Fault Location of Distribution Network Based on Dynamic Matrix

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Keywords: distribution network; fault location; matrix algorithm

Abstract: Distribution network is the closest power supply service terminal in power system to power customers, and its construction level has a great impact on the quality of power supply service. The research of fault location in distribution network can improve the self-healing level of distribution network, help to quickly find fault segments and isolate them, and realize the restoration of power supply in fault segments. In this paper, a fast fault location method without RTU information is proposed for the non-measurement and control area of distribution network. Based on the coordinate information provided by the hotline telephone, other fault nodes are searched from the base point to both sides by using the dynamic hierarchical method of power network, and then all the equipment in the whole dispatching area is traversed. The different fault membership functions of all devices are given. By synthesizing the information of several hotlines, the comprehensive membership degree of each switch element is obtained. When the comprehensive membership degree of a component is greater than the preset threshold, the fast fault location can be achieved. The simulation results show that the algorithm is feasible and effective.

1. Introduction

Electric energy has become the most important energy in contemporary society. With the rapid development of modern society and economy, the demand for electricity in the whole society is also rising. The role of electric energy in economic development and people's lives can not be replaced [1-2]. Such demand includes two aspects, one is the demand for power load capacity, the other is the demand for the stability of power system operation. Distribution network is the closest power supply service terminal in power system to power customers, and its importance is self-evident. Based on the theory of fuzzy sets, the method of fault location in non-measurement and control area adopted in this paper combines the topological structure and dynamic matrix of distribution network to locate fault elements quickly. This method is very convenient and flexible to use, especially suitable for the complex and changeable characteristics of distribution network.

2. Distribution Network Structure Matrix Modeling

Distribution network power system is composed of power supply, transformer, circuit breaker, bus and transmission line. [2] Among them, the power supply generally refers to the active system outside the system. This paper does not consider its composition and structure, and universally identifies it as a stable active system that can supply power to the distribution network [3]. Transformers, buses and transmission lines are all separated by circuit breakers, which form a small subsystem. Similarly, it can be considered that power system is a whole which is connected by circuit breakers to transformers, buses and transmission lines. Therefore, transformers, buses and transmission lines are unified as a component of distribution network, and circuit breakers are the contact switches between components.

According to the power system structure, starting from the upper left corner node, four power supply S1~S4 are numbered as: 1, 7, 8, 12; two transformers T1, T2, numbered as: 3, 10; two lines L1, L2 numbered as: 5, 6; four buses B1~B4, numbered as: 2, 4, 9, 11. Circuit breaker is the connection switch between components, so the number of K1-K12 circuit breaker is composed of the number of two components connected with it, in turn:

  DOI: 10.25236/iwmecs.2019.117

K1	(1,2)	K3	(2,5)	K5	(4,6)	K7	(8,9)	K9	(9,10)	K11	(10,11)
K2	(2,3)	K4	(3,4)	K6	(4,7)	K8	(5,9)	K10	(6,11)	K12	(11,12)

At the same time, according to the above numbering order, a matrix of 12*12 is established (Fig. 1), and the corresponding circuit breaker is placed in the corresponding position. In this way, the power system structure shown in Figure 2 is clearly represented by a 7-order matrix. Among them, the rows and columns of the matrix are all components, the corresponding AIJ is the connection between components, the name of the circuit breaker is filled in with the circuit breaker connection, and the rest is 0.

1	S1	0	K1	0	0	0	0	0	0	0	0	0	0
2	B1	0	0	K2	0	K3	0	0	0	0	0	0	0
3	T1	0	0	0	K4	0	0	0	0	0	0	0	0
4	B2	0	0	0	0	0	K5	K6	0	0	0	0	0
5	L1	0	0	0	0	0	0	0	0	K8	0	0	0
6	L2	0	0	0	0	0	0	0	0	0	0	K10	0
7	S2	0	0	0	0	0	0	0	0	0	0	0	0
8	S3	0	0	0	0	0	0	0	0	K7	0	0	0
9	B3	0	0	0	0	0	0	0	0	0	K9	0	0
10	T2	0	0	0	0	0	0	0	0	0	0	K11	0
11	B4	0	0	0	0	0	0	0	0	0	0	0	K12
12	S4	0	0	0	0	0	0	0	0	0	0	0	0
13		S1	B1	T1	B2	L1	L2	S2	S3	B3	T2	B4	S4
14		1	2	3	4	5	6	7	8	9	10	11	12

Fig.1. structure matrix of 12-order power system

When a new component or power supply is needed, the original matrix need not be changed, only the rows and columns of the matrix need to be added correspondingly. For example, if a switch K13 is added to bus B1, and K13 is connected to B1 and an external system S5, then the node number corresponding to S5 is 13, and the matrix is added with rows 13 and 13, and K13 is located in (2, 13). When the grid structure of power system is adjusted, the matrix structure can be used only by adding switch number in the corresponding position. For example, when a contact switch K14 is added between bus B1 and B2, only the switch name "K14" is filled in at (2,4) position, which can be used for fault analysis of new grid structures. Figure 2 shows the power system structure matrix after two adjustments.

1	S1	0	K1	0	0	0	0	0	0	0	0	0	0	0
2	B1	0	0	K2	K14	K3	0	0	0	0	0	0	0	K13
3	T1	0	0	0	K4	0	0	0	0	0	0	0	0	0
4	B2	0	0	0	0	0	K5	K6	0	0	0	0	0	0
5	L1	0	0	0	0	0	0	0	0	K8	0	0	0	0
6	L2	0	0	0	0	0	0	0	0	0	0	K10	0	0
7	S2	0	0	0	0	0	0	0	0	0	0	0	0	0
8	S3	0	0	0	0	0	0	0	0	K7	0	0	0	0
9	B3	0	0	0	0	0	0	0	0	0	K9	0	0	0
10	T2	0	0	0	0	0	0	0	0	0	0	K11	0	0
11	B4	0	0	0	0	0	0	0	0	0	0	0	K12	0
12	S4	0	0	0	0	0	0	0	0	0	0	0	0	0
13	S5	0	0	0	0	0	0	0	0	0	0	0	0	0
14		S1	B1	T1	B2	L1	L2	S2	S3	B3	T2	B4	S4	S5
15		1	2	3	4	5	6	7	8	9	10	11	12	13

Fig.2 structure matrix of 13-order power system

From this, we can see that the power system structure matrix established by this method is very convenient and flexible, especially suitable for the complex and changeable characteristics of distribution network.

3. Fault Location in Non-TT&C Zone

Firstly, according to user feedback information, a basic fault range (i, j) is determined, where i, J denotes the number of the component I or J. At the same time, the dynamic hierarchical root node AIJ of power grid is determined, and then I row, J row, I column and j column i n the matrix are searched to find all non-zero amns. The switches represented by AMNS and the components represented by I and j constitute the first layer of the dynamic hierarchical distribution network. Next, m row, M column and n column i n the matrix are searched to find all non-zero axies, and so on, until all non-zero axies are traversed i n the network. Node.

Considering that the closer the users are to the fault point, the greater the impact of the fault will be, we use the three-component method to establish the membership function, and give the fault membership of the first and second layer components a larger weighting factor. At the same time, for the three-layer and later components, in order to prevent the occurrence of misjudgments, the weighting factor of the fault membership is set to a smaller value.

Fault location in non-TT&C area of distribution network is expressed by the following formula:

$$A_1(l_i) = \omega_i(n-i+1) / \sum_1^n \omega_i(n-i+1) \tag{1}$$

In formula, $A_1(l_i)$ Represents the membership of layer I in the first fault complaint telephone feedback. ω_i Represents the weighting factor of layer i, n being the number of layers; where, ω_i The method of value selection is determined by the following formula:

$$\omega_i = \begin{cases} 0.6, & i=1 \\ 0.4, & i=2 \\ 0.2, 3 \le i \le n \end{cases} \tag{2}$$

For example, when all nodes in the network are traversed and divided into six layers, the weighting factor of the first layer is 0.6, the weighting factor of the second layer is 0.4, the weighting factor of the third layer to the sixth layer is 0.5, and the membership degree is 0.6. $A_1(l_1) = 0.6*6/(0.6*6+0.4*5+0.2*(4+3+2+1)) = 0.473$, Give this value to the first layer switch and calculate it step by step. $A_1(l_2) \sim A_1(l_6)$ And give the switch on the corresponding layer. Then, we get the fuzzy set of fault location when the first fault complaint telephone feedback is made:

A1={(l1,A1(l1)),(l2,A1(l2)),......,(l6,A1(l6))} (3)

After the assignment of fault membership degree of all switches is completed, the average fault membership degree of each component corresponding to the switch is taken as the fault membership degree of the component according to the power network structure. Taking busbar B1 as an example, there are three switches connected to busbar B1, namely K1, K2 and K3. Then the basic fault membership of busbar B1 is:

$$A(B1) = (A(K1) + A(K2) + A(K3))/3 \tag{4}$$

When there is a second fault complaint telephone feedback, the fault membership of each layer can be calculated according to the above method. $A_2(l_i)$ 。

The formula for calculating the comprehensive fault membership of a single switch:

$$A(*) = A_1(*) \cup A_2(*) \cup \cdots \cup A_n(*) \tag{5}$$

When A (*) is greater than the preset threshold of fault membership, the switch fault of the component is identified.

4. Simulation examples

When a fault occurs in the distribution network, according to the feedback information of the first user, it can be judged that the approximate fault range is between transformer T1 and bus B1. Therefore, $a_{ij} = a_{(2,3)}$, Then look for two rows, three rows, two columns and three columns in the matrix, find that a (1,2), a (2,3), a (2,5), a (3,4) has non-zero items, find all non-zero items amn_0, and the corresponding switch name K*, as the first level suspicious fault switch; then search for four rows, five rows, four columns, five columns in the matrix to find all non-zero items axy_0, and the corresponding switch name K*, as the second level. Suspicious fault switch. After the traversal of all the nodes is completed, we have experienced four traversals altogether. As shown in Figure 3.

1	S1	0	K1	0	0	0	0	0	0	0	0	0	0
2	B1	0	0	K2	0	K3	0	0	0	0	0	0	0
3	T1	0	0	0	K4	0	0	0	0	0	0	0	0
4	B2	0	0	0	0	0	K5	K6	0	0	0	0	0
5	L1	0	0	0	0	0	0	0	0	K8	0	0	0
6	L2	0	0	0	0	0	0	0	0	0	0	K10	0
7	S2	0	0	0	0	0	0	0	0	0	0	0	0
8	S3	0	0	0	0	0	0	0	0	K7	0	0	0
9	B3	0	0	0	0	0	0	0	0	0	K9	0	0
10	T2	0	0	0	0	0	0	0	0	0	0	K11	0
11	B4	0	0	0	0	0	0	0	0	0	0	0	K12
12	S4	0	0	0	0	0	0	0	0	0	0	0	0
13		S1	B1	T1	B2	L1	L2	S2	S3	B3	T2	B4	S4
14		1	2	3	4	5	6	7	8	9	10	11	12

Fig.3 The 12 order matrix traverses the result graph for the first time

After the first traversal, the maximum value of fault membership is 0.571, which fails to reach the preset threshold of fault membership. It is impossible to judge the fault component or switch for the time being.

Therefore, we need more information to complete the fault diagnosis and input the feedback information of the second user. The fault range is between bus B3 and line L2. After the traversal of all nodes is completed, four traversals are also experienced. As shown in Figure 4.

1	S1	0	K1	0	0	0	0	0	0	0	0	0	0
2	B1	0	0	K2	0	K3	0	0	0	0	0	0	0
3	T1	0	0	0	K4	0	0	0	0	0	0	0	0
4	B2	0	0	0	0	0	K5	K6	0	0	0	0	0
5	L1	0	0	0	0	0	0	0	0	K8	0	0	0
6	L2	0	0	0	0	0	0	0	0	0	0	K10	0
7	S2	0	0	0	0	0	0	0	0	0	0	0	0
8	S3	0	0	0	0	0	0	0	0	K7	0	0	0
9	B3	0	0	0	0	0	0	0	0	0	K9	0	0
10	T2	0	0	0	0	0	0	0	0	0	0	K11	0
11	B4	0	0	0	0	0	0	0	0	0	0	0	K12
12	S4	0	0	0	0	0	0	0	0	0	0	0	0
13		S1	B1	T1	B2	L1	L2	S2	S3	B3	T2	B4	S4
14		1	2	3	4	5	6	7	8	9	10	11	12

Fig.4 The 12 order matrix traverses the result graph for the second time

After the second traversal, the maximum comprehensive fault membership value is 0.694, which fails to reach the preset threshold of fault membership and fails to judge the fault component or switch.

Continue to input the feedback information of the third user. The fault range is between bus B2 and line L2. When all nodes are traversed, the final 12-order matrix is divided into four layers. As shown in Figure 5.

1	S1	0	K1	0	0	0	0	0	0	0	0	0	0
2	B1	0	0	K2	0	K3	0	0	0	0	0	0	0
3	T1	0	0	0	K4	0	0	0	0	0	0	0	0
4	B2	0	0	0	0	0	K5	K6	0	0	0	0	0
5	L1	0	0	0	0	0	0	0	0	K8	0	0	0
6	L2	0	0	0	0	0	0	0	0	0	0	K10	0
7	S2	0	0	0	0	0	0	0	0	0	0	0	0
8	S3	0	0	0	0	0	0	0	0	K7	0	0	0
9	B3	0	0	0	0	0	0	0	0	0	K9	0	0
10	T2	0	0	0	0	0	0	0	0	0	0	K11	0
11	B4	0	0	0	0	0	0	0	0	0	0	0	K12
12	S4	0	0	0	0	0	0	0	0	0	0	0	0
13		S1	B1	T1	B2	L1	L2	S2	S3	B3	T2	B4	S4
14		1	2	3	4	5	6	7	8	9	10	11	12

Fig.5 The 12 order matrix traverses the result graph for the third time

After the third traversal, the first five switches and components of the comprehensive fault membership are K10 and L2, in which K10's comprehensive fault membership value is 0.808 and L2's comprehensive fault membership value is 0.802, which all reach the preset fault membership threshold. It can be judged that the regional power outage caused by K10 side circuit breaker tripping due to L2 line fault.

K10 is the fault switch for this fault location, and K10 is not in the first layer of the suspicious fault switch list in the first user's feedback information. The reason for this is that when we use user feedback information, the accuracy of information is limited by the user's personal knowledge level and his perception of the network. The user's feedback information does not clearly describe his geographical location, provides biased information, or the staff has biased understanding and input biased information. After removing the second fault information and recalculating, the comprehensive fault membership of K10 is 0.816. Therefore, the biased information provided by the first user does not have a serious impact on the results, indicating that the algorithm has a certain degree of fault tolerance.

5. Conclusion

In this paper, we adopt the dynamic layering method of the power network, using the coordinate information provided by the hotline telephone as the basis point, as the first layer of fault, and then find the second layer of fault node by spreading the first layer of fault node to both sides, and so on, until all the devices in the whole dispatching area are traversed, and then assign different fault membership to all the devices. By synthesizing the information of several hotlines, the synthetical membership degree of each switch element is obtained. When the synthetical membership degree of a certain element is greater than the preset threshold, the fault location is completed. This algorithm is convenient, fast and fault-tolerant. The dynamic matrix algorithm adopted in this paper is not affected by redundant configuration and complex connections of distribution network, and it is also very convenient to adjust. Because no fixed root nodes are set, the advantages of the algorithm can be better reflected in the face of the huge distribution network architecture. However, due to the different level of power knowledge of users, the algorithm based on user information must pay special attention to the requirement of fault tolerance.

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