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Fault Recovery of Distribution Network Based on Genetic Algorithm

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Abstract

Fault recovery of distribution network is realized by operating switches to change topological structure of the network. The final destination of fault recovery is power loss minimization, fault isolation and power load transfer. This article has built the mathematical model of fault recovery considering constraints of node voltage, line capacity and power flow balance. The objective function is power loss reduction. Further, the genetic algorithm is used to solve the proposed model. The optimal network structure and recovered power load could be derived through calculation. Finally, the author complied the program with Matlab and tested it on the IEEE33 bus system. The simulation and analysis results have verified the effectiveness of the proposed method.

Keywords: *distribution network, fault recovery, genetic algorithm*

1. Introduction

The fault recovery of distribution network aims at power service restoration of non-fault area based on fault location and isolation. After the fault is detected, the network reconfiguration function should transfer power load in fault area to healthy feeder lines. Simultaneously, the restrictions of power capacity and operation environment can't be breached. The final solution of network reconfiguration is a series of switch operations [1-4].

The distribution network fault recovery can be considered as a nonlinear combinational optimization problem with numerous constraints mathematically. Since the amount of optimization variable is very large, enumeration method shall have the combination explosion problem. The enormous size of solution space also means complicated calculation. There is no guarantee for convergence of the solution. Hence this article has applied the modified genetic algorithm in distribution network fault recovery. The experiment on IEEE33 bus system has verified the efficiency of the method. The fault area could be minimized while reducing power loss and stabling node voltage.

2. Mathematical Model

2.1. Objective Function

The distribution network structure in our country is very weak. The heavy power loss has been a serious problem that puzzles electric enterprises for long. Fault recovery is an important method of reducing power loss. It is not hard to understand that the goal of fault recovery model should be minimizing power loss.

$$\min \ f = \sum_{i=1}^{N_b} k_i R_i \frac{P_i^2 + Q_i^2}{U_i^2} \tag{1}$$

In the equation, f stands for system active power loss which can be calculated by power flow calculation. k_i stands for the state of switch i. Zero means the switch is open and one means it is closed. Ri stands for the resistance of branch i. P_i and Q_i stand for active and reactive power of the branch. U_i stands for the terminal node voltage of branch i.

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2.2. Objective Function

Constraint of power flow

The structure change along with network reconfiguration requires repeated power flow calculation. Constraint of line capacity

$$S_i \leq S_{max} \tag{2}$$

Constraint of node voltage

$$U_{imin} \leq U_i \leq U_{imax} \tag{3}$$

Constraint of radiant structure

The distribution network usually applies closed loop design and open loop operation, which means the network structure, must stay radiant. Closed loops are uncommon and forbidden.

In Equation (2) and (3), S_i and S_{max} are calculating value and maximum permissible value of power. U_i, U_{imax} and U_{imin} are the node voltage and its upper and lower limit value.

3. Basic Principles and Realization of Genetic Algorithm

In this section, it is explained the results of research and at the same time is given the comprehensive discussion. Results can be presented in figures, graphs, tables and others that make the reader understand easily [2, 5]. The discussion can be made in several sub-chapters.

3.1. Basic Principles of Genetic Algorithm

The genetic algorithm is an optimization method based on biological evolution and simulation of the propagation, survival of the fittest and reproduction process. Its basic principal resembles natural evolution. It only needs to evaluate chromosomes generated by calculation and select those with better qualities according to fitness value. Chromosomes with higher ability to adapt to the environment shall have better chances to survive and breed. In genetic algorithm, the solutions to objective function randomly emerge as digital codes, also known as chromosomes, which formed the initial population. The fitness function estimates every individual with a specific number. Individuals with low fitness would be eliminated. Others with high fitness are chosen to carry out further genetic operation. The chosen individuals would generate the new population, which shall proceed another round of evolution [5-8].

3.2. Realization of Genetic Algorithm

a) Basic process

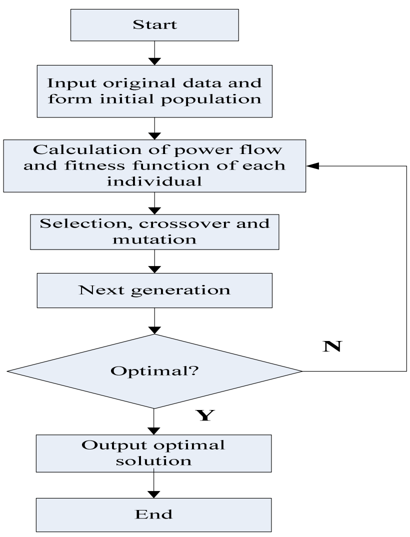

Figure 1. Flow Chart of Genetic Algorithm

The problem solving process of the genetic algorithm mainly includes following procedures. At first, the chromosomes shall be coded and randomly generating initial population. Secondly, fitness value of each individual in the population will be calculated. Thirdly, the genetic operations including selection, crossover and mutation will be acted on individuals to form the next generation. At last, quality of the population and iteration number should be tested to check if it meets the certain standard or exceeds the presupposed value. If negative then the third procedure should be repeated. Otherwise the best individual among current population will be the final resolution of the problem. The basic process is described in Figure 1 in detail.

b) Chromosome coding

In some literature, the binary coding is used to express the state of switch in distribution network. Zero means open and one means closed. Each switch occupies one position of the chromosome. One chromosome has been the combination of all branch states. The length of chromosome is up to the number of switches. This method is simple and neat. However, it has ignored the characteristics of distribution network and produced a large amount of infeasible solutions, which lowers efficiency of the algorithm.

Researches on structure of distribution network have revealed two principles which have to be obeyed for continuous power supply of all power load of the distribution power system. The first one is that switches that are not on any branch within a loop must be closed. The second one is that when minimization of power loss is the objective function, the switches connected with power sources should also be closed on the premise of network structure being normal. With these two principles the corresponding position on the chromosome could be erased. Thus the length of chromosome is shortened greatly.

c) Generation of initial population

The generation of initial population relies on random matrix. The value of elements in the matrix could only be zero or one. The operation status on different conditions can be expressed by the matrix. To keep radiant structure of the network, there can't be connection between any two power sources. Systems with possible connections between two power resources could be set aside. Then each chromosome of the initial population would be estimated. If the constraint of radiant structure couldn't be satisfied, then randomly pick one power source and open the switch.

d) Fitness function

The fitness function is directly concerned with convergence of genetic algorithm. Normally, the fitness function is the transformation of objective function. To build direct connection between fitness function and the survival chance of individual, the genetic algorithm has set the value of fitness as nonnegative. The higher value simply represents better qualities. But the objective function of real problems can't always be nonnegative. So there is need to build mapping relationship between fitness function and objective function to make sure the fitness value after mapping process is nonnegative and the optimization of objective function is based on increase of fitness value. The objective function of this article is power loss minimization. The mapping relationship between fitness function F(x) and objective function f(x) is expressed as following:

$$F(x) = \begin{cases} C_{\max} - f(x) & f(x) \le C_{\max} \\ 0 & f(x) > C_{\max} \end{cases} \tag{4}$$

In the equation C_{max} could be input or the theoretical maximum value.

e) Basic operations

The genetic operations include selection, crossover and mutation.

Selection is the process of choosing individuals with high adaptability from the population and forming crossness-pools. By this means the average fitness value of the population would rise. However there are not any new individuals generated. The best individual with highest fitness value also cannot be improved. During the selection process, the calculation results of objective function the population will be the estimation standard. Qualified individuals shall be kept, others abandoned.

The crossover operation is also called gene recombination. By this means two parent individuals could recombine and generate tow offspring individuals. The crossover phenomenon is not permanent but intermittent, which mean it is constrained by certain probability. After all, the function of crossover is to let offspring individuals inherit superior genes. The next generation shall be more complicated and advanced in genetic structure.

The mutation operation is the simulation of gene mutation happens on chromosomes of natural creatures. The mutation happens randomly in the population. At first the number of individuals that are going to mutate should be calculated according to the mutation probability. Then which individuals are to mutate how the mutation process is carried out would be decided by chance. The mutation operation could recover the allelic gene information lost in the evolution process and maintain the diversity of the population. Besides, it also improves the local searching efficiency of genetic algorithm.

4. Case Study

The author has taken the IEEE33 bus system as an example. The network structure is shown is Figure 2. The rated voltage of the system is 12.66kV. The system contains two substations, five loop switches, thirty-seven branches, thirty-three nodes. The total active and reactive power load would be 3715kW and 2300kvar.

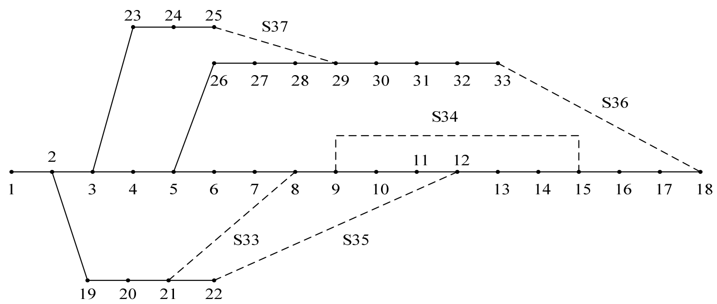

Figure 2. Network Structure of IEEE33 Bus System

In the testing system, symbols S33-S37 represent five loop switches. Switches S1-2 are not within any loop nor coded. The length of chromosome is 36 bits. The number of individuals in the initial population is 50. The crossover probability is 0.6. The mutation probability is 0.05. The optimization results of compiled program using Matlab7.0 are shown in Table 1.

Table 1. Fault Recovery Results of IEEE33 Bus System

	Switch opened	Power loss/kW	Minimum node voltage/p.u.
Before fault recovery	S33, S34, S35, S36, S37	200.122	0.888
After fault recovery	S7-8, S9-10, S14-15, S37	138.688	0.945

The voltage of nodes before and after fault recovery has been compared and shown in Figure 3. Before the fault recovery process the minimum node voltage of the system is 0.888. After fault recovery the number rises to 0.945. The obvious increase in node voltage has made the node voltage curve more gentle inclined, which means the objective function based on power loss is effective in fault recovery of distribution network. The electric power quality is improved while satisfying constraints of power load distribution.

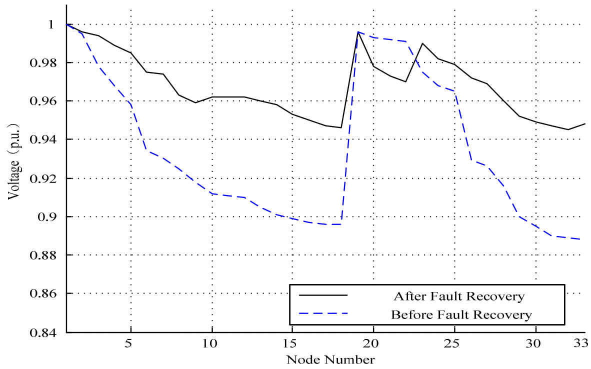

Figure 3. Node Voltage Before and After Fault Recovery

5. Conclusion

The real-time property is the important part of fault recovery of distribution network. Traditional exhaustion search algorithm might meet the combination explosion problem, which makes the method complicated and ineffective. This article has proposed a modified algorithm based on the genetic algorithm and applied it in distribution network fault recovery. The objective function is aiming at minimizing system power loss. The chromosome coding method is also modified. Finally, the effectiveness of the proposed algorithm is verified through simulation experiment on IEEE33 bus system. The results have shown the algorithm could realize fault recovery very quickly and improve electric power quality.

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