic algorithms, the Jaya algorithm is not affected by any specific parameters, so users only need to set simple parameters. The solution flow of the traditional Jaya algorithm as shown in figure 1.

Jaya algorithm occupies less memory and will not generate new occupation during variable update. When the new solution scheme provides a better function value, it is accepted as the new value of the decision variable, otherwise keep the original solution. At the end of the iteration, the accepted function value is retained and becomes the input of the next iteration.
Parameter initialization: population number; variable dimension; iteration number

Calculate individual fitness

Identify best and worst solutions in the population

Modify the solutions based on best and worst solutions

Whether the modified solution is better than the current optimal solution?

No

Keep the previous solution

Yes

Accept and replace the previous solution

Whether the iteration is terminated?

No

Keep the previous solution

Yes

Output the optimal solution

End

**Figure 1.** Jaya algorithm flow chart.

The location update strategy is as follows:

For the objective function \( F(x) \), \( x_i \) is the position of the \( i \)-th candidate solution, and \( D \) is the variable dimension.

\[
X'_{j,k,i} = X_{j,k,i} + r_{ij,j}(X_{j,best,i} - |X_{j,best,i}|) - r_{ij,j}(X_{j,worst,i} - |X_{j,worst,i}|)
\]  

(4)

Where, \( i, j, k \) represent iteration, variable, and candidate solution respectively. \( X'_{j,k,i} \) means the \( j \)-th variable of \( k \)-th candidate solution in \( i \)-th iteration. \( X_{j,best,i} \) and \( X_{j,worst,i} \) represent the population optimal solution and the worst solution of the current iterative variable respectively. \( r_{ij,j} \) and \( r_{ij,j} \) are the randomly generated numbers in the range of [0, 1].

3.2. Chaotic Jaya Algorithm

For Jaya algorithm, when the random value is large in the iterative process, it will speed up the candidate solution to the optimal solution, otherwise it will slow down. This paper proposes a method to determine the random value of the position update formula of Jaya algorithm based on chaos theory [10-11]. Chaos theory is a research on the ways and mechanisms of the formation of internal random processes in deterministic systems, has randomness and convenience. Therefore, the random values obtained from chaotic maps are random and ergodic, which can reduce the influence of random value selection on the optimization ability of the algorithm and improve the global search capability.

The logistic chaotic mapping function was selected as the method of generating random values.

\[
Y_{u+1} = \mu Y_u (1 - Y_u) \quad u = 1,2,3...
\]  

(5)

Where, control parameters \( \mu \in (0,4), Y_u \in (0,1) \). When \( 3.5699... < \mu \leq 4 \), the system is in a state of chaos.

3.3. Individual Coding

The optimization results of variables in individuals should gradually tend to the integer values in the current coding range. To speed up the iterative convergence speed, the individual coding is optimized by setting the threshold, and the variable is modified according to equation (6).
Where: $\lfloor \cdot \rfloor$ stands for rounding; $\xi$ is the correction threshold, which is taken as $\max F / 2$. $X'$ and $X$ represent the modified solution and the original solution, respectively.

### 4. Example Analysis

Based on the improved IEEE33-node distribution network, this paper analyzes the network to verify the feasibility of this method, as shown in figure 2. Node 1 is the main network power supply node, and DG1 to DG3 are distributed power supply nodes, which are controlled by the distributed power switch. Parameter Settings of the improved Jaya algorithm include: the population number is 50, the maximum iteration number is 100, and $\mu = 4$.

![Figure 2. Improved IEEE-33 node distribution network.](image)

The simulation example includes a variety of fault location tests of single and multiple faults when the fault information uploaded by FTU has distortion or not. The difference between the number and distribution location of distributed power can be simulated by changing the power coefficient matrix to show the adaptability of the algorithm under different network distribution structures.

| FTU upload information | Power coefficient | Distortion point | Fault section |
|------------------------|-------------------|-----------------|--------------|
| [1 1 1 1 1 1 1 1 1 1 1 -1 -1 1 -1] | [1 1 1] | - | 9 |
| [1 -1 -1 -1 -1 -1 0 0 0 0 0 0 0 0 0 0 0] | [1 1 1 1] | 11 | 21 |
| [1 1 1 1 1 1 1 1 1 -1 -1 1 -1 -1 -1] | [1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0] | [1 0 0 1] | 16,17 | 13 |
| [1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0] | [1 1 1 1] | 15 | 7,23 |
| [1 1 1 1 1 1 1 1 -1 -1 -1 -1 -1 -1] | [1 0 1 1] | - | 10,15 |

As shown in table 1, the output of the fault location model is consistent with the preset fault situation. Even if the information uploaded by FTU at some switches is distorted due to the influence of the external environment, the model can still identify the fault interval accurately, it reflects the fault tolerance of the fault location model.

In addition to the accuracy of the algorithm, the fast solving ability also needs to be verified. This paper uses different algorithms to solve and calculate the fault location model for the same kind of fault situation in the distribution network. Each algorithm is repeatedly tested for 100 times, and the average value of the index is calculated for comparison and verification. The results are shown in table 2.

| Algorithm | The average computation time / s | Accuracy/ % |
|-----------|---------------------------------|-------------|
| GA        | 2.85                            | 97.7        |
| PSO       | 1.31                            | 100         |
| Jaya      | 1.10                            | 100         |
| Improved Chaotic Jaya (Proposed method) | 0.96 | 100 |
As shown in table 2, this paper takes traditional GA and PSO algorithms as the object of comparative analysis. The Jaya algorithm and the improved chaotic Jaya algorithm proposed in this paper are superior to traditional algorithms in the calculation speed of solving the fault location model and maintain high accuracy. The latter one can further reduce the calculation time of model solving and improve the efficiency of fault location in the distribution network.

5. Conclusion
The main results are as follows: 1) this paper proposes to combine chaos theory with Jaya algorithm, and by optimizing the setting of random number and individual coding of algorithm, the defect that traditional intelligent algorithm is easy to converge to local optimization is improved, the time of calculation is shortened, the efficiency of fault location is improved, and the performance is better than traditional Jaya algorithm. 2) the model proposed in this paper realizes the fault location problem of single and multiple faults under different distributed energy distribution, and can deal with fault location with simple distortion information.

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