Minimization of losses by reconfiguration of radial distribution system using artificial intelligence (AI) technique

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Abstract
There is three functional areas of electrical utility namely Generation, Transmission and Distribution. Out of three functional areas of Electrical utility, the distribution sector needs more attention and it is difficult to standardize due to its complexity. Transmission & Distribution loss in India has been consistently on the higher in the range of 30-40 percent. Out of these losses, major share is at Distribution level. This is due to inadequate investments for system improvement works. This project proposes an efficient approach to reduce active power loss in transmission line. The algorithms are used based on simple heuristic rules and modified genetic algorithm for reconfiguration of radial distribution system. To demonstrate the validity of the used algorithms, computer simulation is carried out on 33 bus distribution system and comparisons of results are done.

Keywords
Radial Distribution system, Real power loss reduction, Network Reconfiguration, Radial Network, Heuristic Technique, Modified Genetic Algorithm.

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1. Introduction
Electrical distribution networks are built as interconnected and meshed networks. However, they are arranged to be radial in operation. Their configurations may be varied with manual or automatic switching operations so that, all the loads are supplied and reduce power loss. Reconfiguration also relieves the overloading of the network components. There are two types of switches used in primary distribution systems; sectionalizing switches (normally closed) and tie switches (normally open). They are designed for both protection and configuration management in the system. Under normal operating conditions, feeders are frequently reconfigured by changing the open/closed state of each switch in order to reduce line losses or to avoid the overloading network branches. Since there are many candidate-switching combinations possible in a distribution system, finding the operating network reconfiguration becomes a complicated combinatorial, non-differentiable constrained optimization problem. In such system the possible number of switching combinations is $3^m$, where $m$ is the total number of tie switches in the system. However, all possible options are not practicable, as they require long computational time for line loss calculation. The radial constraint and discrete nature of the switches prevent the use of classical techniques to solve the reconfiguration problem. So we adapt algorithms based on heuristic search techniques.

In this paper, a new heuristic search methodology is proposed for determining the minimum loss configuration of a radial distribution system. The proposed solution starts with initial configuration with all tie switches are in open position. The voltage differences across all tie switches and the two node voltages of each tie switch are computed using load flow analysis. Among all the tie switches, a switch with maximum voltage difference is selected first subject to the condition that the voltage difference is greater than the pre-specified value.

The tie switch with the maximum voltage difference is
closed and the sectionalize switches are opened in sequence starting from the minimum voltage node of the tie switch. The power losses due to each sectionalize switch are calculated and the opening sectionalize switches are stopped when the power loss obtained due to previous sectionalizing is less than the current one. As the power loss due other sectionalize switches is more than the current, it is not necessary to open the sectionalize switches further in the loop. Based on the above procedure, the best switching combination of the loop is noted. The same procedure is repeated to all the remaining tie switches. This procedure favours the solution with a fewer switching operations. Another advantage with the algorithm is that the number of load flow computations is less and subsequently the computational effort is drastically reduced.

The proposed algorithm is tested on a 33 and 69-bus system.

2. Problem Formulation For Loss Minimization

This work discusses the network reconfiguration of distribution systems. The objective is to minimize the system power loss, subject to operating constraints under a certain load pattern. The mathematical model of the problem can be expressed as follows:

\[ \text{Min} F = P_{\tau, \text{Loss}} \]  

(2.1)

Where, \( P_{\tau, \text{Loss}} \) - total real power loss of the system. The voltage magnitude at each bus must be maintained within its limits. The current in each branch must satisfy the branch’s capacity. These constraints are expressed as follows:

\[ V_{\text{min}} \leq |V_i| \leq V_{\text{max}}, |V_i| \text{ is voltage magnitude of bus, } V_{\text{min}} \text{ and } V_{\text{max}} \text{ are minimum and maximum bus voltage limits, respectively.} \]

Fig 1: Single line diagram of main feeder

The power loss of the line section connecting buses i and (i+1) can be computed as

\[ P_{\text{Loss}}(i, i+1) = R_i, j+1 \left( P_i^2 + Q_i^2 \right) / |V_i|^2 \]  

(2.2)

The power loss of the feeder PF, Loss may then be determined by summing the losses of all line sections of the feeder, as below

\[ P_{\text{PF, Loss}} = \sum_{i=0}^{n-1} P_{\text{Loss}}(i, i+1) \]  

(2.3)

The total system power loss is the sum of power losses of all feeders in the system. With the specified voltage at the substation bus, specified loads at all the other buses expecting the substation bus and assuming a voltage of 1.0 p.u. at the end buses of main feeder and the laterals, the load flow solution is carried out through backward and forward sweeps.

Consider a distribution system consisting of a radial main feeder having n buses, (n-1) branches and one lateral emerging from the ith bus shown in fig 1. In this model, voltage of 1.0 p.u is assumed only at the end busses of the feeder and the laterals. The convergence is based on the substation voltage. Mathematical model is described as follows

The load current at the \( i^{th} \) bus in the \( k^{th} \) iteration is given by:

\[ I_{Li}^k = \left( S_{Li} / V_{1}^k \right)^{*} \]  

(2.4)

\[ I_{L_{i+1}}^k = I_{L_{i+1}}^k + \sum \text{(current in branches emanating from } (i+1)^{th} \text{ branch)} \]

The voltage at the \( i^{th} \) bus in the \( k^{th} \) iteration is given by:

\[ V_i^k = V_i^{k-1} + Z_{1}^k I_{1}^{k-1} \]  

(2.5)

Convergence Criterion of our model is given by

\[ | V1 - V_{sp} | \leq \epsilon \]  

(2.6)

where, \( \epsilon = \) value of tolerance

3. Proposed Methods

In general, many tie or sectionalize switches are to be closed or opened to obtain the feasible network reconfiguration. If the reconfigured network leaves any branches unconnected or forms a closed loop it will lead to an infeasible switching combination for network reconfiguration. Hence, to avoid the infeasible switching combinations, two conditions has to be checked

1. Connectivity from source to all the nodes.
2. Radial structure of the network.

Heuristic Algorithm:

In this work, a simple heuristic rules are formed to select the optimal switches that give the minimum power loss without searching all the candidate switches in the network.

The proposed method involves the following steps:

1. Read the system input data.
2. Run the load flow program for the radial distribution network.
3. Compute the load current at the \( i^{th} \) bus in the \( k^{th} \) iteration.
4. Compute the voltage difference across the open tie switches (i.e., \( \Delta V_{tie} \), for \( i = 1, 2, \ldots, N_{tie} \)). \( N_{tie} \) represents the total number of tie switches.
5. Compute the voltage difference across the closed sectionalize switches (i.e., \( \Delta V_{	ext{tie}} \text{, max} = \Delta V_{tie}(p) \)).
6. If \( \Delta V_{tie, \text{ max}} > \epsilon \) (a specified a value), go to step 7; otherwise discard all switching operations and go to step 13.
7. Pick the two nodes of the tie switch \( p \) and check the node which has the minimum voltage, let it be \( V_x \).
8. Close the tie switch \( p \) to form the loop and open the sectionalize switch \( q \) (to retain radiality) adjacent to \( V_x \). Then, calculate the power loss and store it in \( PL_q \).
9. If the number of iterations (\( n \)) is less than or equal to number of tie switches (\( N_{tie} \), set \( n \) as \( n+1 \) and go to step 2 to repeat the program for the rest of the tie switches.
10. Run the load flow and the print the results.
11. Stop.

**Modified Genetic Algorithm:**

Generally in GA the initial population is formed by randomization but in this modified GA the initial population is formed by using simple heuristic rules. In this project, the initial population has to be checked for radiality and connectivity from source to all the nodes. In initial population by randomization most of configuration does not satisfies the above two condition. Thus the modified GA reduces the computation time.

The proposed algorithm steps can be summarized as follows.

1. Read the bus data and line data for the distribution test system.
2. Generate initial population by heuristic algorithm.
3. Calculate the fitness for the population.
4. Perform cross over operation by taking two chromosomes at a time from the population. Generate a random number for the crossover point
   1. Here the two point cross over is used. Perform crossover operation by interchanging the bits between the two cross over point.
   2. Perform mutation operation (after cross over operation) by generating two random numbers mutating the chromosomes and change the bit 1 to 0 or 0 to 1 for the two chromosomes.
5. Check the radiality for the offsprings. If the distribution network has no closed loops and all the loads were connected, the network is radial.
6. Sort the population and offsprings.
7. Choose the best individuals of population size according to their fitness.
8. With the new repeat the steps 4to 8 until maximum iteration is reached.
9. The switch status and voltage at each bus of the minimum loss configuration is displayed.
10. Stop the process.

**4. Test Results and Discussions**

The distribution network presented in is used to demonstrate the validity and effectiveness of the proposed method. The proposed method is programmed in MATLAB. The proposed method is applied to the 33bus system. The initial system real power loss in the 33 bus system is 199.102 kW.

**33 BUS SYSTEMS**

The distribution network for reconfiguration consists of 33-buses and 5 tie lines; the total loads are 5084.26 kW and 2457.32 kVAr. The normally open switches are 33, 34, 35, 36 and 37 represented by the dotted lines and normally open switches 1 to 32 are represented by the solid lines as shown in fig 2.

**Heuristic Algorithm:**

The voltage differences across all tie switches are computed for the network shown in fig.2 and are shown in Table I. It is observed that the maximum voltage difference occurs across tie switch 35 which is greater than the specified value (\( \varepsilon \)). Hence, the tie switch 35 is closed first as the voltage differences across the remaining tie switches is smaller in.

<table>
<thead>
<tr>
<th>TIE SWITCH NUMBER</th>
<th>VOLTAGE DIFFERENCE ACROSS TIE SWITCH IN P.U.</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>0.0492</td>
</tr>
<tr>
<td>34</td>
<td>0.0196</td>
</tr>
<tr>
<td>35</td>
<td>0.0650</td>
</tr>
<tr>
<td>36</td>
<td>0.0021</td>
</tr>
<tr>
<td>37</td>
<td>0.0418</td>
</tr>
</tbody>
</table>

The tie switch 35 is closed, the two node voltages of the tie switch 35 are evaluated and the minimum of two node voltages
is noted. In this case, the minimum node voltage of the tie switch 35 is 12. The tie switch 35 is closed and sectionalizing switch 11-12 is open to maintain the radiality. And the total real power loss after first switching is obtained as 150.557 kw.

The advantage of this procedure is that it is not necessary to visit all the sectionalizing switches in the loop. Therefore, the search space of sectionalizing switches in the loop is drastically reduced. For the second switching operation, the voltage difference across remaining tie switches (discarding tie switch 35) are computed and shown in Table II.

Table II
Voltage Difference Across The Tie Switches After First Switching

<table>
<thead>
<tr>
<th>TIE SWITCH NUMBER</th>
<th>VOLTAGE DIFFERENCE ACROSS TIE SWITCH IN P.U.</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>0.0308</td>
</tr>
<tr>
<td>34</td>
<td>0.0188</td>
</tr>
<tr>
<td>36</td>
<td>0.0454</td>
</tr>
<tr>
<td>37</td>
<td>0.0348</td>
</tr>
</tbody>
</table>

The maximum voltage difference occurs across tie switch 36 which is greater than the specified value ($\varepsilon$). Hence, the tie switch 36 is closed and the minimum node voltage of the tie switch 36 is 33. Therefore sectionalizing switch 33-32 is opened to maintain the radiality. And the total real power loss after second switching is obtained as 145.484 kw. In the similar way the load flow is done on the remaining tie switch 33,34,37 and their voltage difference table are given in table III, IV, V respectively.

Table III
Voltage Difference Across The Tie Switches After Second Switching

<table>
<thead>
<tr>
<th>TIE SWITCH NUMBER</th>
<th>VOLTAGE DIFFERENCE ACROSS TIE SWITCH IN P.U.</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>0.0288</td>
</tr>
<tr>
<td>34</td>
<td>0.0145</td>
</tr>
<tr>
<td>37</td>
<td>0.0326</td>
</tr>
</tbody>
</table>

Table IV
Voltage Difference Across The Tie Switches After Third Switching

<table>
<thead>
<tr>
<th>TIE SWITCH NUMBER</th>
<th>VOLTAGE DIFFERENCE ACROSS TIE SWITCH IN P.U.</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>0.0139</td>
</tr>
<tr>
<td>34</td>
<td>0.0046</td>
</tr>
</tbody>
</table>

Table V
Voltage Difference Across The Tie Switches After Fourth Switching

<table>
<thead>
<tr>
<th>TIE SWITCH NUMBER</th>
<th>VOLTAGE DIFFERENCE ACROSS TIE SWITCH IN P.U.</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>0.0205</td>
</tr>
</tbody>
</table>

Since the voltage difference across the all the tie switch is less than the specified value, the closing of it will not cause any reduction in the power loss. Hence this switching operation is discarded. The voltage profiles before and after reconfiguration is shown in from fig.3

Fig. 3- 33 Bus system voltage profile (Heuristic method)

It is observed that the minimum voltage before reconfiguration is 0.9111 p.u and after reconfiguration is 0.9619 p.u. The power loss before reconfiguration is 199.102KW and after reconfiguration is 127.07KW. From the results it is observed that reduction in power loss is 72.032 kW which is approximately 36.07 %.

Modified Genetic Algorithm:

In this modified GA, initial population is formed by simple heuristic rules. From the initial population two chromosomes is selected for crossover. The process of crossover leads to offspring. The off springs are subject to constraints such as radiality and connectivity from source to all the nodes.

Fig. 4- 33 Bus system voltage profile (Modified GA method)

The fitness function is calculated for the offspring which satisfy the constraints. Sort the best individuals of population size according to the fitness. The procedure is repeated for 100 iterations. Here the crossover site and mutation site is selected randomly. The optimal real power loss obtained in modified GA is 101.272 KW. The reduction in real power loss is 97.83 KW is approximately 49.13%.

5. Comparison and Conclusion

In this paper, heuristic approach and modified GA is used to minimize the real power loss and improve the voltage profile.
in the system. For the 33 bus configuration shown in fig.2, the number of buses having voltage profile below 0.96(p.u) is 20, but in the case of heuristic and Modified GA method it has been improved to just 7.

Fig. 5- 33 Bus system voltage profile (Comparison between Heuristic method and Modified GA) is less than the modified GA. The real power loss is less (i.e. 13.06 percentage better than heuristic method) and voltage profile are better in modified GA.

References


