Multi-period Reconfiguration of the Distribution Network Based on the Improved EM Algorithm

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Abstract. Developing with the time, the distribution network technology has become increasingly perfect and mature. But with the improvement of people's living standards, the variety of the load is changing, the amount of the load is increasing, such as the electric vehicle as one of the members has gradually come into our life. Large-scale electric cars access to distribution network, the randomness and dispersion of electric cars put forward new requirements to management of the distribution network, and give challenges to the load capacity of transmission lines. In order to make the distribution network that contains electric vehicles run under the condition of safe, economic and steady, this paper make the distribution network into period divisions according to the characteristics of electric vehicle and the similarity of load, put forward a kind of distribution network dynamic reconfiguration scheme that based on the improved EM algorithm to solve distribution network optimal operation state.

Introduction

The distribution network can be expressed by a certain topology[1], different types of the distribution network have different distribution network topologies. For load changes, especially electric vehicles and other distributed powers access in, a single distribution network topology often can not make the electricity system run in the optimal conditions[2]. Randomness and dispersion of the load have an effect on a single distribution network topology: in the part of power quality, the grid voltage amplitude increases, harmonic harm appears, and may lead to a three-phase unbalance. it also affects reliability of power supply; in the part of distribution network’s economic operation, line losses increase, make the distribution transformer overload, and affect the life of the transformer. So it is particularly important to make a distribution network reconfiguration to change this situation. The distribution network Reconstructions can be divided into two parts: static reconfiguration and dynamic reconfiguration[3].

The distribution network reconfiguration takes minimum losses of the distribution network as optimal objective function usually[4]:

\[ \text{min } f = \sum_{i \in \mathbb{N}} P_{i, \text{loss}} = \sum_{i \in \mathbb{N}} \frac{P_i^2 + Q_i^2}{U_i^2} \times R_i \] (1)

\[ \begin{cases} U_{i, \text{min}} \leq U_i \leq U_{i, \text{max}} \\ S_i \leq S_{i, \text{max}} \\ I_{i, \text{min}} \leq I_i \leq I_{i, \text{max}} \end{cases} \] (2)

\[ \text{min } F = \text{min } f + P \left[ \sum_{i=1}^{m} SW_{i, \text{loss}} + \sum_{i=1}^{n} (U_i \cdot U_{i, \text{max}}) + \sum_{i=1}^{n} (I_i \cdot I_{i, \text{max}}) + \sum_{i=1}^{n} (S_i \cdot S_{i, \text{max}}) \right] \] (3)

\[ P_{i, \text{loss}} \] is the power loss of i-th branch, \( U_i \) is the voltage amplitude of i-th branch, \( I_i \) is the current amplitude of i-th branch, \( S_i \) is the load capacity of i-th branch, \( P \) is the penalty coefficient, \( SW_{i, \text{loss}} \) is the losses caused by switching action in i-th branch.
The Improved EM Algorithm

EM algorithm consists of five parts during its process: initialization, local search, calculation of total force vector, population movement and determine to terminate[5,6]. Now we will improve the EM algorithm in the following in the following sections.

The Reverse Learning Initialization

Since the process that the EM algorithm generate the initial solutions is a random process without rules[7,8], so it likely to cause uncertainty in the results. If the initial solutions are uniform so that the EM algorithm optimization will lead to failure. Therefore, the initial solution generating makes an important influence of capacity to subsequent optimization in the algorithm. This paper introduces the reverse learning mechanism to improve the EM algorithm. We define X = (x_1, x_2, ... x_n) as a point in D-dimensional space where (x_1, x_2, ... x_n) ∈ R and x_j ∈ [a_j, b_j](j = 1,2, ..., D), so the X point is reversed follow the formula (4):

\[ x_j' = a_j + b_j - x_j \]

So the population initialization process of the EM algorithm with reverse learning principles are:

It randomly generated initial population N firstly, and calculate the corresponding initial candidate population N' by the formula (4). Mixing population N and population N', and sort particle based on the value of fitness. Lastly, take the front 50 percent of the initial population as the new initial population.

The precision local search

The resultant force calculation method takes the force formula into account, if the individual i-th particle close to the optimal individual X_best, \[|x_i - x_j| \to 0\], then \[F_i \to \infty\], so that a large force comes into being, the moving direction of particles lead to considerable error, the optimal solution can not be found if the particles near the optimal solution. So use the high-precision local optimization operator to optimize the process[9].

In this paper, the Powell local search is used to improve the EM algorithm. The Powell algorithm is not only a pattern search strategy, but also a conjugate direction acceleration method. The method uses initial position randomly given search extremes of each dimension in both directions along the positive and negative. Since this method simply achieves by the function information without having to calculate the derivative function, it is considered as one of most effective strategies to find the minimum value of the function in direct search methods.

The steps of the Powell search method are shown in the following steps[10].

a) Select an initial position \(x^{(0)}\), and determine the solution accuracy \(\varepsilon > 0\), set D initial linearly independent search directions (generally taken to be D coordinate axis directions) \((u_1, u_2, ..., u_D)\). Take \(s_j = u_j + 1(j = 0,1, ..., n - 1; k = 0)\).

b) Take a one-dimensional extremum search, get the \(\lambda_k\), so that \(f(x^{(k)} + \lambda_k s_k) = \min f(x^{(k)} + \lambda s_k)\). Make \(x^{(k+1)} = x^{(k)} + \lambda_k s_k\), if \(k < D - 1\), then \(k = k + 1\), return b; otherwise, turn to c).

c) If \(||x^{(D)} - x^{(0)}|| \leq \varepsilon\), end the search, set \(x^* \approx x^{(D)}\), otherwise take values for \(j(0 \leq j \leq D - 1)\) to make \(\Delta = f(x^{(j)} - x^{(j+1)}) = \max_{0 \leq j \leq D - 1}\left[f(x^{(j)}) - f(x^{(j+1)})\right]\).

d) Set \(f_1 = f(x^{(0)}), f_2 = f(x^{(D)}), f_3 = f(2x^{(D)} - x^{(0)})\). If \(2\Delta < f_1 - 2f_2 + f_3\), do not change search direction \(s_0, s_1, ..., s_{D-1}\), make \(x^{(0)} = x^{(D)}, k = 0\), returns b); otherwise, order \(s_n = (x^{(D)} - x^{(0)})/\|x^{(D)} - x^{(0)}\|\) or \(s_D = x^{(D)} - x^{(0)}, s_i = s_{i+1}, i = j, j + 1, ..., D - 1\), turn to e).

e) Compute the value of \(\lambda_n\), if \(f(x^{(D)} + \lambda s_D) = \min f(x^{(D)} + \lambda s_D)\), get \(x^{(0)} = x^{(D)} + \lambda s_D, k = 0\), return to b).

The main idea of Powell strategy is to search one-dimensional extreme value along the initial D-dimensional orthogonal direction, so that it can generate a new position vector; then determine the new search directions that are closer to the target by researching the difference of calculated vectors, and replacing a primary direction of the search; Search for a new round, to give the vector difference
between the result in the beginning of the cycle and the result that end of the cycle and to achieve substituted direction. Repeat the process, and achieve the goal of the extremum optimization ultimately.

**Chaotic Mapping**

Considering the chaotic motion is not repeated traversing movement within a specific range under some rules, and it has a good variety, this paper takes the method that added the CHAOS algorithm into the EM algorithm can make the population maintain a certain diversity, and strengthen its ability to bounce local extreme. The Tent Mapping has simple structure with good ergodicity and its iteration speed is superior to the Logistic mapping [11], therefore this paper takes the Tent chaotic mapping as a disturbance factor. Specific operations are as follows:

Generate chaotic variables randomly \( X = (X_1, X_2, X_3, ..., X_n) \), to compute chaotic variables by the Tent mapping[12]:

\[
X'_n = \begin{cases} 
2 \cdot X_n, & 0 \leq X_n \leq \frac{1}{2} \\
2 \cdot (1 - X_n), & \frac{1}{2} \leq X_n \leq 1 
\end{cases}
\]

By formula (6), chaotic variables will be mapped to the new solution domain of Inversely to seek a new variable, it can be expressed as

\[
X_{n,new} = \min_{n,l} + (\max_{n,l} - \min_{n,l}) \cdot X'_n
\]

\( \min_{n,l} \) and \( \max_{n,l} \) are the lower limits and upper limits of the original solution domain variables.

**References the Analysis of the Example**

Use an IEEE 33 nodes single feeder system as an simulation example. The system has 33 nodes, 37 branches and five contact switches, rated voltage of the system is 12.66kV, the power is 100MVA. The power load that this distribution network carries is 3710kV + j2200kvar. As shown in Figure 1.

![IEEE 33 nodes single feeder system](image)

Figure 1. IEEE 33 nodes single feeder system.

Assume the number of electric cars in the charge operation in a day as shown in Figure 2.

![Load curve of electric cars](image)

Figure 2. Load curve of electric cars.

Take the experimental data to calculate, following results were obtained and algorithms were compared with the other programs as shown in Table 1:
Table 1. Single static distribution network reconstruction.

<table>
<thead>
<tr>
<th>before reconstruction</th>
<th>Improved tabu search algorithm</th>
<th>the method in this paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS5,9</td>
<td>S24-25</td>
<td>S24-25</td>
</tr>
<tr>
<td>CS1-16</td>
<td>S25-29</td>
<td>S26-27</td>
</tr>
</tbody>
</table>

The switches is opened

<table>
<thead>
<tr>
<th>CS12-22</th>
<th>S29-20</th>
<th>S19-20</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS19-25</td>
<td>S12-22</td>
<td>S1-2</td>
</tr>
<tr>
<td>CS13-26</td>
<td></td>
<td>S1-2</td>
</tr>
</tbody>
</table>

| Network Loss (Kw·h) | 4846.3 | 3182.4 | 2876.64 |

Make the distribution network into period divisions according to the characteristics of electric vehicle and the similarity of load. Segment results is: the part from 16 o'clock to 21 o'clock is subsection I, the part from 22 o'clock to 24 o'clock is subsection II, the part from 1 o'clock to 7 o'clock is subsection III, the part from 8 o'clock to 16 o'clock is subsection IV. The simulation results are shown in Table 2.

Table 2. Distribution network reconfiguration by the similarity of load.

<table>
<thead>
<tr>
<th>Subsection I</th>
<th>Subsection II</th>
<th>Subsection III</th>
<th>Subsection IV</th>
<th>Switching losses/Kw-h</th>
<th>Switching times</th>
</tr>
</thead>
<tbody>
<tr>
<td>disconnect:</td>
<td>disconnect:</td>
<td>disconnect:</td>
<td>disconnect:</td>
<td>1123.34</td>
<td>10</td>
</tr>
<tr>
<td>S27-28, S24-25</td>
<td>S26-27</td>
<td>S6-2</td>
<td>S20-21</td>
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<td></td>
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<td>closure:</td>
<td>closure:</td>
<td>closure:</td>
<td></td>
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<tr>
<td>CS13-26, CS1-16</td>
<td>CS19-25</td>
<td>CS27-28</td>
<td>CS26-27</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Assumed there is a loss that costs 7 yuan for one switch action, and the electricity price is 0.9 yuan/kw·h, the results that are computed according to the data above are shown in Table 3.

Table 3. Comparison of dynamic reconfiguration.

<table>
<thead>
<tr>
<th>status</th>
<th>Network Loss / Kw-h</th>
<th>Switching times</th>
<th>Switching losses</th>
<th>Operating cost / yuan</th>
</tr>
</thead>
<tbody>
<tr>
<td>before reconstruction</td>
<td>4846.3</td>
<td>0</td>
<td>0</td>
<td>4361.7</td>
</tr>
<tr>
<td>1 time reconstructions</td>
<td>2876.6</td>
<td>8</td>
<td>56</td>
<td>2644.9</td>
</tr>
<tr>
<td>24 times reconstructions</td>
<td>1117.7</td>
<td>194</td>
<td>1358</td>
<td>2364</td>
</tr>
<tr>
<td>4 times reconstructions in this paper</td>
<td>1123.3</td>
<td>10</td>
<td>70</td>
<td>1081</td>
</tr>
</tbody>
</table>

Conclusions

According to the simulation results, the improved EM algorithm presented in this paper on the optimization accuracy better than improved tabu search algorithm in other literature, which can get better solution. At the same time, the use of sub-period similarity classification techniques make the similar load periods classified segment, change the dynamic reconfiguration into static reconfiguration, then this article use the improve EM algorithm solve static reconfiguration problems. The dynamic reconfiguration of the distribution network method in this paper is better than the method that without the distribution network reconfiguration and the method of assigning averaging period into the distribution network in aspects of reducing network losses, saving power grid and so on. The optimization accuracy of the improved EM algorithm is higher compared to other optimization algorithms, it can make into account the distribution network that electric cars access in work at its optimal operating state. The method in this paper can solve randomness, dispersion problem that
bring from electric cars successfully and effectively, it make optimize network Optimized, the distribution network run with the lowest cost in the whole running time. So that the distribution network topology is more appropriate for the current load distribution, more conducive to improve power quality and improve reliability of the distribution network.

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References