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 accidences 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 CLASSIFICATIOIN

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.

Tab.1 Scenario Classification

Categories	The situation of power damage	Time of power outages（h）
Normal	None	0
	Transformer or line “N-1”	(0,3]
Sub-extreme	Transformer “N-1-1”	(4,24]
	Transformer “N-2”	(4,24]
	Single 110kV transformer	(8,72]
	Several 110kV transformers damage caused by 220kV lines damage	(8,72]
Extreme	Lose all or most of the external power supply	>=24

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 reliably 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.

Tab.2 Load Classification

Load classification	Basis requirement
Extreme vital	It's the basic load that must be secured and the key load for restoring power supply
Vital	It's the key load for restoring power supply after a disaster occurred for some time period.
Transition	It's the key load for restoring power supply when a disaster just occurred.
General	It's the load can be removed in the early times of disaster occurring

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.

Tab.3 Case of load classification

User	Level	Constitution of load	Load (kW)	Ratio (%)
Hospital	Extreme vital	Extreme vital	420	35
		Vital	580	48.33
		General	200	16.67
Museum	Transition	transition	200	40
		Vital	0	0
		General	300	60

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:

$$\min F = \min\left(C_I + C_M + C_{ON} + C_{OS} + C_{OE}\right) \quad (1)$$

$$s.t \quad V_{\min} \le V_i \le V_{\max} \quad i \in I_i \quad (2)$$

$$S_{ij} \le S_{ij\max} \quad i, j \in I_i \cap i \ne j \quad (3)$$

$$P_{e.\min} \le P_{DG_j} \le P_{e.\max} \quad (4)$$

$$\sum_{DG_j \in I_i} P_{DG_j} = \sum_{L_k \in I_i} P_{L_k} + \sum \Delta P \quad (5)$$

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:

$$C_I = \varepsilon \sum_i x_i l_i \quad (6)$$

$\varepsilon = \frac{a(1+a)^b}{(1+a)^b - 1}$ is coefficient of annual value cost, a is discount rate, this paper obtains 7.2%，b is service life of equipments, this paper obtains 40 years, so $\varepsilon = 0.077$.
$i = 1,2,...,n$, 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:

$$C_M = yC_I + C_{loss} \quad (7)$$

y is the proportional coefficient of maintenance costs accounts for integrated investment costs of lines, C_{loss} is the costs of network losses. Its specific formula is shown as follows:

$$C_{loss} = \lambda_e T_{\max} P_{loss} \quad (8)$$

λ_e 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_{on} is the power losses costs in normal scenarios. The specific formula is shown as follows:

$$C_{ON} = \mu \cdot Q \quad (9)$$

μ is unit cost of power shortage in normal scenarios, Q is power shortage of system.
C_{os} is the power losses costs in sub-extreme scenarios. The specific formula is shown as follows:

$$C_{OS} = C_{tot} \cdot \varphi \quad (10)$$

C_{tot} is the total costs of power losses per year which doesn't consider microgrid, φ 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, $V_{\min}$ is the lower limit of node voltage.
In formula (3), i, j is any two connected adjacent nodes for 10kV lines, S_{ij} is power flow of lines, $S_{ij\max}$ is maximum permitted power flow of lines.
In formula (4), DG_j is the number *j* DG in 10kV line, $P_{e.\max}$ and $P_{e.\min}$ are the maximum and minimum output power limits of DG respectively.
In formula (5), DG_j is the DG of microgrid I_i, P_{DG_j} is the output power of DG_j. L_k is the load of microgrid I_i, P_{L_k} is on behalf of the load size of corresponding scenarios, $\sum \Delta P$ is representative of the network losses in microgrid I_i. For the physical and electrical distances from DGs to loads in the same microgrid are short, it can simplify the calculation of network losses and regard it as 0.

Method of emergency planning

The method of heuristics with expert suggestion is often used in practical large-scale distribution network planning schemes. This paper presents a practical method of microgrid emergency planning as follows:
(1) Determining alternative schemes of emergency planning. According to the given hypothesis premise, known conditions and constraints, experts provide alternative schemes of network planning by using heuristic method. It includes the number and alignments of 10kV lines, location of DG accessing to network and domain, structure and operation modes of microgrid.
(2) Calculating the costs of power losses and annual value costs. According to the planning models of this section, using formula (1 ~ 10) , known results of load forecasting, technical and economic parameters to calculate the costs of power losses and annual value costs of each scheme.
(3) Determining optimal scheme by comparing technical and economic results. Firstly, finding out the optimal scheme with microgrid, then making a quantitative comparison with the traditional scheme, verifying the superior or inferior of optimal scheme to traditional scheme. Finally, adjusting the optimal scheme as needed.

CASE STUDY

Case introduction

This case selects a CBD commercial area in Tianjin China as study object. According to the location and capacity of microgrids, it researches each scheme by considering different penetration and grid structures. The load forecasting of this area is 351.674MW. The capacities of three 110kV substations are all 3 × 50MVA. And all the lines are cables.

Alternative planning schemes

Original scheme is traditional planning scheme which doesn't contain microgrid and consider disaster situations. Other schemes all contain microgrid. They are separated into two categories for each penetration. One are still retained the original network after adding microgrid. The others are simplified after adding microgrid.
According to the penetration and grid of each schemes is simplified or not, eight schemes are denoted as scheme one to eight and as shown in Table 4:

Tab.4 Planning schemes

Schemes	penetration（%）	Grid simplify	The total length of lines（km）
Original scheme	0	No	68.13
Scheme one	20	Yes	59.34
Scheme two	20	No	68.13

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 station 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:

Tab.6 Comparison of optimal scheme and traditional scheme

Item	Optimal scheme	Traditiona -l scheme	Result
Line loss rate （%）	0.2	0.31	Significantly better
Power shortage （kWh）	183401	198645	Slightly better
Integrated investment costs of lines（10^4 Yuan/year）	528.2	572.1	Slightly better
Power losses costs in extreme scenarios（10^4 Yuan/year）	457.93	1208.27	Significantly better
Power losses costs in sub-extreme scenarios（10^4 Yuan/year）	408.87	1078.8	Significantly better
Annual value costs（10^4 Yuan/year）	2508.04	4623.84	Significantly better

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.

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