A Practical Method for Multi-stage Fault Location of Distribution Network with Incomplete Measurement

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Keywords: distribution network with incomplete measurement, measurement area, non-measurement area, multi-stage; fault location

Abstract. This paper is to propose a practical method for two-step fault location of distribution network with incomplete measurement. In the first step, the Ant Colony Optimization Algorithm (ACO) which is applied for location in measurement areas is used to locate in the whole networks. In the second step, the theory of rough set is used, which can locate faults in non-measurement areas. This paper is proposed a calculation flow for location model, and a 10kV distribution system of Hangzhou was used for simulating and verifying that the proposed method was effective.

Introduction

In the large distribution networks in practice, the main feeders are usually equipped with measuring and control devices. But some branch lines may not have these devices [1]. Areas have these functional devices called measurement areas, on the contrary called non-measurement areas. In measurement areas, FTU equipped on switches provides fault information [2,3], while fault phone calling does it when faults happen in non-measurement areas [4,5]. Recent researches usually focus on the location in measurement areas only or non-measurement areas only. And there isn't a method to locate faults in mixed distribution networks. In this paper, a two-step method of fault location in incomplete measurement distribution networks is proposed.

Incomplete measurement distribution network two steps fault location practical model

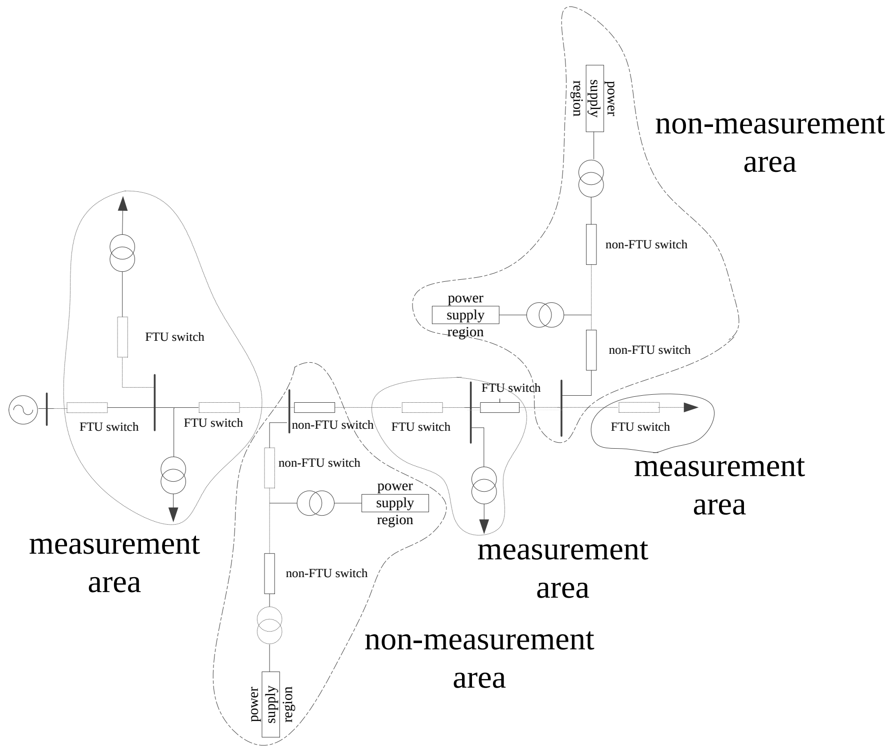

Fig. 1 Schematic diagram of incomplete measurement and control distribution network

The incomplete distribution network can be shown in figure. 1. For such kind of networks, there are two steps to locate. In the first step, we locate in the whole network roughly; in the second step we locate in the fault areas accurately. And its model can be shown in figure. 2.

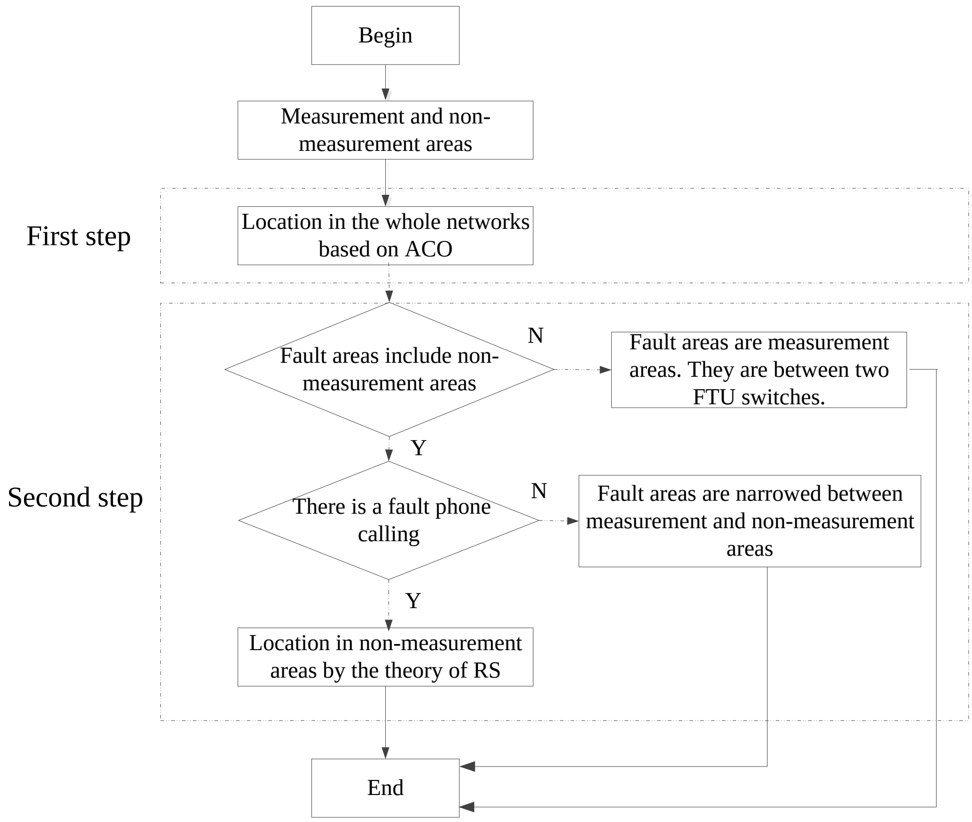

Fig. 2 Fault location calculation flow of incomplete measurement and control distribution network

1) First step: primary location in the whole network

In the consideration of the fact that distribution network usually have FTU switches in the main feeder line, so we can get fault information from FTU and SCADA in the main substation. And then, we can use the Ant Colony Algorithm to locate faults in the main feeder line switches and roughly judge where faults are in the main feeder line, mean narrow fault areas into measurement areas or between two FTU switches in the main feeder line or behind FTU switches in final terminal of the main feeder line.

2) Second step: accurate location in fault areas

After the finish of the first step to locate in the whole network, for narrow fault areas further, we can take these actions below:

A If fault areas don't include non-measurement areas, mean the fault areas stay the same with the results of the first step. And we just need to trip off these two FTU switches.

B If fault areas include non-measurement areas, we can narrow fault areas further by the judgment that whether there is fault phone calling in non-measurement areas or not.

①If it happens in measurement areas, there wouldn't be fault phone calling, now we can narrow fault areas between measurement areas and non-measurement areas, namely between non-measurement areas and a FTU switch in measurement areas.

②If it happens in non-measurement areas, we use the theory of rough set to locate. Based on large amounts of complaint information from users in different regions, we can rise the accuracy of location.

Besides, fault information from FTU has the problem of error codes and delay, which makes information from measurement areas unreliable. That will cause errors in the first step location. So this paper proposes a new way which combines information from FTU and fault phone calling and can correct the errors in location for FTU messages' inaccuracy. Its flow chart can be shown in figure 5

Location in measurement areas based on the Ant Colony Algorithm. Based on information offered by FTU and SCADA, we can use a method mentioned in article [3] which describes a new way in fault location with Ant Colony Algorithm. Details are written as follow:

$$F = \sum_{j=1}^{N} | I_j - I_j^*(S_B) | + \sum_{k=1}^{N} | I_k - x(k) | \tag{1}$$

In the equation, I_j is the j^{th} switch's fault current off-limit message; N is the amounts of all switches; x(k) is the information of status of the device connected to a interconnection switch or a single power supply radial network's devices in its end; I_k is a current off-limit message of switches connected these devices mentioned before; I*j(x) is an off-limit expectation function of the j^{th} switch's determined by devices' status. More details are shown in article [9].

In practice, FTU is located outdoors. Its environment is serous and fault information may be not accurate. As a result, an optimizing algorithm which is applied to locating faults in distribution networks needs a high ability of fault tolerance. So the Ant Colony Algorithm will be chosen for the reason that its optimal path of Ant Colony Algorithm is based on the amounts of pheromones given off by ants. And it has a high ability of fault tolerance and a feature of greedy heuristic. And it can work out the best combination of the conditions of all devices, which meets information offered by FTU, which means the F is small enough.

In detail, there are two ways FTU uploads datum: one is telemetering input, the other is telesignalisation input, which means the fault current collected by FTU can be calculated by Fault Electrical Quantity Correlation Function ρ(Ii). And its details can be shown as follow:

$$\lambda = \begin{cases} 1, & I \ge I_b \\ e^{\frac{-(I-I_b)^2}{2\sigma_I^2}}, & 0 \le I < I_b \end{cases}, \quad \sigma_I = \frac{I_b - I_a}{3} \tag{2}$$

I_a is the current quick-break protection setting and I_b is over-current protection setting. λ is among 0 to 1. When λ is equal to or above 0.5, FTU judges the current passing the switches as fault current and uploads the number '1'. Otherwise, it uploads '0'.

If FTU uses telemetering input, datum can be changed into 0 or 1 by the method mentioned above; If FTU uses the other way, datum uploaded are just 0 or 1. Then datum in the form of 0 or 1 can be used to locate faults in measurement areas with the Ant Colony Algorithm.

Fault location in non-measurement areas based on the theory of rough set. Faults in non-measurement areas can be located by the theory of rough set proposed by article [4], which can be carried out without obtaining all fault information.

Firstly, build the network fault location decision table based on fault phone calling by GIS network topology analysis. Secondly, reduce attribution of the decision table based on binary logic. At last, reduce attribute values by optimal algorithms and get the most simplified form of the fault location decision table.

Analysis of examples

This paper researches fault location of practical 10kV distribution network in Hangzhou by Matlab R2012a. The result of simulation analysis is shown as follows. This paper supposes 5 faults in the networks and they all happen in different times. And the information uploaded by FTU of the 5^{th} fault is incorrect. And the network which is used for simulation is shown in figure. 3.

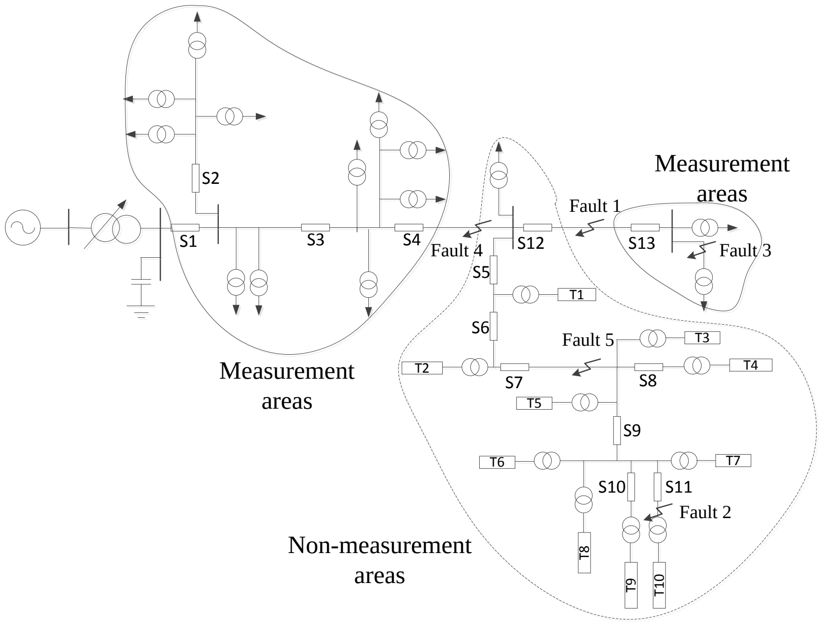

Fig. 3 A 10kV distribution system of Hangzhou

Factors of calculation. In location of measurement areas, for the reason that the electrical distance between two FTU switches isn't useful for heuristic of ants' search. So β=1, η_{ij}=1. And the transition probability P_{ij} is only associate with pheromone amounts of every device, choosing by the density of pheromones. For more simplified calculations, α=1, pheromone volatile coefficient ρ=0.95, constant Q=30. The amount of ants is 20, maximum iterations is 100.

And table. 1 shows the simplified decision table in the non-measurement areas of figure 1. The '*' means fault phone calling from this region have no influence on fault location of the decision table.

Tab. 1 Simplified decision table for fault location in distribution network

Sample	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	The switch tripped off
1	1	*	*	*	*	1	1	1	*	*	S5
2	0	1	*	*	1	1	1	1	*	*	S6
3	0	0	1	*	1	1	*	*	*	*	S7
4	*	*	0	1	*	*	0	*	*	*	S8
5	0	*	*	*	0	*	*	*	1	1	S9
6	0	*	*	0	0	*	*	*	1	0	S10
7	0	*	*	0	0	*	*	*	0	1	S11

Results and analysis of the example. This paper simulates 4 faults which happened in networks during different time and analyses features of this model. The table 2 is the contrast of methods proposed in this paper and the ACO.

Tab. 2 Fault location solution of distribution network

fault	This paper's method	ACO
1	Between s12 and s13	Between s4 and s13
2	Behind s11	Between s4 and s13
3	Behind s13	Behind s13
4	Between s4 and s12	Between s4 and s13
5	Between s6 and s7	Behind s13

According to table 2, in the case that FTU has no error in codes, the method of two-step location proposed in this paper is more accurate than the ACO. Fault 5 is the case that the FTU has error in codes. According to the ACO, it can be located behind s13. Taking the method of this paper, we locate fault 5 behind s13 in the first step too. But we use the fault phone calling in the second step. And we get different results. At this time, FTU is thought to have error in codes.

Conclusion

In this paper, a two-step method which is applied to incomplete measurement distribution networks is proposed. In the first step, we locate by the ACO in the whole networks; After getting an initial location result, in the second step, we use the theory of RS based on the fault phone calling.

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