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Optimal Configuration of Fault Indicator Based on Bacterial Foraging Algorithm in Distribution Network

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Abstract. Fault indicator (FI) plays a crucial rule in enhancing service reliability in distribution network. This device is helpful to quickly find the fault location. To realize the economic configuration of fault indicator, this paper proposes an objective function with the consideration of equipment investment costs, operation maintenance costs and interruption costs. This paper takes use of the bacterial foraging algorithm (BFA) to solve the objective function and analyzes the fault indicator configuration of a small-scale network and makes algorithm simulation. In view of the BFA existed in solving discrete domain by defining the evolution domain to determine the direction of bacteria to promote chemo taxis solution, which can make it to solve 0~1 programming problem well. The simulation results prove the effectiveness and scientificity of the scheme.

1. Introduction

The fault outage time is becoming an important criterion for customer satisfaction. In order to quickly to find fault location, the fault indicator is more and more widely used in distribution network. FI is a representative intelligent device able to detect passage of fault current [1]. Allocating FIs to networks could restrict the faulted zone identified by supervisory control center, so the time needed to locate the fault would substantially decline [2]. This leads to improving restoration time and service reliability indices.

Many researches about FI are focusing on the fault criteria, acquire energy, communication and make some progress. There are many sophisticated products in market, but few researches are about the number and location of the FI. Historically, the number and location of FIs were determined by rule-of-thumb techniques and engineering judgments [3]. Those methods, however, are likely to result in uneconomical and inefficient outcomes, in that they hardly provide the optimum number and location of FIs. In this regard, some optimization methods have served to achieve the optimum solution. Genetic algorithm is used to achieve the optimum number and location for FIs in distribution networks. Genetic algorithm isn't the best algorithm because of random and degradation phenomena during the iterations[4].In[5],the authors examined the effectiveness of immune algorithm versus genetic algorithm and showed its superiority by considering vaccination. It need long time to derive consequences. In this paper, the bacterial foraging algorithm (BFA) is applied to the optimal configuration of fault indicator. Compared with genetic algorithm, this algorithm has the advantages of fast searching speed, easy to jump out of local optimal solution and so on.

2. Mathematical Model

2.1 Section Headings.

This section intends to develop a mathematical model to optimally place FIs in a distribution network. FIs deployment might considerably reduce service interruption costs. However, FIs relevant costs are the major barriers in deploying FIs in distribution network. In this regard, a FI deployment strategy is cost-effective if it results in the minimum system cost including FI deployment costs and service interruption costs. The objective of the developed model is minimizing total system cost as follows.

$$\text{Min } TC = C^{cap\&inst} + C^{main} + C^{int} \quad (1)$$

Where, $C^{cap\&inst}$ is designated as the capital and installation cost of FIs. C^{main} represents the operation and maintenance cost of FIs over the planning horizon. C^{int} is also related to the service interruption cost imposed on customers following likely failure events. The capital and maintenance cost of FIs can be calculated as follows.

$$C^{cap\&inst} = N \cdot C^{up} \cdot \frac{DR(1+DR)^{t_0}}{(1+DR)^{t_0}-1} \quad (2)$$

In (2) N is the number of FI, C^{up} is the unit price of FI include the cost of the purchase and installation, DR is annual discount rate, t_0 is the economic life of FI. The operation and maintenance cost of FIs can be calculated as follows:

$$C^{main} = C^{up} \cdot \mu + N \cdot C^{GPRS} \quad (3)$$

in (3) μ is the coefficient of unit price, $C^{GPRS}$is the annual cost of communication. The expected interruption cost can be calculated as follows:

$$C^{int} = \sum_1^n \{[load_i \cdot C'_{Li}(t) + \sum_{j\in Q} load_j \cdot C'_{Li}(t)]\varepsilon_i \cdot l_i\} \quad (4)$$

in(4) $load_i$ is the average load, ε_i is the failure rate(time/km/year), l_i is the length of distribution line i , $C'_{Li}(t)$ is the unit outage cost, it is related to time *t*, Q is the outage area because of distribution line *i*. From (4),we can know it vary from user properties and outage time. The outage time can be calculated as follows:

$$T = T^{seek} + T^{repair} = \frac{1}{V} \cdot \sum_{i=1}^n l_i \quad (5)$$

In (5) V is repair crews speed to patrol feeder sections for locating fault. $\sum_{i=1}^n l_i$ is the length of the patrol feeder.

3. The Application of The Bacterial Foraging Algorithm

3.1 Bacterial foraging algorithm

BFA is a new algorithm proposed by K. M. Passino in2002 based on group competition and cooperation mechanism expressed by E. coli when foraging [6]-[7]. This algorithm solves problem by three operators: Chemotaxis operator, Reproduction operator and Elimination-dispersal operator. Chemotaxis operator is the core part 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*-thchemotaxis, *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

$$S_i(j+1, k, l) = S_i(j, k, l) + STEP \cdot \varphi(j) \quad (6)$$

In (6) STEP represents the distance when a bacterial move a step. φ(j) is the rotational factor and it is given in (2)

$$\varphi(j) = \frac{S_i(j,k,l) - S_{rand}(j,k,l)}{||S_i(j,k,l) - S_{rand}(j,k,l)||} \quad (7)$$

in (6), $S_{rand}(j,k,l)$ is a random position near $S_{rand}(j,k,l)$.

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.

3.2 Parameter coding

In the species whose scale is S, each individual is represented by S=$(\theta_{1,}\theta_{2,}\cdots\theta_i\cdots\theta_n)$, the dimension n is the number of the candidate place for FI. Each dimension θ_i is represented by 0 or 1.0 means there is no FI in this poit.1means there is a FI in this point.

3.3 The definition of fitness

Fitness represent the bacteria's degree of excellence, which can be calculated as follows:

$$F=C_{max}-\min TC \quad (8)$$

in (8) C_{max} is big enough to make sure fitness is positive, minTC is objective function. F is bigger, the bacteria is fitter for the surroundings.

3.4 The improvement of bacterial foraging optimization algorithm

1) STEP is a moving distance of a bacteria. The location of a bacteria is $S_i=(\theta_{i1},\theta_{i2},\cdots,\theta_{in})$, after a movement The location become $S_j=(\theta_{j1},\theta_{j2},\cdots,\theta_{jn})$,the distance of this movement can be calculated as follows:

$$STEP=\sum_{\omega=1}^{n}(\theta_{i\omega}-\theta_{j\omega})^2 \quad (9)$$

According (9), in order to get the binary encoding programme outcomes , *X* dimensional can be turned over. For example if STEP equal to 2,θ_2,θ_3 can be turned over. STEP is faster, computational speed is higher. At the same time, calculation accuracy will be down.

2) The improvement of Chemotaxis operator

The direction of bacteria forward is determined by direction of forward .It is important for algorithm convergence and the quality of the solution. In (6) , $\varphi(j)$ is a continuous real. It doesn't apply to 0-1 Programming. It need to improve Chemotaxis operator. After a movement, the fitness should be calculated F_i is the fitness of S_i, $F_j$is the fitness of S_j, $S_j$is the new location. If $F_j > F_i$, it shows the changed dimension is in evolution universe. The next movement should based on this movement. If $F_j < F_i$, the next movement should choice other direction as chemotaxis direction.

4. Simulation Example

This section intends to demonstrate the effectiveness of the proposed model by applying it to a test distribution network. Hereunder, a brief introduction about the systems is followed by thorough examinations over the simulation results and sensitivity analyses.

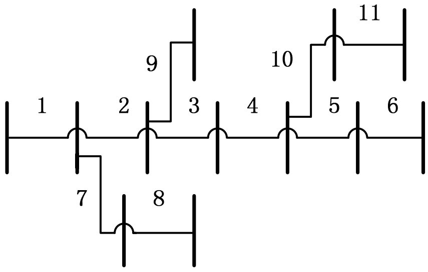

Fig. 1 Test distribution network

This test distribution network has 12 nodes, 11 lines. Further data such as components failure rate and load points average demand are given in [8]. The capital investment and installation cost of a FI is assumed to be US $1000, and its annual maintenance cost is considered to be 5% of the capital investment and installation cost. GPRS communication fee of a FI is assumed to be US $15/year. Repair crews speed to patrol feeder sections for locating fault is assumed 10 km/h in all feeders sections. Repairing time of a faulted section is presumed 4 hours. S (The number of bacteria in the population) is assumed to be 20. N_{ed}(the number of elimination-dispersion events) is assumed to be 2, N_{re}(the number of reproduction steps) is assumed to be 5.N_c(the number of chemo-tactic steps) is assumed to be 10.

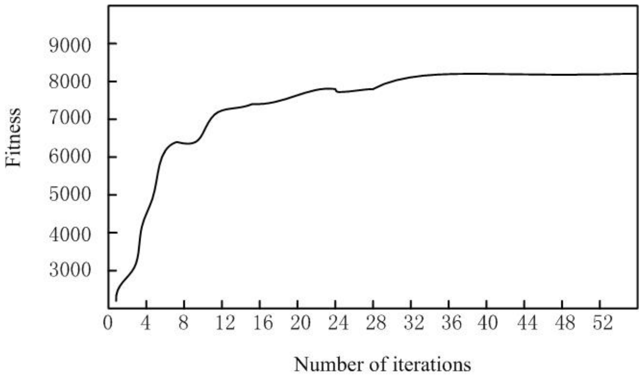

Fig. 2 The fitness value

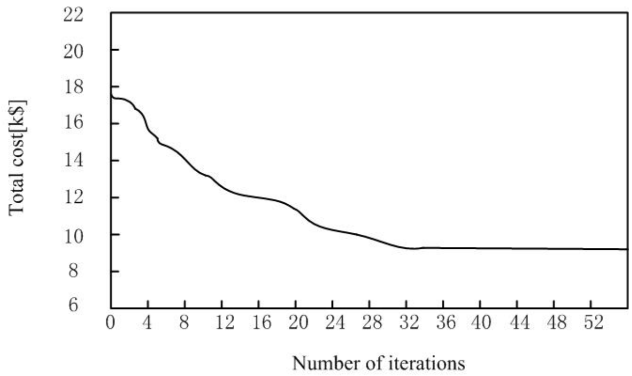

Fig. 3 Total cost of a year

Fig.2 shows the relationship between number of iterations and fitness. As we can seen, BFA need 35 iterations to get the biggest fitness. The speed of convergence is faster than immune algorithm in [8].

From Fig.3 we can seen that the total cost decline with the number of iteration increasing. At first the total cost of a year is 17646, it becomes 9274 after use BFA. The optimal placement of FI expressed in binary is 10111000110.From the result, we can see that the lines which are short with few loads are not installed FI.

5. Summary

This paper introduced a model to find the location and number of FIs in distribution systems. The model aims to minimize the total cost of interruption as well as capital investment, installation, and maintenance costs of FIs. And the application of the improved BFA to solve the optimal placement of FIs for distribution networks is presented. The results obtained through applying the model on a test system proved the effectiveness of the proposed model and the improved BFA. Finally, impacts of applying other fault location techniques related to wide-area monitoring and big data on optimal FI placement is a potential future research area.

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