A SELECTIVE PARTICLE SWARM OPTIMIZATION FOR LARGE SCALE PRACTICAL DISTRIBUTION SYSTEM RECONFIGURATION

Tamer M. KHALIL SELIM
Canal Co. for Elec. Dist. – Egypt
tamerml@yahoo.com

Alexander V. GORPINICH
Pryazovskyi State Tech. Univ. – Ukraine
gorpinich@ieee.org

Irena WASIAK
Lodz Univ. of Technology – Poland
irena.wasiak@p.lodz.pl

ABSTRACT

This paper proposes a selective particle swarm optimization (SPSO) for solving the large scale distribution network reconfiguration (DNR) problem. The problem is posed as an optimization problem with an objective to maximize the losses reduction. The optimization procedure is subject to some technical (maximum permissible branch current) and operational constraints (load connectivity and radial network structure). SPSO is a simple modification of the binary particle swarm optimization (PSO). The search space for proposed algorithm is a set of branches (switches) which are normally closed or normally opened, this search space may be dissimilar for different dimensions. The proposed algorithm has been implemented and tested on the practical distribution network supplying the eastern part of city Mariupol, Ukraine. Simulation results demonstrate an effectiveness of the proposed algorithm in reducing the power and energy losses, improving the voltage profile and increasing the total annual benefits after DNR.

INTRODUCTION

The distribution network usually operates in a radial configuration, with tie switches between circuits to provide alternate feeds. Whenever components fail, some of the switches must be operated to restore power to as many customers as possible. DNR is a process of changing the status of the network topology through opening or closing tie switches to optimize the network parameters. Thus, under normal operating conditions the network is reconfigured to reduce the system's losses and/or to balance load in the feeders. Under conditions of permanent failure, the network is reconfigured to restore the service, minimizing the zones without power.

DNR is a problem of complicated multi-objective mixed-integer combinatorial nonlinear optimization. The complexity of the problem arises from the fact that distribution network topology has to be radial and power flow constraints are nonlinear in nature. The first recognized work which attempts to solve the problem of distribution system reconfiguration for losses reduction was presented by Merlin and Back [1]. Since this work up to date many algorithms have been developed to solve this problem. Most of these algorithms are based on heuristic techniques and artificial intelligence methods. Merlin and Back [1] proposed a heuristic algorithm to determine the minimum losses configuration. In this algorithm, all network switches are first closed to form a meshed network. The switches are then opened successively to restore radial configuration.

Other heuristic algorithms were proposed by Civanlar et al. [2] and Baran et al. [3]. These algorithms are based on the branch exchange heuristic method, where a simple formula has been derived to determine how a branch exchange affects the losses. In [4], an exhaustive survey of the modern heuristic methods to solve the DNR problem is presented. Artificial intelligence methods were also applied to DNR problem extensively, for example, simulated annealing [5], neural networks [6], genetic algorithms [7], tabu search [8], ant colonies [9], fuzzy logic [10] and PSO [11].

This paper proposes a SPSO to solve the problem of large scale practical distribution system reconfiguration. The practical network used in this paper is a real urban distribution system with 274 buses and 284 branches used for supplying the eastern part of Mariupol city, Ukraine. The total benefits resulting from power and energy losses reduction after DNR are presented.

PROBLEM FORMULATION

Feeder reconfiguration is performed by selecting, among all possible configurations, the one that incurs the smallest power losses and that satisfies a group of constraints. Usually a minimum of network losses is considered to be objective. Thus objective function is to minimize the real power losses of distribution system \( P_L \) considering the following constraints.

1. Branch current constraint
   \[
   I_b \leq I_{b\text{max}} \tag{1}
   \]
   where \( I_b \) is the current of branch \( b \), and \( I_{b\text{max}} \) is the maximum permissible current of branch \( b \).

2. Load connectivity (each bus should be connected to substation via only one path).

3. Radial network structure (loops are not allowed in the network).

SOLUTION METHOD

SPSO was presented in [12] as a simple modification of the binary PSO to search in a selected space. In basic PSO, the \( d \)-dimensional search space is modeled via
position, velocity, best previous position for each particle (i-th particle) and best position for all particles. These parameters are represented by vectors described as 

\[ X_i = [x_{i1}, x_{i2}, ..., x_{in}], \quad V_i = [v_{i1}, v_{i2}, ..., v_{id}], \quad PB_i = [pb_{i1}, pb_{i2}, ..., pb_{id}] \] 

respectively. At iteration \( k \) the velocity and position for \( d \)-dimension of \( i \)-th particle are updated by (2) and (3) respectively:

\[ u_{id}^{k+1} = w u_{id}^k + c_1 r_1 (pb_{id}^k - x_{id}^k) + c_2 r_2 (gb_{id}^k - x_{id}^k) \]  

(2)

\[ x_{id}^{k+1} = x_{id}^k + u_{id}^{k+1} \]  

(3)

where \( i = 1, 2, ..., n \); \( n \) is the set of particles in swarm (i.e. “population”) described as \( pop = [X_1, X_2, ..., X_n] \); \( w \) is the inertia weight; \( c_1 \) and \( c_2 \) are the acceleration constants; \( r_1 \) and \( r_2 \) are the two random values in range [0,1].

In SPSO, the search space at each \( d \)-dimension \( S_d = [s_{d1}, s_{d2}, ..., s_{dn}] \) is the set of \( dn \) positions, where \( dn \) is the number of the selected positions in dimension \( d \). The sigmoid transformation is presented by (4), and the \( i \)-th coordinate of each particle’s position at a dimension \( d \) is a selective value updated by (5)

\[ \text{sigmoid}(u_{id}^{k+1}) = \frac{1}{1 + \exp(-u_{id}^{k+1})} \]  

(4)

\[ x_{id}^{k+1} = \begin{cases} 
  s_{d1}, & \text{if sigmoid}(u_{id}^{k+1}) < 1 \\
  s_{d2}, & \text{if sigmoid}(u_{id}^{k+1}) < 2 \\
  s_{d3}, & \text{if sigmoid}(u_{id}^{k+1}) < 3 \\
  \vdots & \text{otherwise} \\
  s_{dn}, & \text{if sigmoid}(u_{id}^{k+1}) < dn 
\end{cases} \]  

(5)

where \( s_{d1}, s_{d2}, s_{d3}, ..., s_{dn} \) are the selected values in dimension \( d \).

Velocity values are restricted to some minimum and maximum values \([V_{\text{min}}, V_{\text{max}}]\) by means of (6):

\[ u_{id}^{k+1} = \begin{cases} 
  V_{\text{max}}, & \text{if } u_{id}^{k+1} > V_{\text{max}} \\
  u_{id}^{k+1}, & \text{if } |u_{id}^{k+1}| \leq V_{\text{max}} \\
  V_{\text{min}}, & \text{if } u_{id}^{k+1} < V_{\text{min}} 
\end{cases} \]  

(6)

Equation (7) is used to avoid invariability of the value of \( i \)-th particle velocity in a \( d \)-dimension at the maximum or minimum values and force each particle going through the search space:

\[ v_{id}^{k+1} = \begin{cases} 
  \text{rand} \times u_{id}^{k+1}, & \text{if } |u_{id}^{k+1}| = |u_{id}^k| \\
  u_{id}^{k+1}, & \text{otherwise} 
\end{cases} \]  

(7)

**SIMULATION RESULTS FOR PRACTICAL DISTRIBUTION SYSTEM**

The proposed SPSO has been applied to 6 kV practical distribution network supplying the eastern part of city Mariupol, Ukraine. It consists of 37 feeders connected to three substations. These feeders contain 274 buses and 284 branches and are normally closed and 11 are normally opened. The single line diagram and the load data for this network are given in [13].

**Implementation of SPSO for DNR**

Based on algorithm of SPSO [12], there are two main requirements before applying SPSO to any problem: 1) specifying the number of dimensions; 2) finding the search space for each dimension.

**1) Specifying the number of dimensions.**

Distribution network is designed as multiloop circuits but it runs in open loop to assure the network in the form of a tree. To specify the number of dimensions for DNR problem, all tie switches must be closed to give number of loops. The number of dimensions equals the number of loops. For given practical network the number of dimensions will be 11. Herein all tie and sectionalizing switches which belong to any loop are considered as candidate switches for reconfiguration process.

**2) Finding the search space for each dimension.**

The practical network used in this paper has 284 branches, 273 sections and 11 tie switches. In this network some branches don’t belong to any loop so these branches will be not considered in the search spaces [14]. Fig. 1 shows the candidate branches for DNR based on the single line diagram given in [13]. It should be noted that the branches belonging to more than one search space will be appeared randomly in only one search space per iteration.

From the loops presented in Fig. 1 the search spaces could be identified as follows:

\[ S_1 = [85 87 89 111 274 181]; \]
\[ S_2 = [112 275 169 167 274 161]; \]
\[ S_3 = [113 114 116 276 30 29 28 27]; \]
\[ S_4 = [16 18 19 20 21 277 170]; \]
\[ S_5 = [180 278 44 43 279 182 181]; \]
\[ S_6 = [179 42 170 43 279 182 181]; \]
\[ S_7 = [172 173 175 176 178 280 185 186 191 192]; \]
\[ S_8 = [193 194 281 246 245 244 238 232 232 185 186 191 192]; \]
\[ S_9 = [124 125 126 127 162 132 136 137 282 161]; \]
\[ S_{10} = [128 129 131 283 132 136 137 282 161]; \]
\[ S_{11} = [146 151 153 154 155 156 157 159 160 284 267 266 265 264 262]; \]

After specifying the number of dimensions, and finding the search space for each dimension, SPSO would be used to select the optimal solution from the search space for each dimension by Equations (2), (6), (7), (4) and (5), respectively.

**CIRED 2015**

**2/4**
Simulation Results

In the base configuration, the normally opened branches (tie switches) have numbers 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, and 284. This configuration causes 7.4% power losses, 5% energy losses, and 0.79 p.u. minimum voltage. After applying the proposed algorithm, the optimal configuration is obtained by keeping the branches with numbers 275, 276 and 278 to be opened and closing the rest of tie switches. In this configuration, the branches with numbers 111, 275, 276, 170, 278, 181, 178, 281, 132, 129, 157 become as a tie switches and power losses reduced to 6.2%, energy losses reduced to 4.2%, and minimum voltage improved to 0.88 p.u. Table 1 shows simulation results.

Table 1: Simulation results

<table>
<thead>
<tr>
<th>Item</th>
<th>Base Case</th>
<th>After DNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tie switches</td>
<td>274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284</td>
<td>111, 275, 276, 170, 278, 281, 132, 129, 157</td>
</tr>
<tr>
<td>Min. voltage (p.u.)</td>
<td>0.79</td>
<td>0.88</td>
</tr>
<tr>
<td>Max. voltage (p.u.)</td>
<td>1.06</td>
<td>1.06</td>
</tr>
<tr>
<td>Power losses (kW)</td>
<td>4637.0</td>
<td>3902.2</td>
</tr>
<tr>
<td>Energy losses (kWh)</td>
<td>15853464</td>
<td>13341410</td>
</tr>
<tr>
<td>Power losses (%)</td>
<td>7.4</td>
<td>6.2</td>
</tr>
<tr>
<td>Energy losses (%)</td>
<td>5</td>
<td>4.2</td>
</tr>
</tbody>
</table>

Economic Evaluation

The annual benefits after DNR are obtained from power and energy losses reduction. The benefits from power losses reduction are obtained from the savings produced by avoiding the costs due to investment deferral in the expansion of network. In other words, reducing the power losses means reducing the capital costs of network. The benefits from energy losses reduction at different load levels are obtained from reduction the running costs of network. In this paper, the costs per unit of power and energy losses are assumed to be 168 $/kW and 0.035 $/kWh respectively. Table 2 shows the total annual benefits resulting from power and energy losses reduction after DNR. These benefits are equal to 211356.7 $/year representing 15.8% from the total cost of power and energy losses before DNR.

Table 2: Total benefits resulting from power and energy losses reduction

<table>
<thead>
<tr>
<th>Item</th>
<th>Base Case</th>
<th>After DNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power losses cost ($/year)</td>
<td>779012.6</td>
<td>655577.8</td>
</tr>
<tr>
<td>Energy losses cost ($/year)</td>
<td>554871.2</td>
<td>466949.3</td>
</tr>
<tr>
<td>Total cost ($/year)</td>
<td>1333883.8</td>
<td>1122527.1</td>
</tr>
<tr>
<td>Benefits ($/year)</td>
<td>0</td>
<td>211356.7</td>
</tr>
<tr>
<td>Benefits (%)</td>
<td>0</td>
<td>15.8</td>
</tr>
</tbody>
</table>
CONCLUSIONS

To solve the problem of large scale distribution system reconfiguration effectively, a SPSO has been proposed as a simple modification of the binary PSO with search space representing a set of selected values. The proposed SPSO has been applied to 6 kV practical distribution system with 274 buses and 284 branches used for supplying the eastern part of Mariupol city, Ukraine. After applying SPSO, the power losses reduced from 7.4% to 6.2% and energy losses reduced from 5% to 4.2% (these benefits are equal to 211356.7 $/year or 15.8% from the total cost of power and energy losses before reconfiguration) while minimum voltage improved from 0.79 p.u. to 0.88 p.u. Future work will be addressed to application of SPSO for solving the reconfiguration, capacitor placement and reconductoring problems of large scale practical distribution system simultaneously.

REFERENCES


