A NEW METHODOLOGY FOR DISTRIBUTION NETWORK INTEGRATION PLANNING

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Abstract

In order to resolve the distribution network integration planning, this paper presents a new solution algorithm, which is constituted of twice nesting improved genetic algorithms and once nesting shortest path algorithm. The methodology can be used to solve synthetically planning of distribution network, route planning of feeder and reconfiguration of distribution network flexibly. The model and the methodology proposed in this paper are shown to be effective to solve some practical problems in distribution network planning.

ABBREVIATION

Distribution network planning, Integration planning

1 INTRODUCTION

There are many existing models for distribution network planning [1-3]. But majority of them can only consider either the problem of the substation planning [4] or the problem of the feeder programming respectively. At the present, the methodologies that used to solve distribution network planning can be divided into three kinds: 1) classical mathematical optimization methods, 2) heuristic planning methods, 3) stochastic optimization methods that spring up in last few years. As for classical mathematical optimization methods, the branch and bound method is used most frequently. This kind of method needs large amounts of computer time to achieve the optimal solution, especially for large-scale distribution systems [5]. Heuristic planning methods, such as spur track exchange method etc, are faster than classical ones, but these methods are not the proper optimal method [6-7]. Stochastic optimization methods, take genetic algorithm as a model [8-9], these methods are better in obtaining the global optimal solution or the solution very close to the global optimal ones and have no limit for the complexity of problems.

Considering the shortcoming of the existing models, this paper presents a new integrated model for distribution network planning, which can solve the substation planning and the feeder programming at the same time. Furthermore, considering the characteristics of distribution networks and all optimal methods, this paper presents a new solution algorithm, which is constituted of twice nesting improved genetic algorithms and once nesting shortest path algorithm. The methodology can be used to solve integration planning of route planning of feeder and substation planning flexibly.

The numerical example for the real system indicated that the model and the methodology proposed in this paper can effectively give attention to CPU time and the optimal degree of the obtained solution. In addition, the model can solve the problem of the radiation planning of distribution network more effectively than the optimization of loop network planning, which can increase reliability of power supply to higher degree.

2 INTEGRATED PLANNING MODEL

2.1 Assumptions

The construction expense of substation is the same at different districts in the one area. The spanning fee of unit length of feeder line of the same type is the same at the same planning region.

2.2 Integrated planning model

Objective function: minimize load moment
min \sum_{j=1}^{m} \sum_{j=1}^{n} y_{ij} \overline{d}_{ij} l_{j}

= \sum_{j=1}^{m} \sum_{j=1}^{n} y_{ij} \left( \sum_{k=1}^{n} \left( \sum_{j=1}^{m} d_{ijk} x_{ijk} \right) \prod_{j=1}^{n} x_{ijk} \right) l_{j} \quad y_{ij} = \begin{cases} 0, & \text{candidate is not selected} \\ 1, & \text{candidate is selected} \end{cases}

2.3 Symbol explanation

- \( m \): total number of substations; \( n \): number of load sites;
- \( y_{ij} \): decision-making variables of substation's location;
- \( \overline{d}_{ij} \): length of optimal feeder line route from load site \( j \) to substation site \( i \);
- \( l_{j} \): length of load site \( j \);
- \( x_{ij} \): decision-making variables of feeder line connection status (\( x_{ij} = 1 \), there is feeder line between node \( i \) and node \( j \), otherwise \( x_{ij} = 0 \) without feeder line);
- \( R \): ratio of capacity and load;
- \( s_{i} \): capacity of substation \( i \);
- \( \overline{s}_{i} \): capacity upper bound of substation \( i \);
- \( Y_{ij} \): supply and demand relation between substation \( i \) and load site \( j \) (\( Y_{ij} = 1 \) if substation \( i \) supply electric power for load site \( j \), otherwise \( Y_{ij} = 0 \)).

\( V = \{ v_{0}, v_{1}, v_{2}, \ldots, v_{n} \} \): Node set of network; \( v_{j} \): node; \( E = \{ e_{1}, e_{2}, \ldots, e_{m} \} \): set of spur track in network \( G \);

\( \forall i, j \in E \), \( v_{i}, v_{j} \in V \); \( L = \{ l_{u}, l_{1}, l_{2}, \ldots, l_{u} \} \): vector of load (or capacity) of node set;

\( \overline{d}_{ij} \): length of spur track between node \( v_{i} \) and node \( v_{j} \) (if there is no spur track \( \overline{d}_{ij} = \infty \)); \( N_{ij} = \left[ \left( v_{ij}, v_{ik} \in V \right) \right] \): set of spur track which start at node \( v_{j} \); \( N_{ej} = \left[ \left( v_{e}, v_{e} \in V \right) \right] \): set of spur track which end at node \( v_{j} \);

\( h_{ij} \): one feeder route from load site \( j \) to substation site \( i \); \( v_{k0}, v_{m0} \): nodes which route \( h_{ij} \) pass.
3 THE PROPOSED ALGORITHM FOR DISTRIBUTION NETWORK INTEGRATED PLANNING

3.1 Outline of the algorithm

This paper presents a new solution algorithm, which can be used to find global optimal solution or solutions very close to such optimal one in all feasible solution space. The proposed method is constituted of four sub-calculates and one global optimal algorithm, where, sub-calculate (1) and sub-calculate (2) are basic, sub-calculate (3) and sub-calculate (4) are local optimal algorithms. Each sub-calculate is stated as follows:

Sub-calculate (1): calculate set of feasible feeder route to substations for certain load site.

Sub-calculate (2): calculate optimal feeder route to substations for certain load site using improved most short path method.

Sub-calculate (3): call sub-calculates (1) and sub-calculates (2), find optimal feeder route for certain sequence of load sites.

Sub-calculate (4): using improved genetic algorithm call sub-calculates (3) to calculate optimal sequence of load sites and optimal feeder route to certain substation.

The relationship between these four sub-calculates is sub-calculate (3) calls sub-calculate (1) and sub-calculate (2); sub-calculate (4) calls sub-calculate (3). The difference between sub-calculate (3) and sub-calculate (4) is differ search areas. Search area of sub-calculate (3) is only a subset of sub-calculate (4).

Each of these four sub-calculates can solve some problems in certain range. For example, if only add a load site (*) in distribution network, using sub-calculate (3), can gain optimal feeder route from load site (*) to substations. If only add a series of load sites but not have to construct new substations, calling sub-calculate (4), can get optimal feeder routes for all of these load sites. In addition, sub-calculate (4) also can solve network reconfiguration problem. Therefore, distribution network integrated planning could be solved using total optimal algorithm proposed in the paper.

3.2 Main optimization procedure

This algorithm using improved genetic algorithm to call sub-algorithm (4), and can realize global optimization of substation and feeder at the same time. This algorithm combines improved most short path algorithm (that is sub-calculate (2)) with network feasibility method (that is sub-calculate (1)) in order to find feeder route for all load site, which one side makes it easy to radial configuration of network other side there is no limit for complexity of initial network.

In order to insure feasibility of the solution (that is all substations and feeder lines do not over loading and do not form ring route), must found set of feasible feeder routes before working-out the optimal one from load sites to substations.

Procedure 1:

Suppose load site node(k) will enter into the network, so can describe network feasibility method as follows:

For all substations in substation-set (keep as: Initil_Sub), judge that whether existing load of substation add the load of node(k) less than the capacity up bound of the substation, yes, network fixedness, no, amend property of substation as midst-node.

For all nodes, judge that whether in-degree of node is one and power flow of in-arc add the load of node(k) more than arc-flow up bound, yes, delete all rest-arcs that point to node(k), no, network fixedness.

For all arcs, judge that whether the existing arc-flow add load of node(k) less than arc-flow up bound, yes, network fixedness, no, delete the arc from network.

Sub-calculate (2): Improved most short path (Dijkstra) algorithm.

Routes from node(k) to substation more than one, so there is one route whose length is the shortest one. Substations in network also more than one, so there is one substation, to which relative shortest route from node(k), is the absolute shortest one comparing with other relative shortest routes from node(k) to other substations.
Procedure 2:

Suppose load site node\(k\) will enter into the network, the set of substations is Tmp_Sub through network feasibility improving. The following is Improved most short path, which can calculates optimal path from node\(k\) to Tmp_Sub.

\[
\text{order } T := \{\text{node}(k)\} \\
f(k) = 0, \quad \text{Path}(k) := \{\text{node}(k)\}, \quad I := V \setminus \{\text{node}(k)\} \\
p := \text{node}(k), \quad f(i) := \infty, \quad \text{Path}(i) := \emptyset, \quad \text{for all } \text{node}(i) \in I \\
\]

Judge that whether node\(p\) belongs to Tmp_Sub, yes, execute, no, execute

For all node\(i\), node\(i) \in I\), judge that whether \(f(p) + d(p,i) < f(i)\), yes, order \(f(i) := f(p) + d(p,i)\) and \(\text{Path}(i) := \text{Path}(p) \cup \text{node}(p)\);

choose node\(i_o\) \in I\) and \(f(i_o) \leq f(i)\) to all node\(i\) \in I\);

order \(T := T \cup \{\text{node}(i_o)\}, \quad I := I \setminus \{\text{node}(i_o)\}\),

node\(p := \text{node}(i_o)\), return to

For all node\(i)\) belongs to set path\(p\) and is not node\(p\), order number of in-arc belongs to node\(i)\) is 1, that is in\(\text{edge}(i) := 1\), and make corresponding in-arc \((k,i)\) in file.

For all arcs belongs to path\(p\), order current arc-flow of the arc equals to inhering arc-flow add the load of node\(k\)

Order current load of substation site node\(p\) equals to inhering load of node\(p\) add the load of node\(k\); Add node\(p\) to load-site set, which are supply by substation node\(p\);

Order \(f(k) = f(p), \quad \text{path}(k) = \text{Path}(p)\);

return out \(f(k), \text{path}(k)\).

4 NUMERICAL EXAMPLE

The numerical example is given in Table1. Settle the problem of the location of substations and the path of feeder lines, which requests that the load rate of substation less than 65%, load of one feeder line less than 3.5MW.

Figure1 is the initial network before planning, where, dashed lines are proposed routes of feeder line. Node S1 and S2 is old substations; S3 and S4 is the proposed locations of new substations. Figure2 is the result of optimization. Table2 is the result of feeder planning including feeder lines and load sites. Table3 is the result of substation planning including substation capacity, load quantity, load rate and feeder-line set of substations.
Figure 2 is the optimization result of Figure 1 using the methodology proposed. Where, real lines are new lines (that is feeder line paths). In Figure 2 node S4 turns into real that is there is a new substation built in here.

Table 3: The result of substation planning

<table>
<thead>
<tr>
<th>Sub</th>
<th>Capacity (MVA)</th>
<th>Load (MW)</th>
<th>Load-rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>20</td>
<td>10.3</td>
<td>51.50%</td>
</tr>
<tr>
<td>S2</td>
<td>20</td>
<td>10</td>
<td>50.00%</td>
</tr>
<tr>
<td>S3</td>
<td>0</td>
<td>0</td>
<td>no</td>
</tr>
<tr>
<td>S4</td>
<td>20</td>
<td>9.63</td>
<td>48.15%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sub</th>
<th>Feeder-line set</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>{Line1, Line4}</td>
<td>old</td>
</tr>
<tr>
<td>S2</td>
<td>{Line5, Line7}</td>
<td>old</td>
</tr>
<tr>
<td>S3</td>
<td>{}</td>
<td>no</td>
</tr>
<tr>
<td>S4</td>
<td>{Line8, Line10}</td>
<td>new</td>
</tr>
</tbody>
</table>

5 CONCLUSIONS

The paper presents a new solution algorithm, which is constituted of twice nesting improved genetic algorithms and once nesting shortest path algorithm. The methodology can be used in practical distribution network planning project and the compiling of distribution network planning software.

6 REFERENCES