Particle Swarm Optimization algorithm for optimal settings of distributed sources

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Abstract

This paper deals with a method for the optimal settings of distributed sources in order to reduce the power losses in the distribution network. The sizing of distributed sources may be considered as a complex optimization problem. In this paper, a Particle Swarm Optimization Algorithm (PSO) as a suitable tool is used.

1. Introduction

Distribution networks are facing tremendous challenges which are dependent on several factors. One of them is the increasing penetration of distributed energy resources (DERs), especially those based on renewable energies. Following the way in which the power system has evolved from conventional structures into structures with more dispersed energy generation, some basic problems can be pointed out. In the conventional power system the energy generation takes place in the central units. The energy flow is one-directional and the system structure corresponds to a ‘top-down’ structure. A big disadvantage of this structure is that the produced energy needs to be transported through long distances from generation to consumption points, what is connected with high costs and energy losses. Dispersed generation (DG), based on renewable energy resources was introduced as a solution to reduce the impact of that problem [1].

DG can provide benefits for the consumer, for the utilities and the reasons for the implementing DG units are energy efficiency or rational use of energy, deregulation or competition policy, diversification of energy resources, availability of a modular generating plant, ease of finding sites for smaller generators, shorter construction times and lower capital cost of smaller plants and proximity of the generation plant to a heavy load, which reduces transmission costs [2].

The sizing of DG units may be resulted as a complex optimization problem in distribution networks. In this paper, the Particle Swarm Optimization Algorithm (PSO) is used for the optimal settings of distributed sources to reduce the power losses in the distribution network [3].

The PSO was firstly introduced by Kennedy and Eberhart in 1995 as a new heuristic method based on simulation the social behavior of bird flocks and fish school. They found out that with some modifications, their social behavior model can serve as a powerful optimizer [4].

2. Particle Swarm Optimization

PSO is a fast, simple and efficient population-based optimization method. The coordinates of each particle represent a possible solution associated with two vectors, the position ($x_i$) and velocity ($v_i$). A swarm consists of a number of particles that fly through the solution space to find out points of optimal solutions. During their searching, particles interact with each other to optimize their search experience. In each iteration, the particle updates its position based on its own best position (Pbest) as well as global best position among particles (Gbest) and its previous velocity vector according to the following equations [5]:
\[ v_i^{k+1} = w \cdot v_i^k + c_1 \cdot r_1 \left( P_{\text{best}}^k - x_i^k \right) + c_2 \cdot r_2 \left( G_{\text{best}} - x_i^k \right), \]
\[ x_i^{k+1} = x_i^k + \lambda \cdot v_i^{k+1}, \]
where,
- the velocity of \( i \)th particle at \((k+1)\)th iteration
- an inertia weight of the particle
- the velocity of \( i \)th particle at \( k \)th iteration
- positive constants having values between \([0, 2.5]\)
- randomly generated numbers between \([0, 1]\)
- the best position of the particle
- the best particle position based on overall swarm’s experience
- the iteration index
- the position of \( i \)th particle at \((k+1)\)th iteration
- the position of \( i \)th particle at \( k \)th iteration
- the constriction factor. It may help to insure convergence

Suitable selection of the inertia weight \( w \) provides a balance between global and local explorations. The inertia weight can be set according to the following equation:
\[ w = w_{\text{max}} - \frac{w_{\text{max}} - w_{\text{min}}}{\text{iter}_{\text{max}}} \times \text{iter}, \]
where, \( w_{\text{max}} \) is the value of inertia weight at the beginning of optimization, \( w_{\text{min}} \) is the value of inertia weight at the end of optimization, \( \text{iter} \) is the current iteration number and \( \text{iter}_{\text{max}} \) is the maximum number of iterations [5].

The velocity vector in the equation (1) consists of three elements. These elements determine the next position [6]:
1. Previous velocity – determines velocity which is stored from the previous iteration.
2. The cognitive component – this element represents the attraction force.
3. The social component – this element corresponds to each particle tendency to be attracted toward the best position discovered among the entire individuals in a swarm.

3. Problem formulation

The objective is to find out the optimal size of DGs in order to minimize the real power losses. The total active power losses in distribution system are given by
\[ P_{\text{loss}} = \sum_{i=1}^{N} R_i \cdot I_i^2, \]
where, \( R_i \) is the resistance of the \( i \)th branch and \( I_i \) is the magnitude of the branch current. In this paper, the branch current is obtained by using a node voltage method. The branch current consists of two elements, an active element and reactive element. The losses are associated with active and reactive elements of branch currents [2].

3.1 Objective function

The objective function to be minimized is given by following equation:
\[ F_0 = \sum_{N} P_{\text{loss}} + P_{\text{f}}, \]
where, \( N \) is number of branches, \( \sum_{N} P_{\text{loss}} \) are total power losses in the distribution system and \( P_{\text{f}} \) is a penalty function.

The penalty function is defined according to the following equation:
\[ P_{\text{f}} = \lambda_1 \sum_{i=1}^{N} f(V_i - V_i^{\text{lim}})^2 + \lambda_2 \sum_{i=1}^{N} f(P_{gi} - P_{gi}^{\text{lim}})^2, \]
where, \( \lambda_1, \lambda_2 \) are penalty factors, \( V_i \) is the voltage magnitude at \( i \)th node and \( P_{gi} \) is the power output of \( i \)th generator, \( V_i^{\text{lim}} \) and \( P_{gi}^{\text{lim}} \) are defined as
\[ V_i^{\text{lim}} = \begin{cases} V_i^{\text{max}}, & V_i > V_i^{\text{max}} \\ V_i^{\text{min}}, & V_i < V_i^{\text{min}} \end{cases} \]
\[ P_{gi}^{\text{lim}} = \begin{cases} P_{gi}^{\text{max}}, & P_{gi} > P_{gi}^{\text{max}} \\ P_{gi}^{\text{min}}, & P_{gi} < P_{gi}^{\text{min}} \end{cases} \]

4. Case study

A 22-kV power system is fed by two 110-kV systems (S_1, S_2). There are three circuit breakers opened in the basic connection. The loads are connected at the individual nodes. The single line diagram of the network is shown in Fig. 1 and lengths of the segment lines are presented in Table 1.
Active and reactive load powers are summarized in Table 2. Distributed sources are also included in the system and their installed capacities are summarized in Table 3.

### Tab. 2 Buses data

<table>
<thead>
<tr>
<th>bus no.</th>
<th>P [MW]</th>
<th>Q [MVar]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.69</td>
<td>0.228</td>
</tr>
<tr>
<td>4</td>
<td>2.945</td>
<td>0.92</td>
</tr>
<tr>
<td>5</td>
<td>1.96</td>
<td>0.612</td>
</tr>
<tr>
<td>9</td>
<td>1.13</td>
<td>0.353</td>
</tr>
<tr>
<td>10</td>
<td>1.11</td>
<td>0.347</td>
</tr>
<tr>
<td>11</td>
<td>1.13</td>
<td>0.353</td>
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<tr>
<td>12</td>
<td>1.42</td>
<td>0.443</td>
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<tr>
<td>13</td>
<td>1.72</td>
<td>0.537</td>
</tr>
<tr>
<td>15</td>
<td>0.5</td>
<td>0.156</td>
</tr>
<tr>
<td>17</td>
<td>0.51</td>
<td>0.159</td>
</tr>
<tr>
<td>18</td>
<td>0.5</td>
<td>0.156</td>
</tr>
<tr>
<td>21</td>
<td>1.42</td>
<td>0.443</td>
</tr>
</tbody>
</table>

### Tab. 3 DR data

<table>
<thead>
<tr>
<th>DR no.</th>
<th>bus no.</th>
<th>Pinst [MW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>2.97</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>3.999</td>
</tr>
<tr>
<td>3</td>
<td>21</td>
<td>3.983</td>
</tr>
</tbody>
</table>

In this paper is considered that distributed sources are limited and the boundaries for generated power of sources will be following:

- \( 0 \leq P_{g1} \leq 2.97\text{MW} \)
- \( 0 \leq P_{g2} \leq 3.999\text{MW} \)
- \( 0 \leq P_{g3} \leq 3.983\text{MW} \)

### 5. Simulation results

The Particle Swarm Optimization algorithm was implemented in the Matlab computing environment in order to minimize the active power losses in the 22-kV network. In this paper is considered that distributed sources are working with power factor \( \cos \varphi = 1 \). Node voltages and branch currents are determined by using a node voltage method. Selected parameters of PSO are presented in Table 4. Convergence characteristic of PSO is illustrated in Fig. 2.

### Tab. 4 Parameters of PSO

<table>
<thead>
<tr>
<th>parameter</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>population size</td>
<td>50</td>
</tr>
<tr>
<td>acceleration constants ( c_1, c_2 )</td>
<td>1.2 and 0.2</td>
</tr>
<tr>
<td>constriction factor</td>
<td>0.729</td>
</tr>
<tr>
<td>max. and min. inertia weights</td>
<td>1 and 0.2</td>
</tr>
<tr>
<td>max. and min. velocity of particles</td>
<td>1 and -1</td>
</tr>
</tbody>
</table>

As it can be seen from the convergence characteristic of PSO, the power losses are reduced to the value 235.47 kW. The optimal settings of distributed sources obtained by the proposed PSO are summarized in Table 5.

### Tab. 5 Optimal power generation of DGs

<table>
<thead>
<tr>
<th>DR no.</th>
<th>bus no.</th>
<th>Pgoptimal [MW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>2.667</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>3.124</td>
</tr>
<tr>
<td>3</td>
<td>21</td>
<td>0.381</td>
</tr>
</tbody>
</table>
6. Conclusion

Nowadays, a big emphasis is put on the reduction of CO₂ emissions and therefore is necessary to find a way how to reduce them. One possibility of mitigating this problem is a renewable distributed resources deployment.

This paper has presented the PSO algorithm which is used for the optimal settings of generated power of distributed sources in order to minimize the power losses. The algorithm is created in the Matlab computing environment. The power losses before optimization were 370.32 kW and after optimization, the power losses were reduced to the value of 235.47 kW. As it can be seen, the power losses are possible to minimize with the increased penetration and the optimal settings of distributed resources. These are first results in our research work and in the future, we would like to deal with the optimization of reactive powers of distributed resources.

7. Bibliography And Authors

Bibliography


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