A Robust Technique for Optimal Placement of Distribution Generation

Vahid.Rashtchi, Mohsen.Darabian, Saeid Molaei

Abstract—This paper presents optimal placement of Distribution Generations (DGs) using Bacterial Foraging Algorithm (BFA). The capability of the proposed method has been investigated. The optimal placement and sizing problems of distributed generation are formulated as a multi-objective function including the network power losses and better voltage regulation, which is solved by a BFA algorithm. The effectiveness of the approach is confirmed on 33 and 69 bus systems.

Keywords—Distributed generation, optimal placement, Bacterial Foraging Algorithm (BFA), loss

I. INTRODUCTION

Increasing role in emerging electrical power systems. Studies have predicted that DG will be a meaningful percentage of all new generations going on lines. It is predicted that they are about 20% of the new generations being installed [1].

Optimization techniques should be employed for deregulation of the power industry, by applying the best allocation of the distributed generations (DGs). The advancement in technology and the demand of the customers for cheap and reliable electric power has led to an increasing interest in distributed generation. The issues related to reliability and maintenance has impeded the penetration of DG resources in distribution systems [2]–[4]. The DG units might bring different benefits such as: network investment deferral [5], active loss reduction [6–8], and reliability improvement [9],[10]. The benefits of DG units highly depend on the size and location of them in the network. Many methods have been proposed in the literature to find the optimal location and size of DG units in the network which have considered various technical aspects such as: voltage limits, feeder capacity limits and number of installed DG units [11]. In [12], a GA method is proposed to minimize the distribution systems active power flow. In [13], a combination of GA and simulated annealing meta-heuristic methods is used to solve optimal DG power output. A TS method to size the DG optimally, as well as the reactive sources within the distribution system, is presented in [14]. A multi-objective function is proposed to determine the optimal locations to place DGs in distribution system to minimize power loss of the system and enhance reliability improvement and voltage profile [15]. [16] Considered an analytical expression to calculate the optimal size and an effective methodology to identify the corresponding optimum location for DG in primary distribution systems.

In this paper, the problem of optimal DG location and sizing in distribution systems is formulated as a multi-objective optimization problem and BFA is used to solve this problem. The optimal DG location and sizing problem is converted to an optimization problem with the multi-objective function including the network power losses and better voltage regulation. The effectiveness of the proposed BFA is tested on 33 and 69 bus systems in Distributed generation. Results show that the proposed method provides the correct answers with high accuracy in the initial iterations in comparison with other methods and is superior to them.

II. BACTERIAL FORAGING ALGORITHM (BFA)

Natural selection tends to eliminate animals with poor foraging strategies and favor the propagation of genes of those animals that have successful foraging strategies since they are more likely to enjoy reproductive success. After many generations, poor foraging strategies are either eliminated or shaped into good ones. The E. coli bacteria that are present in our intestines also undergo a foraging strategy. The control system of these bacteria that dictates how foraging should proceed can be divided into four sections namely Chemotaxis, Swarming, Reproduction and Elimination and Dispersal [19].

A. Chemotaxis

This process is achieved through swimming and tumbling via Flagella. Depending upon the rotation of Flagella in predefined direction (swimming) or altogether in different directions (tumbling), in the entire lifetime. To represent a tumble, a unit length random direction, say φ, is generated; this will be used to define the direction of movement after a tumble in a tumble, the position of the ith bacterium is updated as:

\[ \theta^i(j+1,k,l) = \theta^i(j,k,l) + C \times \angle \phi \]  

Where \( \theta^i(j,k,l) \) is the position of the \( i_{th} \) bacterium at the \( j_{th} \) chemotactic step of the \( k_{th} \) reproduction loop in the \( l_{th} \)
elimination-dispersal event, \( C \) is the size of the step taken in the random direction specified by the tumble, \( \angle \phi \) is the angle of the direction which is randomly generated in the range of \([0, 2\pi]\).

**B. Cell-to-cell Communications**

E-coli bacterium has a specific sensing, actuation and decision-making mechanism. As each bacterium moves, it releases attractant to signal other bacteria to swarm towards it. Meanwhile, each bacterium releases repellent to warn other bacteria to keep a safe distance from it. BFA simulates this social behavior by representing the combined cell-to-cell attraction and repelling effect as:

\[
J_{cc}(\theta'(j,k,l),\theta(j,k,l)) = \sum_{i=1}^{S} J'_{cc}(\theta', \theta) =
\]

\[
\sum_{i=1}^{S} \left[ -d_{\text{attract}} \exp(-\omega_{\text{attract}} \sum_{m=1}^{P} (\theta'_m - \theta'_m)^2) \right] + \sum_{i=1}^{S} \left[ -d_{\text{repellant}} \exp(-\omega_{\text{repellant}} \sum_{m=1}^{P} (\theta'_m - \theta'_m)^2) \right]
\]

Where \( J_{cc}(\theta', \theta) \) is the cost function value to be added to the actual cost function to be minimized to present a time varying cost function. \( S \) is the total number of bacteria and \( P \) the number of parameters to be optimized which are present in each bacterium. \( d_{\text{attract}}, \omega_{\text{attract}}, d_{\text{repellant}}, \omega_{\text{repellant}} \) are different coefficients that are to be chosen properly.

**C. Reproduction**

In BFA, a fixed total number of reproduction steps, \( N_{re} \) is given. Only the first half of populations survive in each reproduce step a surviving bacterium splits into two identical ones, which occupy the same position in the environment as the one in previous step. Thus the population of bacteria keeps constant in each chemotactic step. After \( N_c \) chemotactic steps, the fitness values for the \( i_{th} \) bacterium in the chemotactic loop are accumulated and calculated by:

\[
j^i_{\text{health}} = \sum_{j=1}^{N_c} j^i (j,k,l)
\]

Where \( j^i_{\text{health}} \) presents the health of the \( i_{th} \) bacterium the smaller the \( j^i_{\text{health}} \) is, the healthier the bacterium is. To simulate the reproduction character in nature and to accelerate the swarming speed, all the bacteria are sorted according to their health values in an ascending order and each of the first \( S_r \) ( \( S_r = S / 2 \) , for convenience \( S \) is assumed to be a positive even integer) bacteria splits into two bacteria. The characters including location and step length of the mother bacterium are reproduced to the children bacterium. Through this selection process the remaining \( S_r \) unhealthier bacteria are eliminated and discarded. To simplify the algorithm, the number of the bacteria keeps constant in the whole process.

**D. Elimination-dispersal**

For the purpose of improving the global search ability, elimination-dispersal event is defined after \( N_{re} \) steps of reproduction. The bacteria are eliminated and dispersed to random positions in the optimization domain according to the probability \( P_{ed} \). This elimination-dispersal event helps the bacterium avoid being trapped into local optima. The number of the event is denoted as \( N_{ed} \).

**III. PROBLEM FORMULATION**

The optimal placement and sizing problems of distributed generation are formulated as a multi-objective function including the network power losses, better voltage regulation and improve the voltage stability. The goal is to converge these three objective functions into one, using the penalty coefficient.

**A. Fitness Function**

The objective function is calculated as follows:

\[
OF = \text{Min}\left(f_1 + f_2 + f_3\right) + \beta_1 \sum_{i \in N_{ac}} \max(V_{ii} - V_{i_{\text{max}}}) + \beta_2 \sum_{j \in N} \max\left(|S_{ji} - |S_{ji_{\text{max}}}|, 0\right)
\]

Where \( f_1, f_2 \) and \( f_3 \) are the objective functions to the real power losses, improve voltage profile and for improving voltage stability index, respectively which are expressed in components as follow:

\[
f_1 = \sum_{i=2}^{n_n} \left( P_{gni} - P_{dhi} - V_{mi}V_{ni}Y_{ni} \cos(\delta_{mi} - \delta_{ni} + \theta_{ni}) \right)
\]

\[
f_2 = \sum_{j=1}^{n_n} \left( V_{ni} - V_{\text{rated}} \right)^2
\]

Where:

\[
S_i(n) = |V_{ni}|^2 - 4[P_{ni}(ni) + Q_{ni}(ni)X_{ni}]V_{mi}^2 - 4[P_{ni}(ni) + Q_{ni}(ni)X_{ni}]
\]

It is very important to identify weak buses for nodes with minimum voltage stability index that are prone to voltage instability. Investigating the voltage stability index behavior demonstrate that the buses which experiencing large voltage drops are weak and within the context of remedial actions. So, it makes sense to act on controls that will improve the voltage magnitudes at weak buses.

**B. Power flow Constrains**

The power flow equations to be satisfied for each bus as follows:

\[
P_{gni} = P_{dhi} + \sum_{j=1}^{N} V_{nj}Y_{nj} \cos(\delta_{ni} - \delta_{nj} - \theta_{nj}) = 0
\]

\[
Q_{gni} = Q_{dhi} + \sum_{j=1}^{N} V_{nj}Y_{nj} \sin(\delta_{ni} - \delta_{nj} - \theta_{nj}) = 0
\]
C. Voltage profile Constrains
The voltage should be kept within standard limits at each bus as follow:

\[ V_{ni} \text{min} < V_{ni} < V_{ni} \text{max} \]  

(10)

D. DG units Constrains
It is necessary for the DG units to be constrained capacity between the maximum and the minimum levels as follow:

\[ P_{gni} \text{min} < P_{gni} < P_{gni} \text{max} \]  

(11)

E. Thermal constraint
Thermal limit of distribution lines for the network should not be exceeded:

\[ |S_{ni}| \leq |S_{ni} \text{max}| \]  

(12)

IV. CASE STUDY
The proposed BFA scheme for optimal placement and sizing of DG has been tested for several power systems. Here, the test results for two different distribution systems to demonstrate its effectiveness are presented and investigated. The pre installation values of the objective functions for DG have been shown in Table I.

A. 33 Bus Radial Distribution Systems
At first the proposed technique is applied on a radial system with the total load of 3.72 MW, 2.3 MVAR, 33 bus and 32 branches as it is shown in Fig. 1. The real power and reactive power losses in the system are 210.998 (kW) and 143 (KVAR) respectively. The voltage profile before installation DG and after optimally placing DGs and voltage stability index are given in Fig. 2 and Fig. 3 respectively. The minimum fitness value evaluating process has been shown in Fig.4. Table II demonstrates the results for optimal placement and sizing problems of distributed generation.

<table>
<thead>
<tr>
<th>Method</th>
<th>Objective function value</th>
<th>DG Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>BFA</td>
<td>0.2109</td>
<td>0.3141</td>
</tr>
<tr>
<td></td>
<td>0.2217</td>
<td>0.2197</td>
</tr>
<tr>
<td></td>
<td>0.7771</td>
<td>31</td>
</tr>
</tbody>
</table>

Table I

Table II

<table>
<thead>
<tr>
<th>Objective function value</th>
<th>DG Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>F2</td>
</tr>
<tr>
<td>33-Bus</td>
<td>0.2109</td>
</tr>
<tr>
<td>69-Bus</td>
<td>0.2217</td>
</tr>
<tr>
<td></td>
<td>0.7771</td>
</tr>
</tbody>
</table>

Example of Table:

<table>
<thead>
<tr>
<th>System</th>
<th>Objective function value</th>
</tr>
</thead>
<tbody>
<tr>
<td>33-Bus</td>
<td>0.2109</td>
</tr>
<tr>
<td>69-Bus</td>
<td>0.2217</td>
</tr>
</tbody>
</table>

Fig. 1. The 33 bus radial distribution system

Fig. 2. Voltage profile of 33-bus

Fig. 3. Voltage stability index of 33-bus

Fig. 4. Variations of objective function
B. 69 Bus radial distribution systems

The other system employed to evaluate the proposed method is the 69 bus radial distribution system that has the total load of 3.80 MW and 2.69 MVAR and it is demonstrated in Fig. 5.

To have a better understanding, the voltage profile and voltage stability index are illustrated in Fig. 6 and Fig. 7. The minimum fitness value evaluating process DG location and capacities are represented in Fig 8 and Table III.

Fig. 5. The 69 bus radial distribution system

Fig. 6. Voltage profile of 69-bus

Fig. 7. Voltage stability index of 69-bus

V. Conclusion

A BFA for optimal placement and sizing of DG units is presented in this paper. The proposed BFA algorithm for optimal placement of DG is easy to implement without additional computational complexity. The capability of the proposed approach is tested on 33 and 69 bus systems to minimize the losses, to increase the voltage stability and to improve the voltage profile. Also the proposed technique exhibits a higher capability in finding optimum solutions by taking into account the active power losses, reactive power and the value for objective function.

APPENDIX

Nomenclature

- \( n_i \) receiving bus number (\( n_i =2,3, \ldots, n \))
- \( m_i \) bus number that sending power to bus \( n_i \) (\( m_2 = n_1 =1 \))
- \( i \) branch number that fed bus \( n_i \)
- \( N_{DG} \) total number of DG
- \( P_{gni} \) active power output of the generator at bus \( n_i \)
- \( Q_{gni} \) reactive power output of the generator at bus \( n_i \)
- \( P_{dni} \) active power demand at bus \( n_i \)
- \( Q_{dni} \) reactive power demand at bus \( n_i \)
- \( P_{ni} \) total real power load fed through bus \( n_i \)
- \( Q_{ni} \) total reactive power load through bus \( n_i \)
- \( P_{min} \) Minimum active power of DG at bus \( n_i \)
- \( P_{max} \) Maximum active power of DG at bus \( n_i \)
- \( V_{ni} \) voltage of bus \( n_i \)
- \( V_{mi} \) voltage of bus \( m_i \)
- \( V_{min} \) Minimum voltage at bus \( n_i \)
- \( V_{max} \) Maximum voltage at bus \( n_i \)
<table>
<thead>
<tr>
<th>$S_{ni}^{\text{max}}$</th>
<th>Maximum apparent power at bus $n_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y_{ni}$</td>
<td>admittance between bus $n_i$ and bus $m_i$</td>
</tr>
<tr>
<td>$\theta_{ni}$</td>
<td>Phase angle of $Y_{ni} = \angle \theta_{ni}$</td>
</tr>
<tr>
<td>$\delta_{ni}$</td>
<td>Phase angle of voltage at bus $n_i$ $V_{ni} = V_{ni} \angle \delta_{ni}$</td>
</tr>
<tr>
<td>$\delta_{mi}$</td>
<td>Phase angle of voltage at bus $m_i$</td>
</tr>
<tr>
<td>$V_{\text{ret}}$</td>
<td>rated voltage (1 p.u.)</td>
</tr>
<tr>
<td>$\text{SI}_{(ni)}$</td>
<td>voltage stability index of node $n_i$ , $(n_i = 2, 3, \ldots, n)$</td>
</tr>
</tbody>
</table>

**Constant Values**

- $\beta_1$: penalty coefficient, 0.32
- $\beta_2$: penalty coefficient, 0.3
- $r_1$: penalty coefficient ($k_1 = 0.6$)
- $r_2$: penalty coefficient ($k_2 = 0.35$)
- $f_1$: network real power losses (pu)
- $f_2$: network voltage profile (pu)
- $f_3$: network voltage stability index (pu)

**REFERENCES**


