EMERGENCY PLANNING METHOD OF URBAN DISTRIBUTION NETWORKS BASED ON MICROGRID

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ABSTRACT
This paper proposes an emergency planning method of urban distribution networks based on microgrid which takes extreme disaster situation into account. First, it presents emergency scenario classification and load classification methods. And then an emergency planning model of urban distribution networks based on microgrid is set up. This model can not only apply to the traditional peak load planning scenario, but also suitable for disaster scenarios. Finally, study of this model base on a practical case under different penetration of microgrid has been carried on. By comparing the reliability and economic results of traditional planning method, it has shown that the proposed planning method has higher effectiveness and superiority when both traditional and emergency scenarios need to be considered.

INTRODUCTION
In recent years, a series of accidents about power blackouts occurred due to power system unstable and irresistible external force all around the world. Taking large-scale snow and freezing weather destroying most parts of southern China in mid-January 2008 for example, it caused serious damage and large-area blackouts in some cities for a long time. Urban distribution networks as one of important parts of power systems, it undertakes the task of supplying power directly to load centre, so it must be given high priority.

However, researches on coping with large-area blackouts are mainly focused on damage caused by power system unstable and so on [1]. Such large-area blackouts are mainly caused by internal factors, namely, it stirred up by power system equipment components or human’s misoperation, not by external factors. While, researches due to external forces(ice disaster, terrorist attacks) are very scarce. [2-4] researches "the U.S. and Canada '8 .14 'blackout', "Europe '11 .4' blackout" and "Moscow '5 .25 'blackout" respectively. These blackouts are all caused by internal instability within the system. [5] introduces the framework and content of anti-disaster power system planning. [6-7] studies the designing of different use of lines to improve resilience of transmission system.

For microgrid can switch its operating conditions between the characteristics of normal operating conditions and emergency isolated island operating conditions freely, a lot of researches have been carried on by scholars from various countries so as to improve power supply reliability and reduce power losses by using microgrid[8]. However, the researches by using microgrid to prevent large-area blackouts are rare, it is necessary to do more researches in this aspect in-depth.

This paper proposes an emergency planning method and model of urban distribution network based on microgrid. This is a planning method determines when, where and what type of investments to build power facilities. Making planning grid not only to meet the reliability and economy requirements under normal scenarios in planning period, but also to supply power to basic loads in disaster scenarios before disasters occurred. It’s under the premise of power positions and network structures have not yet been determined.

Firstly, this paper introduces scenario classification and load classification methods. And then, establishing emergency planning model base on microgrid and presenting practical planning method. Finally, verifying above model and method by practical case.

SCENARIO CLASSIFICATION AND LOAD CLASSIFICATION

Scenario classification
Traditional network planning is based on the principle of meeting maximum load provision and "N-1" safety guideline. It doesn’t consider the requirements of disaster prevention. According to the characteristics of emergency planning, situation of network damage and time intervals of power outages, this paper divides scenarios into normal, extreme and sub-extreme three categories. It’s illustrated in Table 1.

<table>
<thead>
<tr>
<th>Normal</th>
<th>Transformer or line “N-1” 0.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformer “N-1”</td>
<td>4.24</td>
</tr>
<tr>
<td>Transformer “N-2”</td>
<td>4.24</td>
</tr>
<tr>
<td>Sub-extreme</td>
<td>Single 110kV transformer 8.72</td>
</tr>
<tr>
<td>Several 110kV transformers damage caused by 220kV lines damage 8.72</td>
<td></td>
</tr>
<tr>
<td>Extreme</td>
<td>Lose all or most of the external power supply &gt;=24</td>
</tr>
</tbody>
</table>

Tab.1 Scenario Classification

Normal scenario supplies power without faults or only suffered "N-1" failure. Its time for power outages is short. Extreme scenario is the scenario with long time power
outages. The time for power outages of sub-extreme scenario is between normal scenario and extreme scenario. The probability of its occurrence is much larger than extreme scenario. At present, many high reliability regions of cities are required power supply normally not only in "N-1" failure, but also needed to consider power supply safely under the situation of transformer “N-1-1”, “N-2” and single 110kV transformer damage. All these problems belong to sub-extreme scenarios.

**Load classification**

Traditional three grades load classification is based on the requirement of power supply reliability and the influence of losses of sudden interruption in economic and political domains. It is suitable for solving problems for normal scenarios, but not for extreme and sub-extreme scenarios. Considering the need of emergency planning and the concept of Urban Lifeline System, this paper divides load classification into extreme vital load, vital load, transition load and general load four categories. It’s shown in Table 2.

### Table 2 Load Classification

<table>
<thead>
<tr>
<th>Load classification</th>
<th>Basis requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme vital</td>
<td>It’s the basic load that must be secured and the key load for restoring power supply</td>
</tr>
<tr>
<td>Vital</td>
<td>It’s the key load for restoring power supply after a disaster occurred for some time period.</td>
</tr>
<tr>
<td>Transition</td>
<td>It’s the key load for restoring power supply when a disaster just occurred.</td>
</tr>
<tr>
<td>General</td>
<td>It’s the load can be removed in the early times of disaster occurring</td>
</tr>
</tbody>
</table>

For studying conveniently, extreme vital load, vital load and transition load are referred to emergency load. It’s needed to research each user’s load characteristics more accurately. As in disaster conditions, it’s probably lack of superior power, and local power may not meet all the emergency loads sufficiently. Moreover, it’s not all the extreme vital loads in extreme vital loads’ user. Table 3 is a case of load classification in emergency planning.

### Table 3 Case of load classification

<table>
<thead>
<tr>
<th>User</th>
<th>Level</th>
<th>Constitution of load</th>
<th>Load (kW)</th>
<th>Ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospital</td>
<td>Extreme</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>vital</td>
<td>Extreme vital</td>
<td>420</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vital</td>
<td>580</td>
<td>48.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>General</td>
<td>200</td>
<td>16.67</td>
</tr>
<tr>
<td>Museum</td>
<td>Transition</td>
<td>transition</td>
<td>200</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vital</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>General</td>
<td>300</td>
<td>60</td>
</tr>
</tbody>
</table>

As it’s shown in table 3, the user hospital is extreme vital load, but only 35% of its internal load is extremely vital load. And Museum is transition load, yet no extreme vital load in it. Therefore, when superior power is lacked, only extreme vital load in emergency load users needed to be ensured for power supplying in disaster situations.

### EMERGENCY PLANNING MODEL AND METHOD OF DISTRIBUTION NETWORKS BASED ON MICROGRID

**Emergency planning model of distribution networks based on microgrid**

Microgrid is regarded as a "friendly" two-way control unit, with the ability of stand-alone and grid connected operations. It can realize plug and play and seamless switching for the main power grid. This paper makes good use of microgrid in load center of city. For microgrid can combine distributed generation and loads for coordinating control, it can ensure power supply for vital load users when extreme disasters occurred. And it can avoid serious consequences for long time and large areas power outages.

**Known conditions**

1. DG (distributed generation) position, capacity and corresponding penetration;
2. Load classification and load forecasting results in extreme and sub-extreme scenarios;
3. Location and size of transformer substation;
4. Capacity and model of alternative lines;
5. Device reliability index.

**Hypotheses**

1. Users in planning areas have ability of load shedding. The removal order of load is general load, transition load, vital load and extreme vital load;
2. DG is responsible for the supply of some important loads, rather than peak shaving or standby equipments;
3. Power factor of load is a constant which is 0.95.

**Optimum variables**

1. Network expansion schemes with DG, including the number and alignments of 10kV lines, DG location of accessing to network;
2. Operating schemes of microgrid in extreme, sub-extreme scenarios, including range, network structure and operating mode of microgrid.

**Objective function and constraints**

The objective function is required not only to meet the development of maximum loads in normal scenarios, but also to meet the power supply to emergency loads in extreme and sub-extreme scenarios. And the annual value cost is required to be minimized in the premise of reducing power losses in urban power grids. Namely, the integrated investment costs of lines, the operation and maintenance costs, the power losses costs in normal, sub-extreme and extreme scenarios are minimized. At the same time, it is needed to meet several constrains.

The mathematical model is demonstrated as followed:

\[
\begin{align*}
\min F &= \text{min}(C_G + C_{DG} + C_{ON} + C_{ON} + C_{OE}) \\
\text{s.t. } V_{min} &\leq V_i \leq V_{max}, \quad i \in I_i \\
S_{ij} &\leq S_{ij}, \quad i, j \in I_i, \cap i \neq j \\
P_{e, min} \leq P_{e, i} &\leq P_{e, max}
\end{align*}
\]
\[ \sum_{i \in \mathcal{L}} P_{DG, i} = \sum_{i \in \mathcal{I}} P_{i} + \sum \Delta P \]  

The meaning of each formula is explained as follows:
In formula (1), \( C_i \) is the integrated investment costs of lines.
The specific formula is shown as follows:
\[ C_i = \varepsilon \sum x_i l_i \]  
\( \varepsilon = a(1+a)^a \) is coefficient of annual value cost, \( a \) is \( \frac{\text{discount rate}}{1+a} \). 
\( i = 1,2,\ldots,n \), \( n \) is the total number of branches; 
\( x_i \) is the integrated costs of line \( i \); 
\( l_i \) is the length of branch line \( i \).
\( C_M \) is the operation and maintenance costs of lines per year.
The specific formula is shown as follows:
\[ C_M = y C_I + C_{int} \]  
\( y \) is the proportional coefficient of maintenance costs accounts for integrated investment costs of lines, \( C_{int} \) is the costs of network losses. Its specific formula is shown as follows:
\[ C_{loss} = \lambda^2 n \max P_{loss} \]  
\( \lambda \) is the unit costs of network losses, \( T_{max} \) is the maximum hours of load losses, \( P_{loss} \) is the power losses of maximum loads for the whole network.
\( C_{int} \) is the power losses costs in normal scenarios. The specific formula is shown as follows:
\[ C_{int} = \mu Q \]  
\( \mu \) is unit cost of power shortage in normal scenarios, \( Q \) is power shortage of system.
\( C_{tot} \) is the power losses costs in sub-extreme scenarios. The specific formula is shown as follows:
\[ C_{tot} = C_{int} \cdot \varphi \]  
\( \varphi \) is the restoring power losses coefficient.
\( C_{OE} \) is the power losses costs in extreme scenarios. The calculation of it is similar to formula (17).
In formula (2), \( i \) is the nodes of 10kV lines, \( V_{sun} \) is the lower limit of node voltage.
In formula (3), \( i, j \) is any two connected adjacent nodes for 10kV lines, \( S_e \) is power flow of lines, \( S_{loss} \) is maximum permitted power flow of lines.
In formula (4), \( DG \) is the number of DG in 10kV line, \( P_{max} \) and \( P_{min} \) are the maximum and minimum output power limits of DG respectively.
In formula (5), \( C_{DG} \) is the DG of microgrid \( I_i \), \( P_{DG, i} \) is the output power of \( DG \), \( I_i \) is the load of microgrid \( I_i \), \( P_{int} \) is on behalf of the load size of corresponding scenarios, \( \sum \Delta P \) is representative of the network losses in microgrid.
Scheme three  30  Yes  47.53  
Scheme four  30  No  68.13  
Scheme five  40  Yes  42.78  
Scheme six  40  No  68.13  
Scheme seven  60  Yes  22.08  
Scheme eight  60  No  68.13  

Internal structure of a microgrid in one of the switching stations in scheme one is demonstrated in Figure 1:

Fig.1 Internal structure of a microgrid

Figure 1 shows that this microgrid uses radial connection mode. Three DGs are planned in the same line with all the emergency loads which all or part of them would be supplied power by DGs in disaster situation. And general loads are arranged in another line.

After determining alternative schemes and finishing the calculation of power flow and reliability by using network planning software, the integrated investment costs of lines is calculated by formula (6), the operation and maintenance costs by formulas (7) and (8), the power losses costs in normal scenarios by formula (9) and the power losses costs in sub-extreme and extreme scenarios by formula (10). By analyzing the results, scheme one to six meet the constraints at technical level. And scheme five is the best scheme among schemes with microgrid.

Comparison of optimal scheme with microgrid and original scheme

The comparison result of optimal scheme with microgrid (scheme five) and traditional scheme (original scheme) is shown in Table 6:

<table>
<thead>
<tr>
<th>Item</th>
<th>Optimal scheme</th>
<th>Traditional scheme</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line loss rate (%)</td>
<td>0.2</td>
<td>0.31</td>
<td>Significantly better</td>
</tr>
<tr>
<td>Power shortage (kWh)</td>
<td>183401</td>
<td>198645</td>
<td>Slightly better</td>
</tr>
<tr>
<td>Integrated investment costs of lines (10^4 Yuan/year)</td>
<td>528.2</td>
<td>572.1</td>
<td>Slightly better</td>
</tr>
<tr>
<td>Power losses costs in extreme scenarios (10^4 Yuan/year)</td>
<td>457.93</td>
<td>1208.27</td>
<td>Significantly better</td>
</tr>
<tr>
<td>Power losses costs in sub-extreme scenarios (10^4 Yuan/year)</td>
<td>408.87</td>
<td>1078.8</td>
<td>Significantly better</td>
</tr>
</tbody>
</table>

Table 6 shows that optimal scheme with microgrid is superior to traditional scheme in each result. It illustrates that making good use of microgrid in emergency planning of distribution network can have a good effect on technical and economic aspects.

CONCLUSION

As traditional network planning only considers normal scenarios, this paper introduces scenario classification and load classification methods which are suitable for disaster scenarios. Besides, it establishes mathematical model of emergency planning which bases on microgrid and presents practical planning method. By comparing the reliability and economic results of a practical case with traditional planning method, it illustrates this paper’s method effectiveness and superiority.

REFERENCES