Optimal Placement of DG in Distribution System using Evolutionary Algorithm

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Abstract—This paper represents the minimization of the power loss on Distribution System by placing Distributed Generators using a recently developed evolutionary algorithm Biogeography Based Optimization (BBO) method. This objective is achieved while maintaining the voltage levels in specified limits. For calculating the load flow an efficient Backward Forward Sweep method has been used. This helps in calculating the line losses of the distribution system. The Radial Distribution System (RDS) has been used for carrying out the procedure. The proposed method is tested on IEEE-33 bus radial distribution system and is performed in MATLAB under the programming environment. The results are encouraging.

Index Terms—Biogeography Based Optimization, Backward Forward Sweep method, Radial Distribution System, Load flow analysis.

I. INTRODUCTION

The power system consists of three stages for supplying power from the generating stations to the receiving end consumers. The three stages are namely- Generation, Transmission system and the Distribution system. All the three systems play equal and important role in delivering power to the consumers. Since a lot of research work has be done and they are found effective in minimizing power losses in generating and transmission System the power engineers has now moved their attention towards the distribution system. Distribution systems operating structure varies from place to place. So their power loss also varies. Now the aim of the researchers is to find techniques to minimize power losses in the distribution system.

For calculating the power consumption and loss of power, load flow method is used. There are many load flow methods used to calculate the line losses of the distribution system. The traditional methods such as Gauss Seidal, Newton Raphson[3], etc. have been used earlier. These methods are sometimes inefficient for the system for the parameters like increase in R/X ratios, Radial Structure of the system, etc. So to minimize these problems a recently developed Backward Forward sweep method of load flow [2] has been used to calculate the load flow. Since, this method provides the system with good accuracy and computational efficiencies. The problem in [3] can be overcome by the use of Feed Forward Backward Sweep method.

The use of distributed generators helps to maintain the power flow and reduce the losses. There are many methods to find the optimal values of DGs to be placed. Like in [1] R.Shrinivasa Rao has used HSA for finding the optimal values of DGs to be place along with the network reconfiguration. Now for optimal placement of DGs (Distributed Generators) in power system the authors in [4][5][7] determined location and the size of DG at the same time by using optimization techniques such as Particle Swarm Optimization (NSPSO), Non-Dominated Sorting Simulated Annealing (SA), and Non Dominated Sorting Genetic Algorithm (NSGA) respectively. In [8] an enhanced reconfiguration method is used for placing Distributed Generators. Researchers in [9] have used particle Swarm Optimization to solve the reconfiguration problem along with placement of capacitors which provides minimum loss in the system.

From [10] a recently developed Biogeography Based Optimization method is used in this paper. This method has shown good convergence properties and promising results. Hence, this method has been proposed for optimal sizing of DGs to be placed. For finding the optimal positions where the DGs are needed to be placed, the Loss
sensitivity factor [1] of the system is needed to be calculated. This loss sensitivity factors tells the positions, from where the power loss can be minimized, after placing the Distributed Generators.

The remaining parts of the paper are constituted as: Section II defines the problem formulation and Loss Sensitivity Factor, Feed Forward Backward Method is discussed in chapter III, Chapter IV discusses about the BBO technique and its application. Section V provides the results with the test system and the discussion with conclusion is given in section VI.

II. PROBLEM FORMULATION
A. Problem statement
The main objective is to find the effective sizes of DG for application in distribution system which will minimize the system power loss while satisfying operating constraints.

The Objective function is given as,

\[
\text{Minimize } f = \min (P_{T,\text{LOSS}}) \tag{3.1}
\]

The objective function (3.1) is subjected to the following constraints.

1. Power Flow equation must be maintained
\[
P_{SS} = P_{LOSS}^T + P_D^T \tag{3.2}
\]

2. Voltage magnitude must be maintained within its limits,
\[V_{\min} \leq |V_k| \leq V_{\max}\]

3. Radial Configuration Format must be maintained
4. Load Bus should not be interrupted.

B. Radial Topology of Distribution Network
For determination of Radial nature of network, a branch bus incident matrix approach is used. Here \(A\) is the branch-to-node incidence matrix which has one row for each branch and one column for each node with an entry in rows \(i\) and column \(j\) according to the below rules:
\[
a_{ij} = 0 \text{ if branch } i \text{ is not connected to node } j
\]
\[
a_{ij} = -1 \text{ if branch } i \text{ is directed toward node } j
\]
\[
a_{ij} = 1 \text{ if branch } i \text{ is directed away from node } j
\]

The matrix has the row-column dimension for any network with branches and nodes excluding the reference node. It is found that, if the determinant of \(A\) is equal to 1 or -1, then the system is radial and if the determinant is equal to zero, this means that either the system is not radial or group of loads are disconnected from service.

C. Problem Formulation

\[
\begin{align*}
P_{k+1} & = P_k - P_{Loss,k} - P_{Loss,k+1} \\
\text{Minimize } & P_{(minf)_{k+1}} \tag{3.4}
\end{align*}
\]

The total power loss can be calculated as,

\[
\begin{align*}
P_{Loss,k+1} & = R_k \left( P_k^2 + Q_k^2 \right) \left( V_k \right)^2 \\
\text{Total power loss of the feeder } P_{T,\text{Loss}} & = \sum_{k=1}^{n} P_{Loss,k+1} \tag{3.8}
\end{align*}
\]

The total power loss can be calculated as,

\[
\begin{align*}
P_{T,\text{Loss}} & = \sum_{k=1}^{n} P_{Loss,k+1} \tag{3.9}
\end{align*}
\]

The net power loss reduction, \(\Delta P_{Loss}^{R}\) in the system is given as,

\[
\begin{align*}
\Delta P_{Loss}^{R} & = \sum_{k=1}^{n} P_{T,\text{Loss}}(k,k+1) - \sum_{k=1}^{n} P_{T,\text{Loss}}(k,k+1) \tag{3.10}
\end{align*}
\]

D. Loss Sensitivity Factor
Loss sensitivity factor is calculated to identify the buses for installation of DG’s. Sensitivity factors of
candidate bus locations are calculated. This helps to ease the optimization procedure. A line section consisting of impedance \( R_k + jX_k \) and a load of \( P_{lk, eff}^k + Q_{lk, eff}^k \) connected between \( k-1 \) and \( k \) buses as given in Fig 2,

\[
\text{Figure 2 Line section of Power system}
\]

Active power loss in \( k^{th} \) line is given by,

\[
P_{\text{line loss}} = \frac{(P_{lk, eff}^k + Q_{lk, eff}^k)^2}{V_k^2} R_k
\]

The load sensitivity factor (LSF) is calculated with following equation,

\[
\frac{\partial P_{\text{line loss}}}{\partial P_{lk, eff}} = \frac{2P_{lk, eff}^k \cdot R_k}{V_k^2}
\]

Where,

- \( P_{lk, eff}^k \) is the total effective active power beyond bus ‘\( k \)’
- \( Q_{lk, eff}^k \) is the total effective reactive power supplied beyond bus ‘\( k \)’

### III. FEED FORWARD BACKWARD METHOD

#### A. Power Flow

Let us consider a radial network, the backward/forward sweep method for the load-flow computation is an iterative method in which, at each iteration two computational stages are performed: The load flow of a single source network can be solved iteratively from two sets of recursive equations. The first set of equations for calculation of the power flow through the branches starting from the last branch and proceeding in the backward direction towards the root node. The other set of equations are for calculating the voltage magnitude and angle of each node starting from the root node and proceeding in the forward direction towards the last node.

#### B. Forward Sweep

The forward sweep is basically a voltage drop calculation with possible current or power flow updates. Nodal voltages are updated in a forward sweep starting from branches in the first layer toward those in the last. The purpose of the forward propagation is to calculate the voltages at each node starting from the feeder source node. The feeder substation voltage is set at its actual value. During the forward propagation the effective power in each branch is held constant to the value obtained in backward walk.

#### C. Backward Sweep

The backward sweep is basically a current or power flow solution with possible voltage updates. It starts from the branches in the last layer and moving towards the branches connected to the root node. The updated effective power flows in each branch are obtained in the backward propagation computation by considering the node voltages of previous iteration. It means the voltage values obtained in the forward path are held constant during the backward propagation and updated power flows in each branch are transmitted backward along the feeder using backward path. This indicates that the backward propagation starts at the extreme end node and proceeds towards source node.

By comparing the calculated voltages in previous and present iterations, the successive iteration is obtained. The convergence can be achieved if the voltage mismatch is less than the specified tolerance i.e., 0.0001. Otherwise new effective power flows in each branch are calculated through backward walk with the present computed voltages and then the procedure is repeated until the solution is converged.

The backward/forward sweep method is now reformulated in a way suitable for the analysis of the convergence of the iterative process. Consider Fig. , a branch is connected between the nodes ‘\( k \)’ and ‘\( k+1 \)’. The effective active (\( P_k \)) and reactive (\( Q_k \)) powers that of flowing through branch from node ‘\( k \)’ to node ‘\( k+1 \)’ can be calculated backwards from the last node and is given as,

\[
P_k = P_{p_{k+1}} + R_k \left( \frac{P_{z_{k+1}}^2 + Q_{z_{k+1}}^2}{V_{k+1}^2} \right)
\]

\[
Q_k = Q_{p_{k+1}} + R_k \left( \frac{P_{z_{k+1}}^2 + Q_{z_{k+1}}^2}{V_{k+1}^2} \right)
\]
Where,

\[ P_{k+1} = P_{k+1} + P_{L,k+1} \]

\[ p_{Q_k}, l_{Q_k} = Q_{L, k} - Q_{L, k} + Q_{L, k} \]

IV. BIOGEOGRAPHY BASED OPTIMIZATION

Biogeography Based Optimization is a new evolutionary algorithm proposed by Dan Simon [10]. Biogeography describes how species migrate from one island to another, and also how the islands are been upgraded with better species. A habitat is any island (area) that is geographically isolated from other islands. Areas that are well suited as residences for biological species are said to have a high habitat suitability index (HSI). The variables that characterize habitability are called suitability index variables (SIVs). SIVs can be considered as the independent variables of the habitat, and HSI can be calculated using these variables.

In [12], comparison of BBO with GA is carried out for different parameters. It has been pointed out analytically and substantiated by simulation results on benchmarks problems that retention of optimum value is better in BBO compared to GA once it is found. BBO performs relatively better for large population size. In case of mutation rate, if it decreases, performance of BBO improves i.e., the chances of obtaining optimal population increases. A large population and generation size will increase the search space and computation burden will increase. Therefore a trade-off is made with reference to results obtained with GA in [12] and results of economic dispatch in [11] while initializing parameters in the proposed study. Population size or number of members of habitat H is set at 50, habitat modification probability \( P_{m, k} \) is 1, mutation probability=0.005, maximum immigration rate I=1, maximum emigration rate E=1 assuming linear curve, number of iterations or generation \( Iter_{max} \) is set at 100 and elite habitat \( p=2 \). However different set of initial parameters may give different results which are not considered in this study.

The main steps of BBO are as follows:

Step 1) First, initialize the BBO parameters like habitat modification probability \( P_{m, k} \), mutation probability, maximum mutation rate \( m_{max} \) etc.

Step 2) Initialize several numbers within feasible region of habitats depending upon the habitat size. It can be represented in matrix form as,

\[ (H) \begin{bmatrix} x_{i1} & x_{i2} & \ldots & x_{in} \\ x_{j1} & x_{j2} & \ldots & x_{jn} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \ldots & x_{mn} \end{bmatrix} \]

Step 3) Calculate the HSI value for each habitat of the population set for given emigration rate \( \mu \), immigration rate \( \lambda \), the HSI of all N SIV sets is calculated as per the following way,

\[ HSI = \frac{x_{i1}^2 + x_{i2}^2 + \ldots + x_{in}^2}{x_{i1}^2 + x_{i2}^2 + \ldots + x_{in}^2} \]

\[ HSI = \frac{x_{j1}^2 + x_{j2}^2 + \ldots + x_{jn}^2}{x_{j1}^2 + x_{j2}^2 + \ldots + x_{jn}^2} \]

\[ HSI = \frac{x_{m1}^2 + x_{m2}^2 + \ldots + x_{mn}^2}{x_{m1}^2 + x_{m2}^2 + \ldots + x_{mn}^2} \]

Calculate the number of valid species, all habitats using their HSI values. The habitats, whose fitness values, i.e., HSI values, are finite, are considered as valid species S.

Step 4) Elite Habitats are identified based on the optimum HSI values. Modify the Habitat according to migration and mutation operation. After modification of each non-elite habitat using migration operation, each HSI is recomputed.

Step 5) After each habitat is modified, its feasibility as a problem solution should be verified

Step 6) Go to step 3) for the next iteration. This loop can be terminated after a predefined number of iterations have been found.

In this work, objective defined is to find optimum sizes of DGs which will give minimum power loss and improved voltage profile. BBO is initialised randomly with SIV’s which are values of DGs to be placed. Since three DGs are to be applied simultaneously, SIV’s representing combination are three. Likewise, other habitats are generated randomly which makes population size. Every candidate solution of this population undergoes load flow analysis and calculates power loss and voltages at buses. The fitness function is evaluated as power loss which is sorted in ascending order so that minimum loss is at the top. Candidate solution corresponding to this loss which is minimum in the given population is declared best solution for the current generation. Top two candidate solutions will be elite and don’t undergo migration operation; instead these solutions will replace the
worst solutions in the next generation. The process of optimisation is then carried out as outlined above to obtain best solution. DG’s are installed at optimal locations or buses which are identified by loss sensitivity factor (LSF). It has been pointed out in [1] that optimal number of DG’s is three.

V. RESULTS AND DISCUSSIONS

BBO Algorithm is tested on standard IEEE 33 bus radial distribution system (RDS) in MATLAB 2012 programming environment on PC with Intel core i5, 2.40 GHz, 8 GB RAM. In the simulation, following situations are considered for analysis.

<table>
<thead>
<tr>
<th>Network I</th>
<th>System is without reconfiguration and DG (Base case)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network II</td>
<td>System as Base case with DG units installed at candidate buses</td>
</tr>
</tbody>
</table>

**A Test System**

The test system for the case study is IEEE standard 33 bus radial distribution system shown in Fig 3 which is base case. The test system has radial structure with 33 buses, and supply of 12.66-kV. It consists of 5 tie-lines (looping branches) and 32 sectionalizing switches. The normally open switches are 33 to 37, and the normally closed switches are 1 to 32. The line data and load data is taken from [7] and total real and reactive power loads on the system are 3715 kW and 2300 kVAR, respectively.

Using sensitivity analysis [1], loss sensitivity factors (LSF) are computed for installing the DG units at candidate bus locations for network II. After computing sensitivity factors at all buses, they are sorted and ranked. Only top three locations are selected to install DG units in the system. The limits of DG unit sizes chosen for installation at candidate bus locations are 0 to 2 MW. The candidate locations for network II is given in Table I. To assess the performance, the network is simulated for nominal load. Simulation results are presented in Table I.

Initial parameters of BBO algorithm are set as per section IV. 20 trials are conducted of the algorithm to finalize the result.

**B Simulation Results**

<table>
<thead>
<tr>
<th>Network</th>
<th>Switches Opened</th>
<th>Power Loss(kW)</th>
<th>Minimum Voltage (p.u)</th>
<th>% Loss Reduction</th>
<th>DG Size in MW (Bus Number)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case (Network I)</td>
<td>33, 34, 35, 36, 37</td>
<td>208.0</td>
<td>0.910</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Only DG installation (Network II)</td>
<td>33, 34, 35, 36, 37</td>
<td>94.519</td>
<td>0.958</td>
<td>54.56</td>
<td>1.12(3) 1.42(6) 0.78(8)</td>
</tr>
</tbody>
</table>

It is observed from table I at same load; base case power loss (in kW) in system is 208 which is reduced to 94.51 in network scenario II. Similarly the percentage loss reduction for network II at same load is 54.56. It clearly shows that there is significant change in power loss reduction in network II (proposed).

Table II represents the comparison of simulation Results. It can be seen that, significant improvement can be seen wherein BBO has
converged to a better optimal solution than other methods. Power loss has reduced considerably owing to installing a better and matching DG unit at the buses.

Table II Comparison of simulation Results of 33 bus system

<table>
<thead>
<tr>
<th>Method</th>
<th>Item</th>
<th>Scenario I</th>
<th>Scenario II</th>
</tr>
</thead>
<tbody>
<tr>
<td>BBO</td>
<td>Switches Opened</td>
<td>33,34,35,36,37</td>
<td>33,34,35,36,37</td>
</tr>
<tr>
<td></td>
<td>Power loss(kw)</td>
<td>208</td>
<td>94.51</td>
</tr>
<tr>
<td></td>
<td>Min.</td>
<td>0.9107</td>
<td>0.9580</td>
</tr>
<tr>
<td></td>
<td>% Power Loss</td>
<td>-</td>
<td>54.56</td>
</tr>
<tr>
<td>HSA</td>
<td>Switches Opened</td>
<td>33,34,35,36,37</td>
<td>33,34,35,36,37</td>
</tr>
<tr>
<td></td>
<td>Power loss(kw)</td>
<td>202.67</td>
<td>96.76</td>
</tr>
<tr>
<td></td>
<td>Min.</td>
<td>0.9131</td>
<td>0.9670</td>
</tr>
<tr>
<td></td>
<td>% Power Loss</td>
<td>-</td>
<td>52.26</td>
</tr>
<tr>
<td>GA</td>
<td>Switches Opened</td>
<td>33,34,35,36,37</td>
<td>33,34,35,36,37</td>
</tr>
<tr>
<td></td>
<td>Power loss(kw)</td>
<td>202</td>
<td>100.1</td>
</tr>
<tr>
<td></td>
<td>Min.</td>
<td>-</td>
<td>0.9605</td>
</tr>
<tr>
<td></td>
<td>% Power Loss reduction</td>
<td>-</td>
<td>50.60</td>
</tr>
</tbody>
</table>

VI. CONCLUSION

For minimizing the power loss and improving voltage profile DG installation is proposed. A recent load flow technique suitable for distribution system, Feed Forward Backward sweep method has been used.

Drawbacks of classical optimization techniques like optimal global solution, good initial solution etc are overcome by evolutionary algorithms such as Biogeography Based Optimization method which has given promising results for optimization problem [10][11], encouraging to use it for present work.

BBO has been successively applied on the radial distribution system to find optimal values of DGs to minimize power loss and improve voltage profile at buses. DG’s are installed at different optimal buses identified using loss sensitivity factor.

The results discussed in chapter V, it is observed that standard deviation of the best loss from average loss is very low in case of BBO. A smaller standard deviation implies that most of the best solutions are close to the average.

The results obtained using BBO are promising; making this algorithm to be applied to other similar applications, viz., reactive power minimization using DG units or shunt capacitors at optimal locations, multiobjective applications etc in future.

REFERENCES


