Network Reconfiguration for Loss Reduction in Electrical Distribution System Using Genetic Algorithm


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ABSTRACT

Distribution system is critical links between the utility and the nuclear installation. During feeding electricity to that installation there are power losses. The quality of the network depends on the reduction of these losses. Distribution system which feeds the nuclear installation must have a higher quality power. For example, in Inshas site, electrical power is supplied to the nuclear reactor and other nuclear facilities from two incoming feeders (one from new abu–zabal substations and the other from old abu–zabal substations). Each feeder is designed to carry the full load, while the operator preferred to connect with a new abu–zabal substation, which has a good power quality. Bad power quality affects directly the nuclear reactor and has a negative impact on the installed sensitive equipment and instruments of the operation. This paper introduces an optimization technique based on genetic algorithms for distribution network reconfiguration to reduce the network losses to minimum. Simulated results are drawn to show the accuracy of the technique.

Keywords: Electrical Distribution System/ Network Reconfiguration/ Loss Reduction/ Genetic Algorithm.

INTRODUCTION

Most of the electric power distribution systems operate in radial configurations. Normally open and normally closed switches are located along the network in strategic points. By altering the topology to a different radial configuration, one might obtain losses reduction; improve in the network voltage profile, and betterment of reliability indices. When a fault occurs, the faulty zone can be isolated and a new radial configuration might restore the rest of the load. Studies indicate that up to 13% of the total power generation is wasted in the form of line loss at the distribution level. Hence, it is great benefit to investigate methods for network reconfiguration. The objective of network reconfiguration is to reduce power losses and improve the reliability of power supply by changing the status of existing sectionalizing switches and ties.

Network Reconfiguration in distribution networks is realized by changing the status of sectionalizing switches and is usually done for loss reduction. As there are multiple constraints in the distribution networks reconfiguration, it belongs to a complex combinatorial optimization problem. These constraints should not be violated, while finding an optimal or near optimal solution to the reconfiguration problem. In network reconfiguration for loss reduction, the solution involves a search over relevant radial configurations. A variety of approaches of the network reconfiguration problem is
previously surveyed \(^{(2)}\). Many methods for determining radial configuration are implemented, as switch exchange method \(^{(3)}\), Loop Cutting method \(^{(4)}\), discrete branch & bound \(^{(4, 5)}\) and heuristic method \(^{(3, 6, 7)}\). Most of previous methods employ a heuristic search. An exhaustive search \(^{(8)}\) can definitely find the optimal solution but is computationally intensive. More recently, Ant colony and genetic algorithms have been proposed for distribution reconfiguration for loss reduction \(^{(9, 10)}\). The results are very encouraging.

Genetic algorithms have become very popular as a method of finding global optimums. As applied to reconfiguration \(^{(11)}\), the switch states are encoded in strings of 0/1 “chromosomes”, and a population, for example, 50 random generated topologies to be optimized in iterative solution. Each iteration, two parent topologies are selected at random for crossbreeding, which is a process of combining the chromosomes according to some defined algorithm. Then mutation, a random alteration of some chromosomes, may occur with a certain probability. If the resulting child is better, it replaces an existing topology in the population of 50. This process of crossbreeding continues for a number of iterations. The population also has to be re-seeded periodically with random strings to avoid inbreeding. As the population evolves, there will always be a best solution that should steadily improve \(^{(11)}\). Numerical results are presented to illustrate the feasibility of the proposed algorithm.

**PROBLEM FORMULATION**

There are many criteria depending on the performance of the system for an operator to determine the switch statuses in the distribution system. It is known that network operator hopes the MW losses are minimized if the system is in normal state or after the fault clearance. The problem can be formulated as follows:

\[
\text{Min } f(V, X)
\]

Where the variables are defined as follows:

\(V\): is the vector of voltage magnitudes of the different buses.

\(X\): is the vector of the switches status.

\(f(V, X)\): are the power losses which can be calculated from the following equation:

\[
S_L = \sum_{x=1}^{n} \Re\left[\sum_{h=1, h\neq x}^{n} S_L(x, h)\right]
\]

Where \(S_L(x, h)\) is the apparent power from node \(x\) to node \(h\) which is calculated using the following equation:

\[
S_L(x, h) = V_m^n (V_{mh} - V_{nh}) - Y_{mn}
\]

\(Y\) is the \((m, n)^{th}\) element in the bus admittance matrix, and \(V_m\) is bus \(m\) voltage which is calculated by Gauss iterative method.

\[
V_m^{(k+1)} = \frac{1}{V_{mn}} \left[ \frac{P_m + \Sigma_{j=1}^{m} Y_{mj}V_j^{(k)}}{V_m^{(k)}} - \Sigma_{j=1}^{m} Y_{mj}V_j^{(k)} \right]
\]

Where \(K= 0, 1, \ldots\) etc. (to the maximum allowed number of iterations), \(n\) is the number of buses. As the losses \(S_L\) varies with \((V, Y)\), and \((Y, V)\) depends on the switch status \((X)\), then the
fitness function varies with (V, X). The objective of the search is to minimize this fitness function under certain constraints:

1. **Radial network**

   In this constrain, one can define radial feeding as following: as shown in figure (1), if the bus connected to sw2 is supplied by both F1, and F2 a loop is produced, this configuration is not correct for calculation, therefore network configuration should be corrected; briefly, each node has to be supplied from single feeder. In figure (1) any load bus in the configuration is be supplied from one of the two feeders (1) or (2) so that no loop can be configured. By other means at least, one of switches (sw1, sw2, sw3) should be open.

   ![Figure(1): show how to radial configuration](image_url)

   ![Figure(2): show how to all loads serves](image_url)

2. **All load serves**

   Routes of all buses have obtained to satisfy all load serves constraints, therefore routes of all buses need to have one main bus in first of its rout. Briefly, each load node has to be supplied with its load active and reactive power requirement. As shown in the figure (2) all load buses (1, 2, 3, 4, and 5) should be served such that, only one of the switches (sw1, sw2, sw3) is open.

3. **Node voltage magnitude bounds**

   The network reconfiguration is optimized such that the node voltage magnitude V doesn't be out of the voltage limits, or:

   \[
   V_{\text{imin}} \leq |V_i| \leq V_{\text{imax}}
   \]  

   Where, \(V_{\text{imin}}\) and \(V_{\text{imax}}\) are equal to 0.95 p.u. and 1.05 p.u. respectively.

**Genetic Algorithm**

Distribution system loss minimization through system reconfiguration is a difficult problem that has been investigated by many researchers. One of the methods who can give ours a global optimal solution is GA. Genetic algorithms use the principle of natural evolution and population genetics to search and arrive at a high quality near global solution. The required design variables are encoded into a binary string as a set of genes corresponding to chromosomes in biological system. Unlike traditional optimization techniques that require one starting solution, GA uses a set of chromosomes as initial solutions. The group of chromosomes is called a population. The merit of a string is judged by the fitness function, which is derived from the objective function and is used in successive genetic operation. During each iterative procedure (referred to as generation), a new set of strings with
improved performance is generated using three GA operator (normally reproduction, crossover, and mutation).

This paper shows the applicability and efficiency of GA in reconfiguring the distribution system to get minimum losses.

Initial Population
In this stage, the network buses (given table 1) are entered and the genetic algorithm program generates different random solution which presents different status for the switches. Figure (3) gives an example of a single random solution presented by a chromosome with binary genes. Accordingly, a different network configuration is randomly initiated.

| 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | \ldots | \ldots | \ldots |

Figure (3): shown one chromosome

Objective and Fitness Function
Based on the initial random configurations, the objective function and the penalty function composed of the constraints are calculated. The fitness function of each solution is then calculated as follows:

\[
\text{Fitness Function} = \frac{1}{f(V,x) + \text{penalty}(V,x)}
\]

Where Penalty \((v,x)\) is value added to the objective function according to the constraints discussed in the previous section. The strings are stored according to their fitness which is then ranked accordingly.

Genetic Operators
Genetic operators are the stochastic transition rules applied to each chromosome during each generation procedure to generate a new improved population from the previous one. A genetic algorithm usually consists of reproduction, crossover and mutation operators.

Reproduction
Reproduction is a probabilistic process for selecting two parent strings.

Crossover
In this paper the characters to the right of a crossover point are swapped. The probability of parent-chromosomes crossover is assumed to be 0.8.

Crossover is the process of selecting a random position in the parent's strings and swapping the characters either left or right of this point with each other. This random position is called the crossover point.
**Mutation**

The probability of mutation is assumed to be 0.02. Mutation is the process of random modification of a string position by changing ‘0’ to ‘1’ or vice versa, with a small probability. It prevents complete loss of genetic through reproduction and crossover by ensuring that the probability of searching any region in the problem space is never zero.

**APPLICATION AND SIMULATION RESULTS**

The distribution network presented in table (1) is used for feeder reconfiguration testing. The program is written using matlab and tested on windows-7, and the flow chart of the program is given in figure (4). The genetic parameters are population size equal 80, number of generation equal 100, mutation probability equal 0.02, and crossover probability equal 0.08.

The network used contains 3 feeders and 16 nodes. The switches in the network are 9 switches; three tie switches and six sectionalizing switches. As shown in figure (5), the base configuration contains 3 tie switches open (sw5, sw11, and sw16), and 6 sectionalizing switches close (sw2, sw4, sw7, sw9, sw14, and sw15).

**Table 1: Data of the three-feeder simple system**

**Base: 100 MVA, 23 kV**

<table>
<thead>
<tr>
<th>Bus line</th>
<th>No. bus Or sw.</th>
<th>Line data</th>
<th>End bus loading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Reactance (p.u.)</td>
<td>Resistance (p.u.)</td>
</tr>
<tr>
<td>1-4</td>
<td>Sw1</td>
<td>0.10</td>
<td>0.075</td>
</tr>
<tr>
<td>4-5</td>
<td>Sw2</td>
<td>0.11</td>
<td>0.080</td>
</tr>
<tr>
<td>4-6</td>
<td>Sw3</td>
<td>0.18</td>
<td>0.090</td>
</tr>
<tr>
<td>6-7</td>
<td>Sw4</td>
<td>0.04</td>
<td>0.040</td>
</tr>
<tr>
<td>2-8</td>
<td>Sw5</td>
<td>0.11</td>
<td>0.110</td>
</tr>
<tr>
<td>8-9</td>
<td>Sw6</td>
<td>0.11</td>
<td>0.080</td>
</tr>
<tr>
<td>8-10</td>
<td>Sw7</td>
<td>0.11</td>
<td>0.110</td>
</tr>
<tr>
<td>9-11</td>
<td>Sw8</td>
<td>0.11</td>
<td>0.110</td>
</tr>
<tr>
<td>9-12</td>
<td>Sw9</td>
<td>0.11</td>
<td>0.080</td>
</tr>
<tr>
<td>3-13</td>
<td>Sw10</td>
<td>0.11</td>
<td>0.110</td>
</tr>
<tr>
<td>13-14</td>
<td>Sw11</td>
<td>0.12</td>
<td>0.090</td>
</tr>
<tr>
<td>13-15</td>
<td>Sw12</td>
<td>0.11</td>
<td>0.080</td>
</tr>
<tr>
<td>15-16</td>
<td>Sw13</td>
<td>0.04</td>
<td>0.040</td>
</tr>
<tr>
<td>5-11</td>
<td>Sw14</td>
<td>0.04</td>
<td>0.040</td>
</tr>
<tr>
<td>10-14</td>
<td>Sw15</td>
<td>0.04</td>
<td>0.040</td>
</tr>
<tr>
<td>7-16</td>
<td>Sw16</td>
<td>0.12</td>
<td>0.090</td>
</tr>
</tbody>
</table>

In this work, the proposed technique is applied on the network in normal load condition. As shown in figure (6), any transformer can supply all loads in the network for more reliability in the
nuclear installation. The feeder power from transformers is calculated and depends on the switches status. For example, in the base case the switches (sw7, sw9, and sw14) is open, the feeder power can be calculated from equation (7, 8, 9).

\[
\begin{align*}
F_1 &= P_{dt1} = P_d 4 + P_d 5 + P_d 6 + P_d 7 \\
F_2 &= P_d t2 = P_d 8 + P_d 9 + P_d10 + P_d11 + P_d12 \\
F_3 &= P_d t3 = P_d 13 + P_d 14 + P_d 15 + P_d 16
\end{align*}
\]

Where:

\(P_{dt1}, P_d t2, \) and \(P_d t3\) is total demand load power at feeder power \(F_1\), \(F_2\), and \(F_3\). \(P_d 4, P_d 5, P_d 6, P_d 7, P_d 8, P_d 9, P_d 10, P_d 11, P_d 12, P_d 13, P_d 14, P_d 15,\) and \(P_d 16\) denote the scheduled power demand of the load at bus 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, and 16. And so, \(F_1\) or \(F_2\) or \(F_3\) variation depend on case switches.

*Figure (5): Feeder power*

**Base network**

As in figure(6), the switches (sw5, sw11, and sw16) are open. the program is applied to the base network. The result as shown in the table (3).

*Figure (6): Base Three-feeder distribution system.*

*Figure (7): Three-feeder distribution System after using proposed method.*

**Case one:** Proposed technique
The program is applied to network reconfiguration for loss reduction. The new configuration is shown in figure (7) where the switches (sw7, sw9, sw16) should be opened.

A comparison between the solutions obtained by the proposed program and the base network configuration is given in table (8,9). It is clear that the solution obtained here gives lower losses than the base, and the voltage is within the accepted limit.

![Comparison of power losses between base network and case one](image1)

**Figure (8): Compare for Power losses between Base network and case one**

![Comparison of voltage profile between base network and case one](image2)

**Figure (9): Compare for Voltage profile between Base network and case one**

**Case two: After fault occurs**
As shown in figures (8,9) when the fault occurs, the devices protection clear this fault and faults causing some feeders to be taken out. The proposed technique is applied to introduce a new reconfiguration. The fault was assumed on branch (5, 14). The result data after clearance of fault is given in table (3).

Figure (10): Distribution system after fault in branch (5)  
Figure (11): Distribution system after clearance of fault in branch (14)

Figure (12): Figure (13): Shown the result of table (2)

Table 2: Result load flow (Power and Voltage node)
### Table 3: Loss analysis of the sample system

<table>
<thead>
<tr>
<th>Case of network</th>
<th>fitness function</th>
<th>Losses (p.u.)</th>
<th>Opening switch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base network</td>
<td>280.1803</td>
<td>0.0036</td>
<td>Sw. no. (5,11,16)</td>
</tr>
<tr>
<td>Proposed method</td>
<td>292.9996</td>
<td>0.0034</td>
<td>Sw. no. (7,9,16)</td>
</tr>
<tr>
<td>If there is fault on branch (5)</td>
<td>276.9208</td>
<td>0.0036</td>
<td>Sw. no. (4 , 5 , 7)</td>
</tr>
<tr>
<td>If there is fault on branch (14)</td>
<td>253.2804</td>
<td>0.0039</td>
<td>Sw. no. (9 , 14 , 16)</td>
</tr>
</tbody>
</table>

Figure (13): shown the result of table (3)

**CONCLUSION**
Distribution system loss minimization through system reconfiguration is a difficult problem that has been investigated by many researchers. Genetic algorithm is presented to solve network reconfiguration problem at normal operation state and after fault clearance. In all cases the new reconfiguration takes into account all constrains including AC load flow. Presented load flow is used to calculate feeder currents, network node voltage and network losses. The tabulated results of the case studied show high efficiency in power loss reduction.

REFERENCES