Fault-tolerant Ability of Fault Location on Distribution Internet of Things in Electricity Using Genetic Algorithm

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Abstract. To improve the accuracy of fault location of distribution Internet of Things in electricity based on feeder terminal unit (FTU), genetic algorithm is applied to locate fault for distribution Internet of Things in electricity. The basic principles of distribution Internet of Things in electricity fault location based on FTU and genetic algorithm are introduced. The distribution Internet of Things in electricity fault location programs based on improved unified matrix algorithm and genetic algorithm are realized and used to locate fault for IEEE33 feeder section distribution system when FTUs have different wrong information. The results show that the improved unified matrix algorithm is easy to obtain the wrong location results when the FTUs obtain wrong information. The genetic algorithm has good fault-tolerant ability, and the accuracy of fault location is still high even if a small number of FTUs have wrong information.

1. Introduction
When a fault occurs in distribution Internet of Things in electricity, there is fault information on feeder terminal unit (FTU). Therefore, it is very valuable to locate the fault timely and accurately according to FTU. The unified matrix algorithm is firstly proposed and used to locate fault [1], which can determine the fault location of distribution network through simple calculation according to the network information matrix and fault information matrix. The advantage is that the principle is relatively simple. Fault location of distribution network can also be considered as an optimization problem. Some artificial intelligence algorithms have been applied to locate the fault of distribution network, such as genetic algorithm [2-3], particle swarm algorithm [4-5], ant colony algorithm [6-7] and so on. Genetic algorithm is a typical artificial intelligence algorithm, which has been used in fault location of distribution network. But what are the advantages and disadvantages of this algorithm compared with the existing unified matrix algorithm? There is no systematic and in-depth study on this point.

In order to fix the problem, the basic principle of fault location of distribution Internet of Things in electricity based on FTU and genetic algorithm are introduced. The distribution Internet of Things in electricity fault location program based on the improved unified matrix algorithm [8] and the genetic algorithm are coded and used to locate fault for IEEE33 feeder section distribution system when FTU with different wrong information. According to the results, the fault-tolerant ability of the improved unified matrix algorithm and the genetic algorithm is compared.
2. Fault location for distribution network and genetic algorithm

The basic principle of the unified matrix algorithm is to construct the corresponding network information matrix \( D \) according to the distribution network structure. Then, the corresponding fault information matrix \( G \), which is also a \( N \times N \) diagonal matrix, is constructed according to the information of switches’ overcurrent state. The fault judgment matrix can be obtained by Eq. (1).

\[
P = g(DG)
\]

where \( P \) is the fault judgment matrix, and \( g(P) \) represents the normalized operation of matrix \( P \). See Ref. [8] for more information. The fault feeder section can be located according to \( P \). See Ref. [8] for more information.

Genetic algorithm is proposed according to the process of natural selection. By means of the way of mathematics and computer simulation, the optimization problem can be solved according to the process similar to the biologically inspired operators, such as crossover, mutation and selection. It is a probabilistic algorithm of adaptive heuristic global search. It has strong robustness and can search multiple points in solution space at the same time. Therefore, it is a global optimization algorithm.

The key parts of genetic algorithm application in distribution network fault location include coding mode, switching function and fitness function. The state of each feeder section is represented by binary encoding, where 0 means normal and 1 means failure. The length of the code equals to the number of feeder section. The switching function actually realizes the mapping of FTU state to feeder section state, which corresponds to the distribution network architecture. The fitness function reflects the correctness of the solution obtained by the genetic algorithm. Let \( I = [I_1, I_2, \ldots, I_N] \) be the known switch state vector. If the \( n \)th switch has an overcurrent, \( I_n = 1 \). Otherwise \( I_n = 0 \). \( S = [s_1, s_2, \ldots, s_Q] \) is the state vector of the feeder section obtained by the genetic algorithm, where \( Q \) is the number of feeder sections. If the \( q \)th feeder section has a fault, \( s_q = 1 \). Otherwise \( s_q = 0 \). The corresponding fitness can be calculated by Eq. (2).

\[
F(S) = \sum_{n=1}^{N} |I_n - I_n(S)| + \omega \sum_{q=1}^{Q} s_q
\]

where \( I_n(S) \) is the state of the \( n \)th switch corresponding to the state vector \( S \) of the feeder sections; \( \omega \) is the weight coefficient of the minimum set.

3. Comparison of two algorithms

3.1. FTU with correct information

IEEE33 feeder section distribution system as shown in Figure 1 is taken as a distribution Internet of Things in electricity. The two algorithms are used to locate its fault and the results are compared. The switch states are shown in Table 1, and it is clear that the 7th, 23th and 27th feeder sections have failed. In the light of the actual situation of distribution network fault location, the relevant parameters of the genetic algorithm are set as follows: the crossover probability is 0.8, the number of population is 100, the mutation probability is 0.2, \( \omega = 0.5 \), the number of generations changes within the range of 60~250 with a step size of 10. After the training of genetic algorithm, the solution with the best fitness (minimum fitness) is selected from the population as the fault diagnosis results. The genetic algorithm runs 100 times for each parameter combination.

The results of the improved unified matrix algorithm are shown in Table 2. It is obvious that this algorithm can accurately locate distribution network faults. The mean number of misjudgment sections and mean misjudgment rate of genetic algorithm under different number of generations are shown in Figure 2. Both the mean number of misjudgment sections and the mean misjudgment rate decrease with number of generations. When the number of generations is 250, the misjudgment rate is only 7%.
The mean computation time of the two algorithms (number of generations of genetic algorithm is 250) is 99.65μs and 0.93s, respectively. That is to say, the improved unified matrix algorithm is much computationally inexpensive.

![Figure 1. IEEE33 feeder section distribution system.](image)

| No. of switch | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|
| State         | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |

Table 1. State of switches, all FTU with correct information.

| No. of section | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|----------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|
| State          | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |

Table 2. Fault location of improved unified matrix algorithm, all FTU with correct information.

3.2. FTU with wrong information

The research object is the same as that in Section 4.1, except that there is a wrong information in the state of the first switch, which is shown in Table 3. Obviously the most correct result is that the 7th, 23th and 27th feeder sections have failed. The number of generations of the genetic algorithm is set to
250, and other parameters are consistent with those in Section 4.1. The fault location results using the improved unified matrix algorithm are shown in Table 4. Obviously, the state of first feeder section is wrong due to the wrong information of the firth switch. Its mean misjudged section number is 1, and the misjudged rate is 100%. After the genetic algorithm is run, the mean fitness is 2.82, the mean number of misjudged sections is 0.57, and the mean misjudged rate is 31%.

| Table 3. State of switches, first FTU with wrong information. |
|---------------------------------------------------------------|
| **No. of switch** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| **State** | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **No. of switch** | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 |
| **State** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

| Table 4. Fault location of improved unified matrix algorithm, first FTU with wrong information. |
|---------------------------------------------------------------|
| **No. of section** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| **State** | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **No. of section** | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 |
| **State** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

In order to further validate the genetic algorithm, it is assumed that wrong information in the state of the 12th and 18th switches respectively. The corresponding switch states are shown in Tables 5 and 6 respectively. The fault location results using the improved unified matrix algorithm are shown in Tables 7 and 8. Obviously, misjudgment occurs again in the improved unified matrix algorithm. The misjudgment probability is 100%, and the number of misjudgment sections is 2. The mean fitness of the genetic algorithm for these two cases is 2.80, the mean misjudgment probability is 32%, and the mean number of misjudgment sections is 0.57 and 0.52, respectively.

| Table 5. State of switches, 12th FTU with wrong information. |
|---------------------------------------------------------------|
| **No. of switch** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| **State** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| **No. of switch** | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 |
| **State** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

| Table 6. State of switches, 18th FTU with wrong information. |
|---------------------------------------------------------------|
| **No. of switch** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| **State** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **No. of switch** | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 |
| **State** | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

| Table 7. Fault location of improved unified matrix algorithm, 12th FTU with wrong information. |
|---------------------------------------------------------------|
| **No. of section** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| **State** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **No. of section** | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 |
| **State** | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
Table 8. Fault location of improved unified matrix algorithm, 18th FTU with wrong information.

| No. of section | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  | 15  | 16  | 17  |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| State         | 0   | 0   | 0   | 0   | 0   | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   |

| No. of section | 18  | 19  | 20  | 21  | 22  | 23  | 24  | 25  | 26  | 27  | 28  | 29  | 30  | 31  | 32  | 33  |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| State         | 1   | 0   | 0   | 0   | 0   | 1   | 0   | 0   | 0   | 1   | 0   | 0   | 0   | 0   | 0   | 0   |

According to the above results, when there is a wrong information in the switch state, the distribution network fault location results based on the improved unified matrix algorithm may be wrong. The wrong information in the switch state will also increase the misjudgment rate of the genetic algorithm, but both the number of misjudged sections and the misjudgment rate are significantly smaller than that of the improved unified matrix algorithm. Obviously, the genetic algorithm has greater fault-tolerant ability, which is suitable for the case that the switch state is prone to have a wrong information.

4. Conclusion
In this work, fault location of distribution Internet of Things in electricity based on FTU is studied. The improved unified matrix algorithm and the genetic algorithm are realized and used to locate fault of IEEE33 feeder section distribution system when FTU with wrong information. The results reveal that the genetic algorithm has greater fault-tolerant ability, but the computation time is much longer than the improved unified matrix algorithm.

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