Application of Bacterial Foraging Algorithm for Fault Location in Distribution Networks with DG

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Abstract—For the difficulty of traditional fault location method brought by DG, an improved bacterial foraging algorithm is applied to fault location in distribution networks with DG. This method abandoned the construction of complex switching functions in the original intelligent bionic method. The relationship between the switch and the line is hided in the network relationship matrix, and the impact brought by DG is hided in the DG matrix. The mathematical model is improved so that it can be better adapt to multi-DG, multi-fault case. Even when the information is distorted, this method still has the ability of fault tolerance. Simulation examples demonstrate the feasibility of this program.

Index Terms—bacterial foraging algorithm; distribution network; DG; fault location

I. I NTRODUCTION

Distribution network fault is divided into short-circuit fault and small current grounding fault. The fault current is small when small current grounding fault occurs, so it is allowed to run 1~2h. But when short-circuit fault occurs, the fault current is much bigger which damages the distribution network a lot. So whether it can fault location and restore power supply timely is an important indicator of strong smart grid. Especially when a large number of DGs input, the network structure and operation mode become more changeable, which put forward higher demand to traditional fault location method.

At present, a series of centralized fault location methods are proposed which includes matrix algorithm[1]-[3], neural network[4], rough set theory[5], Petri net[6], Bayesian algorithm[7] and so on. Although these algorithms have achieved certain results in the problem of fault location, it generally has the disadvantages of complex model and low positioning efficiency especially when DG access. Swarm intelligent bionic algorithm[8]-[11] has been widely used in electric power industry in recent years, this kind of algorithm is a global optimization algorithm which also has fault tolerance. Reference [8]-[9] can fault location successfully in simple distribution network, but when DG accesses it may make mistake. Reference [10] improved particle swarm optimization algorithm, reference [11] improved harmony algorithm, they both can fault location in distribution network with DG, but they are still unable to avoid the process of constructing complex switching function.

Short circuit fault location of distribution network is a typical NP problem. In this paper, the bacterial foraging algorithm (BFA) is applied to the fault location of distribution network. Compared with genetic algorithm, this algorithm has the advantages of fast searching speed, easy to jump out of local optimal solution and so on. Network relation matrix and DG matrix are introduced to construct mathematical model. The two matrices describe the topological relation between switch and switch and the relation between switch and DG. It can be obtained by the GIS system easily. Compared with the traditional bionic algorithm, it avoids the process of constructing complex switching function and the model is more self-adaptable.

II. BACTERIAL FORAGING ALGORITHM

BFA is a new algorithm proposed by K. M. Passino in 2002 based on group competition and cooperation mechanism expressed by E. coli when foraging[12]-[13]. This algorithm solves problem by three operators: Chemotaxis operator, Reproduction operator and Elimination-dispersal operator.

Chemotaxis operator is the core of BFA. There are two kinds of behavior of E. coli in the process of searching for food in the intestine, forward and flip. First E. coli move a *STEP* in a random direction, if the fitness value becomes better, then we reckon that this individual is closer to the food source and go on moving until it attain the maximum number of steps, or it will change its direction with an angle of $\varphi(j)$. Suppose $s_i(j, k, l)$ i denotes i-th bacterium at j-th chemotaxis, k-th reproductive and l-th elimination-dispersal step. *STEP* is the step size taken in the random direction. Then the bacterium movement may be represented by

$$s_i(j+1, k, l) = s_i(j, k, l) + STEP \cdot \varphi(j) \tag{1}$$

where *STEP* represents the distance when a bacterial move a step. $\varphi(j)$ is the rotational factor and it is given in (2).

$$\varphi(j) = \frac{s_i(j, k, l) - s_{rand}(j, k, l)}{\left\| s_i(j, k, l) - s_{rand}(j, k, l) \right\|} \tag{2}$$

Project supported: project supported by the national high technology research and development program(863Program)(2012AA050213).

As in (2), $s_{\mathrm{rand}}(j, k, l)$ is a random position near $s_i(j, k, l)$.

Reproduction operator follows the law of survival of the fittest. When the chemokines operator finished, S/2 individuals with poor adaptability died and the left S/2 individuals replicate themselves to maintain population size. The fine genes of the parent will be inherited by the offspring due to the reproduction operator and the searching speed can be greatly accelerated.

Elimination-dispersal operator is an important method to find the global optimal solution and avoid the local optimal solution. In the digestive tract of human body, we do not exclude the possibility that some E. coil suddenly dead due to disease or other reasons and some new E. coil happen to appear in another area. So the migration operator is defined as the process that an individual dies with a probability of *Pe*, and generates new individuals randomly in the solution space.

III. MATHEMATICAL MODEL

A. Parameter coding

In the fault location mode based on FTU, the fault information comes from the switch status monitored by FTU. Here gives two provisions: the switch monitored by FTU is seen as node; the area between the nodes is seen as independent line. Stipulating the positive direction is the direction where power flow to when the main power supply alone. So the node in the network has three states, -1,0,1. They represent that there are forward current, normal current or reverse current flow through this node respectively. The independent line also use 0-1 coding, 0 represents the line is normal, 1 represents the line is fault.

B. Network relationship matrix

The network relationship matrix describes the topological relations between switch and switch[3]. Its definition is as in (3).

$$\boldsymbol{A}_{ij} = \begin{cases} 1 & i = j \\ 1 & j \neq i \text{ and node } j \text{ located downstream of node } i \\ 0 & \text{else} \end{cases} \tag{3}$$

As in (3), $\boldsymbol{A}_{ij}$=1(i=j) means node i is observable. Any row vector reflects the relationship between node i and all the nodes which are downstream of node i. It means if node j is located downstream of node i then $\boldsymbol{A}_{ij}$=1, else $\boldsymbol{A}_{ij}$=0.

Fig.1 shows a simple distribution network with DG. *A* is power supply, *CB* represents outgoing breaker, *S* stands for isolating switch, *DG* is distributed power supply, subscript means node number and the ID number of each line is the same as its upstream node.

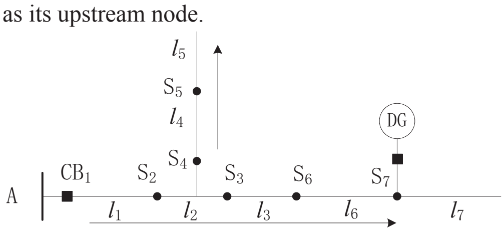

Fig.1 Simple distribution network with DG

The network relationship matrix of Fig.1 is as in (4).

$$\boldsymbol{A} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ & 1 & 1 & 1 & 1 & 1 & 1 \\ & & 1 & 0 & 0 & 1 & 1 \\ & & & 1 & 1 & 0 & 0 \\ & & & & 1 & 0 & 0 \\ & & & & & 1 & 1 \\ & & & & & & 1 \end{bmatrix} \tag{4}$$

Matrix $\boldsymbol{A}$ is a matrix of 7 × 7 order. Because all of the nodes can be observed by FTU, so $\boldsymbol{A}_{ii}$==1(i=1-7). Because node 2 to 7 are located downstream of node 1, so $\boldsymbol{A}_{1j}$=1(j=2-7); There is only node 5 locate downstream of node 4, so $\boldsymbol{A}_{45}$=1, and other elements of this line are set to 0. Compared with the network description matrix mentioned by [2], the network relationship matrix reflects not only the relationship between node i and the first node downstream of i but also the relationship between node i and all the nodes downstream of i. It contains more information and has a stronger global observability.

C. DG matrix

In radial distribution network, node status is only related to the lines which are downstream of this node. Any line downstream of this node is fault, this node will be alarm. But when DG is accessed to the network, the power flow in both directions, some node status can also be affected by the lines which are upstream of it. The DG matrix is used to describe this situation. There gives its definition in (5)-(6).

$$\boldsymbol{A}_{\mathrm{DG}} = \begin{bmatrix} \boldsymbol{A}_{\mathrm{DG}1} & \boldsymbol{A}_{\mathrm{DG}2} & \cdots & \boldsymbol{A}_{\mathrm{DG}n} \end{bmatrix}^{\mathrm{T}} \tag{5}$$

$$\boldsymbol{A}_{\mathrm{DG}i} = \boldsymbol{K}_i \overline{\boldsymbol{A}}_i (i = 1\text{-}n) \tag{6}$$

As in (5), $\boldsymbol{A}_{\mathrm{DG}i}$ is the row vector of $\boldsymbol{A}_{\mathrm{DG}}$. As in (6), $\overline{\boldsymbol{A}}$ is the inverse of $\boldsymbol{A}$, it means if the Boolean is 1, then turns to 0, if the Boolean is 0, then turns to 1. Matrix $\boldsymbol{K}$ is a matrix of n×1 order, it represents the location of node i and DG, if there is a DG located downstream of node i then $\boldsymbol{K}_i$=1(i=1-n), else $\boldsymbol{K}_i$=0. $\boldsymbol{A}_{\mathrm{DG}}$ is the result of matrix $\overline{\boldsymbol{A}}$ to do elementary transformation. The elements of row i in matrix $\boldsymbol{K}$ is multiplied by the elements of row i in matrix $\overline{\boldsymbol{A}}$ respectively. An important reason to restrict the traditional fault location method is the "plug and play" feature of DG. The switch function in traditional algorithm must be modified when any DG input or cut out of the system. In this paper, the change brings by DG is brought into the matrix. We just adjust the matrix $\boldsymbol{K}$ when DG input or cut out of the system can we express such change. Therefore, this algorithm is adaptive. In Fig.1, the DG matrix is shown in (7).

$$\boldsymbol{A}_{\mathrm{DG}} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{7}$$

If the matrix $\boldsymbol{A}$ describes the relationship between node i and its downstream nodes, then the matrix $\boldsymbol{A}_{\mathrm{DG}}$ describes the relationship between the nodes who affected by DG and their upstream nodes. For example, when DG inputs, the power in node 2 flow in both directions and node 1 located upstream of node 2, so $\boldsymbol{A}_{21}$=1. Node 5 and 6 are located on the branch line, the power is still one way flow, its status is not affected by DG, so the elements in row 5 and 6 are set to 0.

D. Evaluation function

When a fault occurs, the fault current is detected by FTU, and the alarm signal will be reported to the main station in the form of -1, 0, 1. Fault location software in main station will find such a line, when this line fault, the theory node information have the smallest difference with the actual fault information submitted by FTU. Evaluation function shall describe the size of this difference.

$$f_{min} = \mathrm{sum}\left|\mathrm{sgn}\boldsymbol{C}\boldsymbol{A}^T - \mathrm{sgn}\boldsymbol{C}\boldsymbol{A}_{\mathrm{DG}}^{\mathrm{T}} - \boldsymbol{B}\right| + \omega\mathrm{sum}\boldsymbol{C} \qquad (8)$$

As in (8), $\boldsymbol{A}^{\mathrm{T}}$ is the transpose of $\boldsymbol{A}$. $\boldsymbol{B}$ is the fault information matrix reported by FTU. $\boldsymbol{C}$ is the suspicious solution of the fault section. $\boldsymbol{C}$ also represents the location of individual bacterial s_i in the bacterial foraging algorithm. $\mathrm{sgn}\boldsymbol{C}\boldsymbol{A}^T - \mathrm{sgn}\boldsymbol{C}\boldsymbol{A}_{\mathrm{DG}}^{\mathrm{T}}$ is a matrix of $1\times n$ order, it represents the theory fault information when the fault line condition matrix is $\boldsymbol{C}$. So as in (8) we can see that the first polynomials represents the difference between the theory fault information cause by matrix $\boldsymbol{C}$ and the practical fault information matrix $\boldsymbol{B}$. If the difference is smaller, it means the $\boldsymbol{C}$ is better. In order to avoid wrong judgment, an additional item $\omega\mathrm{sum}\boldsymbol{C}$ is introduced. ω is the weight coefficient whose rang is (0,1). Specific theoretical analysis can be seen in [8].

IV. SIMULATION EXAMPLE

As is shown in Fig.2, the complex distribution network with DG is simulated. A is the main power supply. DG represents three distributed power supply. There are 33 nodes totally. The ID numbers of each node and line are shown in the figure. According to the method proposed in this paper, it is programmed by MATLAB. The parameters are set as follows, population size S=10, number of chemokines operator N_c=5, maximum number of moving steps of chemokines operator N_a=3, number of reproduction operator N_{re}=3, number of migration operator N_{ed}=1, migration probability P_e=0.1.

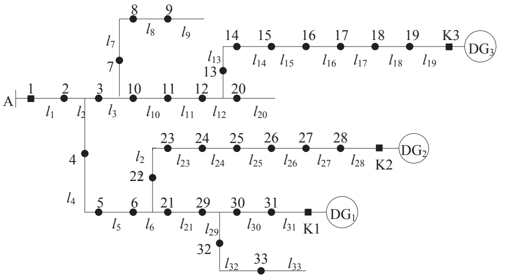

Fig.2 Complex distribution network with DG

A. Fault location of distribution network with single fault and multiple faults

In order to verify the validity of this method, single fault and multiple faults in complex distribution networks are simulated. Supposing three DGs are all put into operation, so the matrix $\boldsymbol{K}$ can be determined $\boldsymbol{K}$=[111111000111111111101111111111100]. Assuming that a single fault occurred at l_{12}, multiple faults occurred at l_{12}, l_{28}, l_{33}, the simulation results are shown in table.I.

Table.I Simulation results of single fault and multiple faults

Fault point	$\boldsymbol{B}$	optimal solution	diagnostic result
f_{12}	[111-1-1-1000111-1-1-1 -1-1-1-10-1-1-1-1-1-1-1 -1-1-1-100]	[000000000001 0000000000000 00000000]	l_{12} fault
f_{12} f_{28} f_{33}	[111111000111-1-1-1-1- 1-1-10111111111-1-111]	[000000000001 0000000000000 00100001]	l_{12} l_{28} l_{33} fault

In table.I, f_{12} means fault occurs on line 12, $\boldsymbol{B}$ represents fault information matrix submitted by FTU when fault occurs. The optimal solution is the result of the BFA, we can see that the 12th element is 1, so algorithm identified line 12 failure and the diagnostic result is right. l_{12}, l_{28}, l_{33} means faults occur on line 12,28,33. Because the 12th, 28th, 33th element in optimal solution is 1, so it identified line 12,28,33 failure and the diagnostic result is right.

B. Fault location under the condition of information distorted

Since FTU is mostly installed outdoors, the fault information it submitted may be distorted or missing owing to the natural environment or electromagnetic interference. This kind of situation is simulated to verify the fault tolerance of the algorithm. The simulation results are shown in table.II.

Table.II Simulation results with the information distorted

Fault point	$\boldsymbol{B}$	optimal solution	diagnostic result
f_{12}	[111-1-1-1000111-1-1-1 1-1-1-10-1-1-1-1-1-1-1- 1-1-1-100]	[00000000000100 000000000000000 0000]	l_{12} fault S_{16} false alarm
f_{12} f_{28} f_{33}	[111110000111-1-10-1- 1-1-10111111111-1-111]	[00000000000100 000000000000010 0001]	l_{12} l_{28} l_{33} fault S_6S_{15} false alarm

From the table.II we can see that supposing the fault line is the same with the line in table.I. The algorithm can also make the right decision when the fault information is distorted. For example when the information of node 16 distorted to 1, or the node 6,15 distorted to 0, the optimum solution is always the same with the table.I. It means though the node information is distorted, the algorithm also have a good fault tolerance.

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