Distribution Network Fault Location Based on Electromagnetism-Like Mechanism Combined with Genetic Algorithm

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***Abstract*—This paper dealt with fault location for distribution networks based on Electromagnetism-like Mechanism Algorithm. Considering that the fault location based on EM is actually constraint optimization with 0-1 discrete constraint often falling into the local optimum, an improved EM algorithm is proposed by combining EM with genetic algorithm. Furthermore, it is employed to perform fault location for distribution networks with multiple power sources. The distribution network is divided into several parts with the positive direction and the mathematical model for fault location is built. The simulation results show that the proposed approach has satisfactory accuracy and availability.**

***Index Terms*—distribution network, fault location, electromagnetism-like mechanism algorithm, genetic algorithm**

I. INTRODUCTION

The improvement of the quality of electricity distribution is actually a subject of increasing interest. Fast and accurate fault location for distribution networks is essential to improve the quality of supply, which is one basic requirement of modern society. However, the traditional practice of manual switching and circumambulating consumes a lot of time. After working hard for several years, many grounding line selection protections and fault location approaches are developed [1]-[13]. But up to now, the accuracy of fault location is unsatisfactory. Thus, to search for an effective fault location method for the distribution system in order to locate the actual feeder faults becomes more and more important.

At present, some mathematics approaches are applied to fault sector location in distribution networks since some measurement equipments such as FTU (feeder terminal units), RTU (remote terminal units) were set so that the fault signals are easier to be obtained for fault location. By using the 0-1 information, some indirect algorithms can turn the problem of fault location into a optimization problem. In reference [9] by using the Genetic Algorithm and a new mathematical model, the fault setor could be located. Reference [10] presented the application of improved ant colony algorithm in fault location for a distribution network with multiple power sources. Some other indirect algorithms are also used like the particle group algorithm [11], [12] and ect. All of these algorithms have the superiority of fault tolerance when some received information change, but they all need a large population and more iterative times and have a unsatisfactory accuracy.

As a new global optimization algorithm, Electromagnetism-like Mechanism Algorithm (EM) overcomes many shortcomings so that it's more efficient and easy to be realized [13]. But it's apt to fall into local optimum in local search. In order to improve the situation, a crossover operator in genetic algorithm (GA) is introduced and combined with and EM. On the other hand, the distribution network is divided into several parts according to the circuit breakers and contact switches and the positive direction is set in every part. The rapid fault location can be realized for distribution networks with multiple power sources.

This paper is arranged as follows: Section I describes EM algorithm and its improvement as well as basic steps

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of EM algorithm based on the crossover operator. Section II presents fault location principle and the application of the proposed algorithm. In Section IV, the simulation and comparison are represented, and the conclusion is drawn in Section V.

II. EM Algorithm and Its Improvement

A. EM Algorithm

EM algorithm was firstly proposed by Dr. Birbil in 2003 [14]. By imitating the attraction and repulsion mechanism among the electrically charged particles, the population particles will move toward the best direction and in the end the global optimal solution can be calculated out.

EM algorithm consists of four parts during its process: initialization, local search, calculation of total force vector and population movement.

Initialization: First several feasible solutions should be generated in the beginning, and the objective function value will be calculated through the fitness function, then the best solution and its objective function value will be stored.

Local search: mainly involving the update of every individual particle, usually taking use of the linear random search, it's important for the diversification of the population.

Calculation of total force vector: The total force describes the attraction and repulsion among the particles, it's the basis of generating new population. The charge is evaluated by:

$$q_{k,i} = \exp\left(-n \frac{f(X_{k,i}) - f(X_{k,j})}{\sum_{i=1}^{m} (f(X_{k,i}) - f(X_{k,best}))}\right) \tag{1}$$

$q_{k,i}$ represents the charge of number i particle in number k iteration. n is particle dimension, m is the total number of the particles. $f(\bullet)$ is the fitness function. $X_{k,i}$ is the number i particle in number k iteration. $X_{k,best}$ is the best particle in number k iteration. Vector force $F_{k,i}$ represents the vector force algebraic sum of particle $X_{k,i}$ with other particles.

$$F_{k,i} = \sum_{j \neq i}^{m} \begin{cases} \dfrac{q_i q_j (X_j - X_i)}{\left\| X_j - X_i \right\|^2}, & f(X_j) < f(X_i) \\ -\dfrac{q_i q_j (X_j - X_i)}{\left\| X_j - X_i \right\|^2}, & f(X_j) \geq f(X_i) \end{cases} \tag{2}$$

Population movement: According to the vector force of particle X_i bears, particle X_i will move toward the direction of the vector force by a random step length.

The movement formula can be described as follows:

$$Y_i = X_i + \lambda \frac{F_i}{\|F_i\|} \tag{3}$$

λ represents a random step length and its value varies from 0 to 1.

B. Improved EM Algorithm

EM algorithm will be easy to fall into a local optimum in a small neighborhood so that the Search results are not satisfying. In order to improve the situation, a crossover operator-reverse order in GA can be brought in to perfect the local search[15]. The reverse order can be explained in the following:

Generating two integers from 1 to n randomly, a_1 and a_2.

Sorting a_1 and a_2, make sure that $a_1 \leq a_2$.

For the particle X, reverse the position from $X(a_1)$ to $X(a_2)$ .if the objective function value gets smaller, updating X.

The basic step of EM algorithm combined with genetic search for fault location:

1) Generating the initial population and normalized.

2) Find out the best particle X_{best} and its objective function value $f(X_{best})$.

3) Local search for initial population and find the best fitness value $f(Y)$,if $f(Y) < f(X_{best})$,updating X.

4) If the local search arrives at the maximal iteration, go to step 5), else step 3);

5) If the X updates, go to step 8), else go to step 6).

6) Bringing in the crossover operator to update the population.

7) Calculating the fitness function value and find out the best particle.

8) Calculating the total force vector.

9) If arriving at the maximal iteration set of the algorithm, go to step 10), else go to step 3).

10) Algorithm ends. Output the best individual and its objective function value.

III. Fault Location Principle

A. Definition of Switch Function and Fitness Function

The switch function can reflect the relationship between the equipment information and the information received from the FTU. A typical simplified distribution network will be shown in Fig. 1.

The mathematical model for this switch function can be described as follows:

$$\begin{aligned} I_{S1}(X) &= X(1) \vee X(2) \vee X(3) \vee X(4) \vee X(5) \vee X(6) \vee X(7) \\ I_{S2}(X) &= X(2) \vee X(3) \vee X(4) \vee X(5) \vee X(6) \vee X(7) \\ &\ldots \end{aligned} \tag{4}$$

$I_{S1}(X)$ — $I_{S7}(X)$ is the function of switch equipment, value 1 means fault current flowing past, 0 means the opposite. $X(1)$ — $X(7)$ reflect the status signal, value 1 also means fault current flowing past, 0 means the opposite. $\vee$ represents logic "or".

Fitness function can represent the approximate relations between switch function and over-current signal of I_{Si} [9]. It can be described as follows:

$$f(X)=\sum_{i=1}^{n}\left|I_i-I_{si}\right|+w\sum_{k=1}^{m}\left|X(k)\right| \tag{5}$$

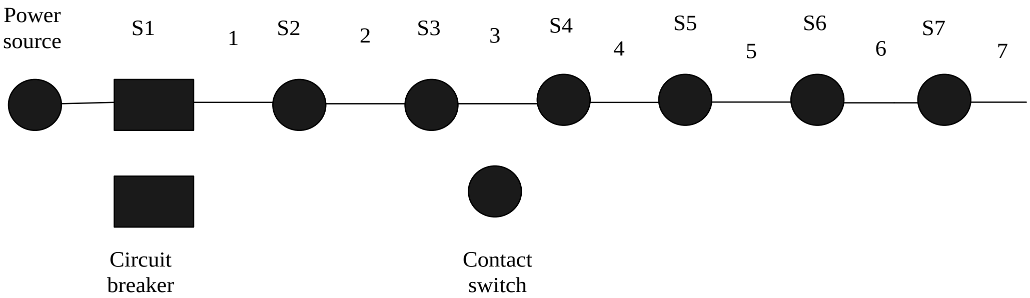

Figure. 1. Typical simplified distribution network

$f(\bullet)$ is the fitness function value, n is the number of switch equipments. m is the number of intervals. I_i is the expectation value of every switch equipment. I_{si} is the practical value of every switch equipment. $X(k)$ is the interval value. w is the weight coefficient, value 0.8[9].

B. Fault Location Strategies

As the scale of distribution network becomes larger and larger, difficult to locate fault area. The module partition is needed to divide the distribution network into several parts .when fault happens, only the part in which the circuit breaker acts needs fault location. After the fault happens, fault currents in different paths will have different directions, as the reverse fault current only exists in the path whose reference direction is from the non-reference power to reference power, a reference direction is needed in every small part, according to which the switch function could be fixed ,then three kinds of status value emerge,0,-1,1.value 0 represents that no fault current flows past ,value 1 represents positive fault current flows past, value -1 represents reverse fault current flows past.

The typical multiple power system distribution network can be seen in the Fig. 2. SA-SD are fourpower, S1, S12, S18, S24 are four circuit breakers.SL1, SL2, SL3 are three contact switches, and the rest are 24 section switches.

The distribution network can be divided into two parts according to the circuit breaker and the contact switch. The first one comprises SA, SB, S1-S14, S19-S22, and the direction from SA to SB is set as the positive direction in this part. As the S7-s12 is powered by SB, in switch function the value of S7-S12 should be the opposite. The rest of the distribution network can be the second part, if the positive direction is set from SC to SD, the value of S23, S24 in the switch function also should be the opposite.

So the improved fitness function model is as follows:

$$f(X)=\sum_{i=1}^{n}K_i f_i(X)$$

$$f_1(X)=\sum_{i=1}^{14}\left|I_i-I_{Si}\right|+\sum_{i=19}^{22}\left|I_i-I_{si}\right|+w\left(\sum_{i=1}^{14}\left|X(k)\right|+\sum_{i=19}^{22}\left|X(k)\right|\right)$$

$$f_2(X)=\sum_{i=15}^{18}\left|I_i-I_{Si}\right|+\sum_{i=23}^{24}\left|I_i-I_{si}\right|+w\left(\sum_{i=15}^{18}\left|X(k)\right|+\sum_{i=23}^{24}\left|X(k)\right|\right) \tag{6}$$

K_i represents the weights, when circuit breaker acts, the value is 1,else 0. n is the number of modules.

IV. An Example for Fault Location in a Distribytion Network

In this paper, with the model built in Fig. 2, the fault location in distribution network by using the algorithm put forward can be achieved. The simulation will be done in the software matlab 7.0.

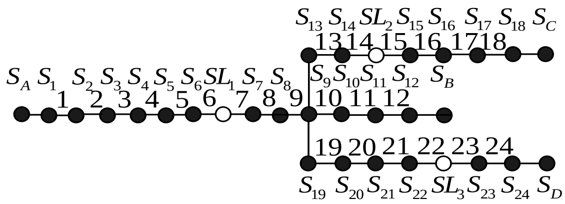

Figure. 2. Typical distribution network

Parameters for the algorithm is set as follows:

Initial Population:5; IterationTimes:10; Termination Criteria: Maximal generations for unchanged fitness value.

The simulation results will be shown in the Table. I, and comparison between the standard EM algorithm and the proposed improved algorithm(GEM) in this paper will be presented in Table. II.

In Table. I the '1' of the input vector means positive direction fault current flowing past, 0means no fault current flowing past,-1 means reverse direction fault current flowing past. Fitness Function Value means the value corresponding to the best solution. The fault area set could be found out through the GEM algorithm and the mathematical model, proves that the GEM algorithm could be applied in the fault location of distribution network. In the meantime, when some distortions occur, the fault section could also be located precisely. In Table. II, compared with the standard EM algorithm ,the population and the iteration of GEM algorithm are much less than the standard EM algorithm, the accuracy rate could reach 94.67%,represents that the GEM algorithm has an advantage in fault tolerance and accuracy.

TABLE I. SIMULATION RESULTS

Fault Serial Number	Input Vector	Distortion Or Not	Fault Section	Fitness Function Value
1	[111110000000000000000000]	No	Section5	0.8
2	[111110000000000100000000]	S16	Section 5	1.8
3	[111110-1-1-1-1-1-1000000000000]	No	Section 5and 7	1.6
4	[111110-1-1-1-1-1 1000000000000]	S12	Section 5and 7	3.6
5	[11111000-1-1-1-11000000000-1-1]	No	Section3,13,23	2.4
6	[11111000-1-1-1-11000000100-1-1]	S20	Section3,13,23	3.4

TABLE II. COMPARISON BETWEEN STANDARD EM ALGORITHM AND GEM

Fault Serial Number	Simulation	Population		Iteration		Run Times		Correct Times	
		EM	GEM	EM	GEM	EM	GEM	EM	GEM
1	1	5	5	10	10	20	20	18	20
	2	10	5	15	10	20	20	19	20
2	1	5	5	10	10	30	30	26	30
	2	10	5	15	10	30	30	28	30
3	1	5	5	10	10	20	20	17	19
	2	10	5	15	10	20	20	18	20
4	1	5	5	10	10	30	30	26	30
	2	10	5	15	10	30	30	28	29
5	1	5	5	10	10	20	20	16	18
	2	10	5	15	10	20	20	17	18
6	1	5	5	10	10	30	30	27	30
	2	10	5	15	10	30	30	29	30

V. CONCLUSION

In this paper, EM algorithm is applied to fault location in distribution networks. Considering the algorithm is apt to fall into a local optimum in the process, an improved EM algorithm is proposed by bring in a crossover operator of GA and employed to perform fault location for distribution networks with multiple power sources. The simulation results show that the fault location based on the proposed improved EM algorithm is more effective and accurate compared with the EM algorithm.

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