NETWORK RECONFIGURATION OF DISTRIBUTION SYSTEM USING FUZZY CONTROLLED EVOLUTIONARY PROGRAMMING

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Abstract

In this paper a new type of evolutionary search methodology is proposed for determining the minimum loss configuration of a radial distribution system. To improve the performance of evolutionary programming a fuzzy controlled evolutionary programming (FCEP) based on heuristic information has been proposed. The designed mutation fuzzy controller adaptively adjusts the mutation rate during the evolutionary process. In addition to it a chain-table and depth breadth search strategy is employed to further speed up the optimization process. The equality and inequality constraints are embedded into the fitness function by some penalty factors to guarantee the optimal solutions searched by the FCEP are feasible.

Index Terms: Network Reconfiguration, Fuzzy Logic, Evolutionary programming

1. INTRODUCTION

Recently, there has been a growing interest in optimizing the operation of distribution networks particularly in the area of distribution system automation. Distribution system reconfiguration (DSR) can be seen as a combinatorial optimization problem, comprising distribution system planning, loss minimization, and energy restoration. In order to deal with these problems, several evolution-based algorithms have been developed. Distribution systems are normally configured radially for effective co-ordination of their protective systems. Networks are reconfigured to reduce the system power loss (network reconfiguration for loss reduction), and to relieve overloads in the networks (network reconfiguration for load balancing). This operation transfers loads from one feeder to another, which will significantly improve the operating condition of the overall system. It is required to reconfigure the network from time to time, since distribution lines show different characteristics as each of the distribution feeders consists of residential, commercial, industrial, etc. type of load. In addition some parts of the distribution system become heavily loaded at certain time of the day and lightly loaded at other times. For load balancing, the loads are required to be rescheduled more efficiently by modifying the radial structure of the distribution feeders. There are many existing methods for determining feeder configuration. Network reconfiguration in distribution systems is realized by changing the status of sectionalizing switches and is usually done for loss reduction. The distribution reconfiguration belongs to a complex combinatorial optimization problem. This is because there are multiple constraints, which must not be violated while finding an optimal or near-optimal solution to the distribution network reconfiguration problem.

2. LITERATURE SURVEY

Distribution system reconfiguration for loss reduction was first propose by Merlin et al.[1]. They employed a blend of optimization and heuristics techniques in their method. Since then many techniques based on network reconfiguration have been proposed.[2]-[11]. All these methods are combinations of heuristics methods and mathematical optimization techniques. Shirmohammadi and Hong [14] modified the method [1] by including feeder voltage and current constraints.. Civanlar et al. [15] have made use solely of heuristics to determine a distribution system configuration, which reduces line losses. By proposing heuristic rules, Civanlar et al. have reduced the number of switching options. The disadvantage of their method are that (a) it is a time consuming process and (b) the final configuration is not independent of the initial configuration.

Huddleston et al. [16] have presented a reconfiguration algorithm based on the linearity constrained quadratic problem. Huddleston et al. have not been able to put forth a continuous representation of the reconfiguration problem.
where the voltage dependences of the loads were considered by exploiting the structure of the distribution network.

Wagner et al. [17] have suggested a reconfiguration algorithm based on the solution of a linear transportation problem.

Goswami and Basu [18] have shown that it is inappropriate to represent initially the distribution network as a meshed network and open the switches until a radial system is obtained. They have introduced an algorithm similar to that of Merlin and Back [19], differing in that the distribution network considered one tie switch at a time. In their method any switch closure is complemented by the opening of another switch to ensure a radial network. Baran and Wu [20] have attempted to overcome the limitations of the branch exchange operation by stating that more complex switching operations could be accounted for by a series of branch exchanges.

Researchers have also paid attention to the application of artificial intelligence (AI) techniques such as an artificial neural network (ANN), genetic algorithm (GA), and expert system (ES) in distribution system reconfiguration (1990,1993). The main disadvantage of artificial neural networks is that it requires a substantial amount of accurate data for training. The solution obtained by using a genetic algorithm is independent from the initial configuration, but computation is very slow. Expert system-based approaches are basically to the heuristic-based methods.

The results of a fuzzy distribution load flow study are not only the possibility distributions of substation current, node voltages, real and reactive power losses, but also to assess the robustness of the system performance and the degree of exposure to an uncertain future.

Most recently genetic algorithm have been proposed for distribution reconfiguration for loss reduction [12], [13]. However as discussed in the paper [12] cross over operation has the danger of generating Individuals which violate radiality constraints by swapping strings of two parent networks.

More over encoding and decoding used in [13] is very complicated and slows down the speed of the algorithm. Fuzzy set theory provides an excellent framework for integrating the mathematical and heuristic approaches into a more realistic formulation of the reconfiguration.

3. FORMULATION OF OPTIMIZATION MODEL

The network reconfiguration problem in a distribution system is to find a configuration with minimum loss while satisfying the operating constraints under a certain load pattern. The operating constraints can be voltage drop, current capacity, and radial operating structure of the system. The mathematical formulation for the minimization of power loss reconfiguration problems is

\[ \text{Min } f = \min(P_{TL}) \]  

Subject to the constraints

\[ V_{\text{min}} \leq |V_i| \leq V_{\text{max}} \]
\[ |I_i| \leq I_{\text{max}} \]
\[ |S_i| \leq |S_{\text{max}}| \]
\[ S_{i-1} = S_i + S_{i+1} \]

Where,

\[ P_{TL} \] the total real power loss of the system.
\[ V_{\text{max}} \] and \[ V_{\text{min}} \] bus maximum and minimum voltage limits respectively.
\[ I_{\text{max}} \] maximum current limit of branch i.
\[ S_i = P_i + jQ_i \] the power flow.

Consider the single line diagram shown in Fig.6.1.

The recursive equations (6.2) to (6.4) are used to compute the power flow.

\[ P_{i+1} = P_i - P_{Li+1} - R_{Li+1} \left( \frac{P_i^2 + Q_i^2}{|V_i|^2} \right) \]  

\[ Q_{i+1} = Q_i - Q_{Li+1} - X_{Li+1} \left( \frac{P_i^2 + Q_i^2}{|V_i|^2} \right) \]
\[ |V_{i+1}|^2 = |V_i|^2 - 2(R_{Li+1}P_i + X_{Li+1}Q_i) + \left( R_{Li+1}^2 + X_{Li+1}^2 \right) \left( \frac{P_i^2 + Q_i^2}{|V_i|^2} \right) \]

Here the distribution system has been assumed to be symmetrical system with constant loads. Where \[ Z_{Li+1} = R_{Li+1} + jX_{Li+1} \] and the load demand is \[ SL = PL + jQL \]. The real and reactive power flows at the receiving end of the branch i+1 is \[ P_{i+1}, Q_{i+1} \] respectively. The voltage magnitude at the receiving end is \[ |V_{i+1}| \]. At first the values of \[ P_0, Q_0 \] and \[ V_0 \] at the first node is estimated, then the same quantities at the other nodes can be calculated by applying the equations (6.2) 5o equation (6.4).
Similarly we can write,

\[ P_{i-1} = P_i + P_{li} + R_{i,i+1} \frac{(p_i^2 + q_i^2)}{|V_i|^2} \quad (6.5) \]

\[ Q_{i-1} = Q_i + Q_{li} + X_{i,i+1} \frac{(p_i^2 + q_i^2)}{|V_i|^2} \quad (6.6) \]

\[ |V_{i-1}|^2 = |V_i|^2 - 2(R_{i-1,i}P_i' + X_{i-1,i}Q_i') + (R_{i-1,i}^2 + X_{i-1,i}^2) \frac{(p_i^2 + q_i^2)}{|V_i|^2} \quad (6.7) \]

Where, \( P_i' = P_i + P_{li} \) and \( Q_i' = Q_i + Q_{li} \)

Applying equations (6.2) to (6.7) successively we get the power flow solution. The power loss of the line section connecting between buses \( i \) and \( i+1 \) is

\[ P_{\text{loss}}(i, i+1) = R_{i,i+1} \frac{(p_i^2 + q_i^2)}{|V_i|^2} \quad (6.8) \]

The total power loss of the feeder \( P_{TL} \) is the summation of the losses of all line sections of the feeder and is given by,

\[ P_{TL} = \sum_{i=0}^{n-1} P_{\text{loss}}(i, i+1) \quad (6.9) \]

4. IMPLEMENTATION OF FUZZY CONTROLLED EVOLUTIONARY PROGRAMMING

The steps for implementing fuzzy controlled evolutionary programming are as follows.

i) **Switching status description**

If the number of switches in a system is \( M \), then the length of the chromosome is \( M \). The status of the switches is represented by a binary number 0 or 1, where 0 indicates the switch is open and 1 indicates the switch is closed. Every chromosome represents one configuration of the distribution system.

ii) **Generation of initial population**

The initial populations are generated randomly. The length of a chromosome equals to the number of sectionalizing switches and ties in a distribution system. Thus, each chromosome string corresponds to an initial network. If the number of the closed switches in the original distribution network is \( K_i \), the number of 1 in the initial chromosome should be \( K_i \), and the root of one tree can never become a leaf of another tree.

iii) **New network formulation**

The data structure of a new network is described by branch nodes and branch status. If the bits in a chromosome are 1, their corresponding branches are added into a new network and the status of the branches are set to 1 otherwise the branch nodes and branch status are set to zero.

iv) **Searching for feeders**

After the status of sectionalizing switches has been changed, that is the bits in a chromosome have been changed, the new network is easy to be formulated in terms of the bits in a chromosome as stated but the membership of all load centre could be totally changed. Hence, we need to search for which feeder a given load centre belongs to. The blend searching technique is employed. In the first place the search begins with the root of a tree. After the branches linked to the root are searched their status will be set to zero and their end nodes will be automatically recorded and used again as a new starting point to search for the other branches and nodes until the searching space is traversed. After that we can further determine whether a load centre has been shed through checking the status of the branches. If the status of a branch is not zero, it shows that the branch has never been searched and a load shedding could occur. There the branch is needed to be added to a corresponding feeder. The reason for this is that when the searching is running into the problem of non consistence, the branch needs to swap its head and end. Of course the end node power sink must be simultaneously changed. To accelerate the searching process, chain-tables are used and all feeders can be searched in parallel at the same time. An example of a chain-table is shown in Fig.6.2.

![Chain-table example](image)

From Fig.6.2 it is obvious that each chain-table stands for one tree, and the power losses of the tree can be easily computed from leaves to root in terms of the chain-table.

v) **Fitness function**

An appropriate fitness function is essential to speed up the convergence of the FCEP. The fitness function should consider the function of equation (6.9) and the constraints of section 6.2.
The voltage constraint can be rewritten as
\[ \alpha_i = \left( \frac{V_{\text{max}}}{V_i} \right)^2 \]
and
\[ \alpha_i = \left( \frac{V_{\text{min}}}{V_i} \right)^2 \]
The capacity constraints can be written as
\[ \beta_i = \frac{P_i^2 + Q_i^2}{(S_i^\text{max})^2} \]
Where \( V_{\text{min}} \) is taken as 0.95 p.u. and \( V_{\text{max}} \) is taken as 1.05 p.u. \( S_i \) is the injected power at the root of the \( i^{\text{th}} \) feeder and \( S_i^\text{max} \) is its corresponding maximum capacity. Thus from equation (6.8) and equation (6.9) the fitness function becomes.
\[ F = \sum_{i=0}^{n-1} \alpha_i \beta_i R_{i,i+1} \frac{(P_i^2 + Q_i^2)}{|V_i|^2} \]  
(6.10)
vi) Fuzzy controlled mutation
The steps to design the mutation fuzzy controller are as follows.

a) Choose inputs and output for the mutation fuzzy logic controller. As a general rule, the changes in fitness \( \Delta f(t) \) and \( \Delta^2 f(t) \) are chosen as the inputs to the fuzzy controller and the change in mutation \( \Delta m(t) \) is chosen as the output. Where,
\[ \Delta f(t) = f(t) - f(t - 1) \]  
(6.11)
\[ \Delta^2 f(t) = \Delta f(t) - \Delta f(t - 1) \]  
(6.12)

b) Define the universe of discourse for \( \Delta f(t) \), \( \Delta^2 f(t) \) and \( \Delta m(t) \). The universe of discourse for \( \Delta f(t) \), \( \Delta^2 f(t) \) and \( \Delta m(t) \) are \([-1.0, 1.0] \), \([-0.5, 0.5] \) and \([-1.0, 1.0] \) respectively.

c) Select the type of membership function to be used and also its linguistic values. Here a triangular membership function has been selected for \( \Delta f(t) \), \( \Delta^2 f(t) \) and \( \Delta m(t) \). The nature of the function and its linguistic hedges of \( \Delta f(t) \), \( \Delta^2 f(t) \) and \( \Delta m(t) \) are shown in Fig.6.3, Fig.6.4 and Fig.6.5 respectively.

Where,
NL is negatively very large.
NR is negatively large.
NS is negatively small.
NM is negatively medium.
ZE is zero.
PL is positively very large.
PR is positively large.
PS is positively small.
PM is positively medium.
d) Frame the fuzzy rules. The inference rules are shown in Table.6.1
5. EXAMPLES

The proposed method was tested for 29–node (Fig.6.6), and 69–node (Fig.6.7) radial distribution system. In the Fig.6.6 and Fig.6.7, the dotted line indicates the position of tie switches. Initially in the normal configuration these tie switches are open.

The results are calculated at 12.66 base kV and 100 base MVA and with substation voltage of 1.00 (pu).

The parameters used in FCEP are as follows. Population size = 100, chromosome length =10. Initial mutation rate =0.1. Desired generation = 100. The results are tabulated in Table 6.3 and in Table 6.5

6. CONCLUSION

In this chapter an improved evolutionary programming technique has been proposed for radial distribution loss minimum reconfiguration. This method reduces combinatorial explosive switching problem into a realizable one and reduces the switching combination to a few number. A mutation fuzzy logic controller is developed to speed up the evolutionary process by adaptively adjusting the mutation rate. This method can be effectively used in real time application of the large distribution system under widely varying load conditions.
REFERENCES


Table 6.2: Tie line data for 29–node system

<table>
<thead>
<tr>
<th>BUS</th>
<th>From</th>
<th>To</th>
<th>Resistance</th>
<th>Reactance</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>21</td>
<td>2</td>
<td>2.274380</td>
<td>0.643967</td>
</tr>
<tr>
<td>12</td>
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<td>1</td>
<td>1.190166</td>
<td>0.496164</td>
</tr>
<tr>
<td>9</td>
<td>15</td>
<td>2</td>
<td>2.050099</td>
<td>0.580464</td>
</tr>
<tr>
<td>18</td>
<td>33</td>
<td>0</td>
<td>0.927017</td>
<td>0.625792</td>
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<tr>
<td>25</td>
<td>29</td>
<td>0</td>
<td>0.477870</td>
<td>0.467677</td>
</tr>
</tbody>
</table>

Table 6.3: System state before and after reconfiguration (29–node)

<table>
<thead>
<tr>
<th>Power Loss kW</th>
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<tbody>
<tr>
<td>Original Configuration</td>
</tr>
<tr>
<td>New Configuration</td>
</tr>
</tbody>
</table>

Table 6.4: Tie line data for 69–node system

<table>
<thead>
<tr>
<th>BUS</th>
<th>From</th>
<th>To</th>
<th>Resistance</th>
<th>Reactance</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
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<td>1</td>
<td>1.0040</td>
<td>0.7400</td>
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<td>14</td>
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<td>1.7210</td>
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<td>50</td>
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<tr>
<td>27</td>
<td>65</td>
<td>0</td>
<td>0.9744</td>
<td>0.9630</td>
</tr>
</tbody>
</table>


BIOGRAPHIES

Mr. Jaydeep Chakravorty is currently attached with University of Petroleum & Energy Studies, Dehradu, in Electrical & Electronics & Instrumentation Department. His area of research is in Electrical Power System, Fuzzy Logic and neural networks. He has published several papers in international journals. He is the author of two technical books.