Multi-Objective Optimization and Reconstruction of Distribution Network based on NSGA-II algorithm Using C++ and MATLAB

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Abstract

The distribution system is "closed-loop design, open-loop operation". In order to improve the security and economy of distribution network operation, this paper designs a multi-objective network reconstruction optimization algorithm based on fast non-dominated sorting genetic algorithm (NSGA-II), which takes maximizing the minimum voltage, minimizing network loss and minimizing switching actions times as the objective functions. With the breadth-first search algorithm, the node order is calculated to be applied into the Forward and Backward Substitution method, and through analyzing the graph, a much easier chromosome coding method is obtained. Also, the problem of premature maturity of the population is analyzed. The algorithm is applied to the IEEE33 node case, and the reconstruction results verify the fastness and effectiveness of both this algorithm. Finally, the MATLAB codes and the C++ codes are compared. In order to make the program more friendly and convenient for others to use, use MATLAB GUI to design a human-computer interaction interface.

Keywords

NSGA-II, Distribution network , Reconstruction , Breadth-First Search , Forward and Backward Substitution method , premature maturity, MATLAB GUI.

1. Introduction

In the distribution system, in order to carry out the necessary load transfer to improve system reliability and economy when accident or normal operation, the distribution system is "closed-loop design, open-loop operation". Sectionalizing Switches are installed on each branch of the Distribution Power System, which are normally closed; the Interconnection Switches are installed between the branches, which are normally open to ensure the radial operation of distribution network as well as the convenience of load transfer.

These Sectionalizing Switches and Interconn ection Switches has made the distribution network run in very flexible ways, where you can easily change the network structure to improve the security and economy. This paper examines the reconstruction of a normal network, which is, by changing the network structure to optimize the normal operation of the distribution network.

Distribution network reconfiguration is a nonlinear hybrid optimization problem, generally the following methods can be used: Optimal Flow Partern(OFP), Braneh Exehange Method(BEM), Simulated Annealing(SA), Genetie Algorithm (GA),etc. We adopt the NSGA-II algorithm because the objective functions, such as the minimum number of switching actions, the smallest of network loss, maximum the lowest voltage of the system and so on, might be contradictory, what’s more, this algorithm meets the topic of our course.

2. Model

2.1 Case Introduction

The following Figure 1 is the one-line diagram of the IEEE 33 bus system, which contains 33 nodes, 32 branches and 5 tie-lines, and the reference voltage takes 12.66KV, the reference power takes 10MW. Try to reconstruct the distribution network to make it optimal. see Fig. 1.

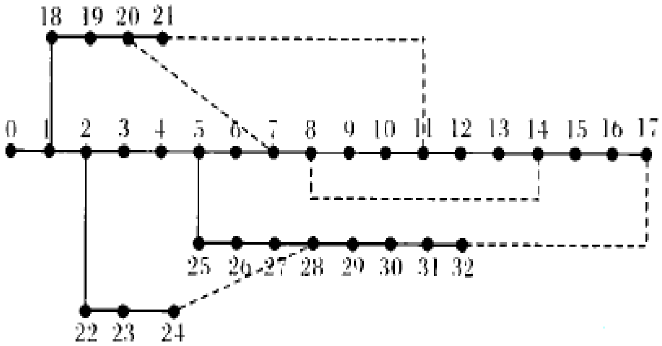

Fig 1. The one-line diagram of the IEEE 33 bus system

2.2 Objective Function

2.2.1 Maximizing the Network Minimum Voltage

First, maximizing the minimum voltage of the system is the first objective function which can improve the reliability and power supply quality of the system, and it is also benefit to the economic operation of the distribution network.

$$\text{Objective\_1}=\text{Max}\ (\text{Umin}) \tag{1}$$

2.2.2 Minimizing the Net Loss

In order to make the distribution network more economical, the net loss is minimized as the second objective function.

$$\text{Objective\_2}=\text{Min}\ (\text{sum\_ploss}) \tag{2}$$

2.2.3 The Least Number of Switch Actions

The number of switching operation times in the process of network reconstruction should be minimized, in order to prolong the life of the switches and reduce the loss of the net, The number of switching operation times in this paper is calculated by XOR operation between the original switch state matrix and post-action switch state matrix.

$$\text{Objective\_3}=\text{Min}\ (\text{num\_operate}) \tag{3}$$

Considering that the NSGA-II algorithm programs defaults to calculate the minimum value, so the multi-objection function is:

$$\text{Min}\ F= [-\text{Umin},\ \text{sum\_ploss},\ \text{num\_operate}] \tag{4}$$

2.3 Restrictions

2.3.1 System without Loop --- Loop Check

The normal state of the distribution network is radial, only in the event of failure or load transfer, it will form a loop, which will lead to a circular current to threat the operation of the grid, so the loop check is necessary.

In this study, there are 32 Sectionalizing Switches and five Interconnection Switches. If the Interconnection Switches are all closed, it will form five independent rings. Disconnecting one Sectionalizing Switch on each loop ensures that no loops exist in the network, but these five disconnected Sectionalizing Switches must be different from each other, also the Electrical Island may occur after disconnection Sectionalizing Switches, which needs to perform the following island-check.

2.3.2 System without Island --- Island Check

After the loop-check, it may lead to the Electrical Island because it randomly disconnects the system Sectionalizing Switches. The presence of power supply islands has led to a loss in user load, unless under accident state to cut the load. How to check the island, when it comes to C ++ and MATLAB, there are two different options:

(1) Matlab:

With rich library functions as support, MATLAB is expert in the matrix operation, so we can directly use the network adjacency matrix A to judge. The (i, j) element of the adjacency matrix is defined as whether the i-th node and the j-th node are connected in the system. Since the graph in this example is an undirected graph, the adjacency matrix must be a symmetric matrix. After obtaining the adjacency matrix, if the dimension of the adjacency matrix is N, define S=A+A^2+A^3 +……+A^(N-1). If there is no zero elements in the upper triangular matrix of the S matrix, the system is Unicom and there is no island.

(2) C++:

C++ is relatively poor in the matrix operation, so the program does not adopt the above ideas, but use the sorting results of branches in 'Forward and Backward Substitution method' to judge. In the process of network refactoring, the branch power flow reversal often occurs, therefore, the number of the branches in the system must be readjusted with the network structure. In this study, the 'Breadth-First Search algorithm' is used to search from the source point. The positive sequence of the search results is used to calculate backward to get the voltage, and the reverse order is used to calculate forward to get the current. However, note that there is no number for Electrical Islands in the sorting process, so the sorted array of branches can be initialized to -1, and if -1 exists in the sorting results, there is an Electrical Islands in the case.

3. Case Study

3.1 Encoding and Decoding

The chromosomes are encoded in real numbers, and each chromosome is represented by a real matrix. Each of the row of the matrix is a gene that represents a unit reconstruction scheme.

The first V bits of the gene is a random real number within 0-1, where the odd number represents the line state, and if the real number is greater than the threshold Percen_Connect, the corresponding contact line will be disconnected; the even bit represents the Sectionalizing Switches on five loops If the loop i has N Sectionalizing Switches, the code multiplied by N is rounded to get the Sectionalizing Switches number to be disconnected on the loop. Here is necessary to form a loop- Sectionalizing Switches matrix and this even bit is only consider when the tie line is closed to reduce the amount of computation.

The coding plan abandoned the general way of 0-1 numbering for all branches (off=1, closed=0), but considering the restrictions of distribution network which cannot exist loop, the number of bits were reduced from 37 to 10 (5 pairs), greatly reducing the amount of computation, speeding up the NSGA-II algorithm.

3.2 Randomly Generate the Initial Population

The NSGA-II algorithm is an evolutionary algorithm, by randomly generating the initial population, the Hereditary and variation operation are used to select the elite individuals, and the cyclic operation gradually evolved the gene into the direction of the Pareto optimal solution. So the size of the initial population may be appropriate to be large, this case takes 100; The V bit of the gene corresponds to the distribution network recon-struction plan, and the posterior M bits are the M objective function values corresponding to the reconstruction plan. And to meet the constraints, the gene also needs to be taken the loop-check and island-check, if not pass, regenerated the gene.

3.3 Algorithm Implementation

After the gene is decoded, five branch numbers (ie, number of Sectionalizing Switches or Inter-connection Switches) are obtained to break, forming a new radial distribution network.

In this case, the Forward and Backward Sub-stitution method is applied to the distribution network. Through the calculation of the current flow, the minimum voltage (Umin) corresponding to the gene can be obtained, which is the first objective function. With the obtained branch current and the node voltage, the second objective function, network loss(Sum_Ploss), can be obtained by using the line parameters. The third objective function is the number of switching operation action, which is calculated by XOR operation between the original switch state matrix and post-action switch state matrix.

3.4 Fast non-Dominated Sorting

The fundamental purpose of the multi-objective optimization algorithm is to obtain the Pareto optimal solution set. For the NSGA-II algorithm, in order to obtain Non-Dominated Order, it is nece-ssary to stratify the population according to the non-inferior level before selecting operation, that is, the non-dominating layer, and all individuals are arranged in ascending order. For each layer of non-dominated, the larger individual crowded distance is, the more uniform the distribution of the solution, so the same layer of individuals in arranged with the individual crowding distance in descending order.

Each gene will increase the last two columns, representing the non-dominating order (i_rank) of the individual and its individual crowding distance (i_distance) at the non-dominated layer. Sorting was in accordance with the last two columns, and the higher priority means the smaller non-dominating order and greater individual crowded distance, which will own more opportunities to be reserved in the selection operation.

3.5 Selection, Crossover and Mutation

In this case, the selection operation does not directly choose the front chromosome, but use the binary tournament, that is, randomly selected two individuals i, j in the existing population. If i_rank <j_rank or meet the requirement that i_rank = j_rank and i_distance> j_distance, then i individual is better than j individual, i will be saved into the parent population.

The cross and mutation operation of the parent population can make the algorithm have good global and local search performance. In this case, the simulated binary crossover and the normal mutation operator are used. After cross and mutations, the parent population produces the offspring.

3.6 Elite Strategy

In order to preserve the first-rate genes, the NSGA-II algorithm proposes a scheme of elite strategies, that is, to keep the outstanding individuals in the parent directly into the offspring and to avoid the loss of the Pareto optimal solution.

4. Key Technologies

4.1 Node Hierarchical Number

In the process of network refactoring, the branch power flow reversal often occurs, therefore, the number of the branches in the system must be readjusted with the network structure. In this study, the ‘Breadth-First Search algorithm’ is used to search from the source point. The positive sequence of the search results is used to calculate backward to get the voltage, and the reverse order is used to calculate forward to get the current.

4.2 Inhibit Premature Maturation of the Population

In the process of programming, premature maturation is found, that is, the elite individual is too similar, leading to premature convergence of the parent population, which may end in the iteration of about 10 generations.

This problem arises because the global search performance of the program and the ability to jump out of the local optimal solution is poor, while these abilities are affected by the crossover rate, the mutation rate, and the initial population number. Only through the repeated experiments these three can achieve the best. In order to make the program's global search performance better, in general, we should increase the mutation rate, reduce the crossover rate, select the smaller number of parent population and larger initial population, etc.

In this case, after repeated experiments, the mutation rate is set to 1.0/(2.0+gen_i/5), where gen_i is the generation number; we choose (1/3) of the parent-and-son population into the new father generation, and, except preserving the best gene in the father generation, the front of the elite is not simply preserved, but use the Binary Tournament, randomly selected parent individuals.

5. Results

5.1 Calculating Results

Applying C++ and MATLAB respectively to deal with this case, the active power network loss of the system before reconstructing was 202.68KW, and the minimum voltage is at bus 17, with the voltage about 0.913; if we don’t take the minimum number of switching actions into account, after the reconstructed calculation, we break the branches: 7,9,14,32,36, then the new radial network power loss is only 139.55KW, the minimum voltage point is in the bus 31, the voltage is about 0.9378, and now the number of action switches is 6. If we take the minimum number of switching actions into account, there will be other plans as following Pareto optimal solution set, see Fig. 2.:

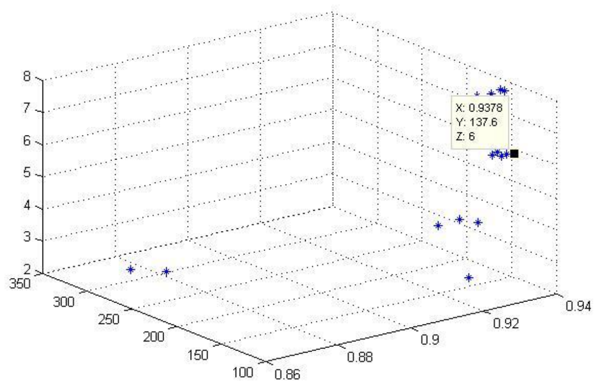

Fig 2. Pareto optimal solution set

5.2 GUI Interface Design

In order to make the program more friendly and convenient for others to use, use MATLAB GUI to design a human-computer interaction interface as shown in Fig.3.

The left side of the screen is an introduction to the case, including the figure and an table shown the line data. The right side is the calculation and output part, population (POP) and generation number (GEN) of NAGA-II algorithm can be edited by the form of text box to put into the MATLAB program, when there is a need to interaction data with the user, there will pop up a dialog. Only when the calculation has been completed, the "Draw" and "View Results" buttons will automatically be enabled (Enable Property: off) to be active (Enable Property: on). You can also view the calculated results in a three-dimensional diagram by clicking the "Draw" button. You can also view the solution.txt calculated by the NAGA-II algorithm directly by clicking the "View Results" button.

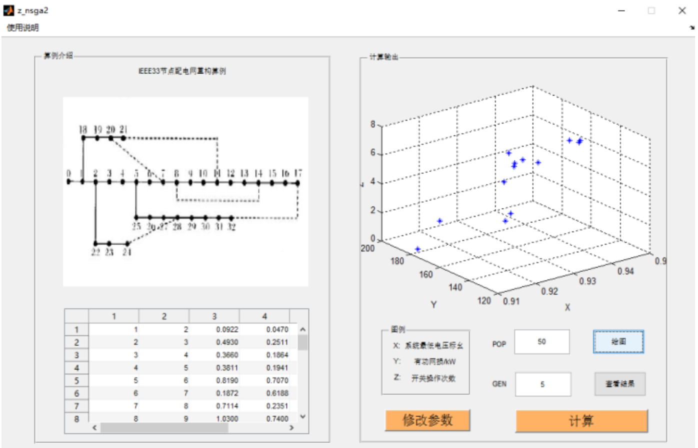

Fig 3. A human-computer interaction interface with MATLAB GUI

5.3 Comparison between MATLAB and C++

Table 1. Comparison between MATLAB and C++

Comparing items	C++	MATLAB	Comparing Results
Computing Results	139.55KW 0.9378U	139.55KW 0.9378U	Same
Computing Time	19.2s	7.37s	MATLAB is better
Programming Difficulty	difficult	Easy	MATLAB is easier
Code Length	1000 lines	About 800 lines	C++ code is longer

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