STATUS QUO AND PROSPECTS OF URBAN MV DISTRIBUTION NETWORK STRUCTURE IN CHINA

Limei ZHOU, Dapu ZHAO, Wei LIU, Jian SU
China Electric Power Research Institute – China
limiezhou@epri.sgcc.com.cn, zhdp@epri.sgcc.com.cn, liuwei75@epri.sgcc.com.cn,sujian@epri.sgcc.com.cn
No.15 Xiaoying East Road, Qinghe, Beijing 100192, P.R.China

ABSTRACT

In order to optimize structure of MV distribution in China and cope with a large number of DER (dispersed energy resources) integrated into distribution, this paper masters status quo of urban MV distribution in China by surveying on distribution configurations, reliability of power supply etc. of 31 large and medium cities in China. The main issues of MV distribution structure optimization in China are analyzed deeply from seven aspects. The objective configurations of MV distribution adapting for the development of economic society and DG (distributed generation) integration are proposed by applying system theory and reliability-based distribution planning method in the paper. The research will meet development needs for building a strong intelligence network, further regulate configurations of urban distribution in China and lay a solid foundation for maximum benefits of utilities and healthy development of distribution in the future[1].

INTRODUCTION

At present, the main voltage sequences of HV distribution network are 500/220/110 (66 or 35) kV, 500/220/110/35 kV and so on. The 500kV or 220kV ring main grids are generally formed outside large cities and 110 (66) kV ring main grids are generally formed outside small cities. When 500kV lines are operated as closed loops, 220kV double loop networks as the main grid are operated as open loops and 110 (66 or 35) kV networks are operated radially.

The basis of MV and LV distribution were weak in China. They were established basically following customers' needs in history and more influenced by the investors. The distribution structure and reliability of power supply have been lack of normative management and specific analysis all the time. In 2009, China's GDP reached 33.535 trillion *Yuan* (average annual growth rate of 8.7%) and total electricity consumption reached 3.643 trillion kWh (average annual growth rate of 5.96%), urban customers' reliability of power supply was only 99.896%.With the rapid growth of load demand, MV and LV customers' (especially important customers') demand for reliability of power supply is increasing; more important, taking into account national energy security strategy, many countries started to focus on the development and utilization of all kinds of new energy (DER in most cases) integrated into power system. The Chinese Government required DG to reach 8% of the total installed capacity of power generation by 2020. A large number of DER integrated into distribution network will have a profound impact on the performance of power systems, network structure and reliability of power supply. How to deal with this new trend has become an urgent problem for international utilities.

The status quo of MV distribution in China is mastered by surveying on distribution configurations, reliability of power supply, distribution automation and DG integration etc. of 31 large and medium cities in China. The main issues of MV distribution structure optimization in China are probed deeply from seven aspects. Considering the influences of DG integration and electric vehicle charging facilities on distribution and reliability, the objective configurations of MV distribution adapting for the development of economic society are proposed by applying system theory and reliability-based distribution planning method [1]. Then the transition programs from status to objective configurations are probed in the paper.

THE TYPICAL CONFIGURATION ANALYSIS OF URBAN MV DISTRIBUTION IN CHINA

The typical configurations

The 10kV is mainly used as medium voltage in China. The 10kV cable network is built in downtown areas of some large and medium cities, while the 10kV overhead network down the street is still set up in most of other areas. According to the requirements of security of power supply, the 10kV distribution is basically a loop operated radially during normal operations [2].

Three typical configurations of overhead network, i.e. radial feeders, single-zone feeders and multi-zone feeders and six typical configurations of cable network, i.e. radial feeders (a single path, two paths from the same substation and two paths from different substations), loop feeders, double-loop feeders and N feeders operated as open loops and one feeder used as public backup, are summarized by analyzing distribution structure of 31 large and medium cities in China. The security of supply and service areas of these configurations are shown in Table 1.

There are generally 3-5 segments and 2-3 zones in overhead distribution and load switches pole-mounted

---

This project is a major issue of State Grid Corporation of China (SGCC) in 2010.

(sometimes circuit breakers) are usually used as sectionalizers and tie switches. Multiple devices on a circuit will "work together" to sectionalize the cable properly according to line length, load density and so on and RMU (ring main units) are used as sectionalizers and tie switches.

In cable network, double-loop arrangement is the most reliable and flexible configuration, in which customers can get two resources from different directions satisfying N-1 of 10kV circuits and service transformers. The radial feeders (two paths from different substations) are constituted by two feeders from two different substations (or switching stations) to avoid the two cables damaged simultaneously and usually formed by system reinforcements. All customers in double-loop feeders and radial feeders (two paths from the same substation and two paths from different substations) usually have two resources.

In N feeders operated as open loops and one feeder used as public backup, although the larger N, the higher utilization, but N is generally not more than 4 for complexity of running and operating.

Table 1 the typical configurations of 10kV distribution in China

line types	configurations	security of supply	utilization at peak (%)	service areas
overhead	radial feeders	-	100	areas of low load density, low reliability and less distribution substations
	single-zone feeders	N-1	50	areas of lower load density and a certain reliability
	multi-zone feeders	N-1	M/(M+1) (M-zone)	areas of medium load density and higher reliability
cable	radial feeders (a single path)	-	100	rural areas and other areas in need
	radial feeders (two paths from the same substation, two paths from different substations)	N-1	50	areas with larger-capacity users requiring a certain reliability
	loop feeders	N-1	50	medium load density areas, single-source users with small and medium capacity and industrial development zone
	double-loop feeders	N-1-1	50	areas of high load density and high reliability, downtown areas
	N feeders operated as open loops and one feeder used as public backup	N-1	N/(N+1) (N≤4)	medium load density areas with larger-capacity users requiring higher reliability

The proportion of typical configurations in 31 large and medium cities of China

In 2009, single-zone and multi-zone feeders were used in all 31 cities and radial feeders were used in 29 cities. The proportion of single-zone and multi-zone feeders was basically between 30% and 60% and the proportion of radial feeders was between 10% and 30% in most cities (see table 2) . In short, the proportion of multi-zone feeders in developed eastern regions was higher than that in less developed western regions.

In 2009, 30 cities adopted loop feeders, 28 cities adopted radial feeders (a single path) , 19 cities adopted double-loop feeders, 18 cities adopted radial feeders (two paths from the same substation) , only 10 cities adopted radial feeders (two paths from different substations) and N feeders operated as open loops and one feeder used as public backup. The proportion of loop feeders was more than 30% and the proportion of radial feeders (a single path) was less than 30% (relatively higher in less developed western regions) in most cities. The double-loop feeders and radial feeders (two paths from the same substation) whose proportion was basically less than 10% were mainly in developed eastern regions.

THE MAIN ISSUES CONSIDERED IN THE PROCESS OF OPTIMIZING URBAN MV DISTRIBUTION STRUCTURE IN CHINA

The changes in external environment

With the rapid development of social economy, population density and load density will be higher and higher in urban areas and it's increasingly difficult to obtain site and line corridor resources for new customers. In addition, the proportion of the third industry and residential electricity consumption will be increasing continuously and customers' requirements for reliability of power supply are higher and higher, which will bring higher demands for the development of MV distribution.

The differences of development stages between domestic and international distribution

In developed countries, load development has been basically very slow (load average annual growth rate of 0.5-1%) and electrical construction have also reached a stable stage accordingly. While in China electric network is in the rapid development period (load average annual growth rate of more than 10%) and the scale of new distribution in the future will be twice as large as existing scale, so it's a good opportunity for optimizing distribution configurations.

Table 2 the numbers of cities in different proportion of 10kV distribution configurations

configurations	above 60%	30~60%	10~30%	1~10%	0%	Total
Overhead						
radial feeders	0	4	21	4	2	31
single-zone feeders	2	22	6	1	0	31
multi-zone feeders	6	16	7	2	0	31
Cable						
radial feeders (a single path)	1	4	13	10	3	31
radial feeders (two paths from the same substation)	2	2	5	9	13	31
radial feeders (two paths from different substations)	1	0	1	8	21	31
loop feeders	14	10	3	3	1	31
double-loop feeders	1	4	4	10	12	31
N feeders operated as open loops and one feeder used as public backup	0	1	2	7	21	31

The development trends of distribution structure optimization

In the process of grid development, developed countries primarily focus on overall optimal development of grid structure, emphasize coordination between different levels and don't apply N-1 criterion to all levels. In the optimization of distribution structure, developed countries emphasize the load transfer ability of the lower level and tend to install multiple service transformers to guarantee the reliability in design.

The improvement of reliability of power supply

The SAIDI is generally less than 2h in developed countries and has reduced to 5min in Singapore, while in China the value is usually above 9h at present. Therefore it is necessary to improve reliability and security of power supply by optimizing distribution configurations. In addition, relying on other resources such as energy storage, DG, distribution automation, live working and condition-based maintenance, a large range of customers' requirements are met by providing different levels of reliability. That means the power price is related with the level of reliability, which give the customers more choices. It is entirely feasible in the market environment today.

The integration of DG and DER

A large number of DER integrated to grid will deeply impact the system performance, network structure and reliability. The optimization of network structure should take into account the new trends, including the optimal planning and design of active distribution network, investment strategy, as well as assessment tools of DG integration and so on[3].

The improvement of self-healing capability of grid

It is the most difficult to improve the self-healing capability of grid in power system. Besides the distribution automation and intelligent technology, network structure planned well, reasonable line paths and strong connectivity are also useful to improve the self-healing capability of grid.

The increase of economic efficiency

In developed countries, the grid is built based on system theory and minimum cost principle. The evaluation indices include quantity, quality and cost and the reliability-based marginal cost-effectiveness is maximized. In China, the grid construction is still at the stage of project-oriented, where the total investment is determined by the project scale. Therefore the reliability-based cost-effectiveness should be considered in the process of optimizing MV distribution structure. That means how to maximize the reliability under given total investment or minimize the total investment under a certain level of reliability [4].

THE OBJECTIVE CONFIGURATIONS OF URBAN MV DISTRIBUTION AND PROSPECTS IN CHINA

The contingency criterion satisfied by objective configurations

Consumers should not be interrupted by the outage of any a component (an incoming circuit, or a step-down transformer, or a feeder bus) in a HV substation. When a fault following an arranged circuit outage happens, part of consumers are permitted to be interrupted but should be restored within the specified time.

When a feeder of 10kV distribution is out of service after a fault, there should not be any interruption except for failure section of the feeder, low voltage and overloading of equipments under normal conditions. When a fault following an arranged circuit outage happens, part of consumers are permitted to be interrupted but should be restored within the specified time.

The objective configurations

Two objective configurations of overhead network, i.e. single-zone feeders (two paths from different substations) and multi-zone feeders, and four objective configurations of cable network, i.e. loop feeders, double-loop feeders and N feeders operated as open loops and one feeder used as public backup, multi-branch and multi-zone feeders are put forward in the paper. Multi-branch and multi-zone feeders referencing 6kV cable network of Tokyo, not only save the number of outlet intervals, but also improves the line utilization during normal operation. For example the utilization of two-branch and two-zone feeders can reach 67%, while three-branch and three-zone feeders can reach 75%.

The device sizing, distribution automation, means of communication and results of reliability assessment and economic evaluation of objective configurations are as follows:

(1) Sectionalization principles: the number of sectionalizers is determined by the number of customers, load character, load density, line length and environmental factors and so on and the position of sectionalizers will be adjusted accordingly with load in overhead network. The number of RMU (ring main unit) should not be too much, usually not more than 6 in order to shorten construction period and avoid the truck too long in cable network.

(2) Line size: 240mm and 185mm (aluminum insulated wire) are used in overhead network and 400mm, 300mm and 240mm (copper or aluminum with the same capacity) are used in cable network.

(3) Size of sectionalizer and tie switches: load switches pole-mounted are selected in overhead network and RMU (ring main units) are selected in cable network.

(4) Capacity of switch: 630A and 400A.

(5) Distribution automation: tie switches and main sectionalizers can generally realize remote control, remote telemetry and remote communication function and other sectionalizers and branch switches are generally equipped with remote telemetry and remote communication function according to actual situation.

(6) Means of communication: optical fiber communication network or broadband wireless are used in overhead network and optical fiber communication network, broadband wireless or power line carrier are used in cable network.

(7) Results of reliability assessment: The minimal cut set method is used for reliability assessment of distribution structure and CYMDIST software package is used as the basic modeling and analysis tool. The results of reliability from high to low are double-loop feeders, three feeders operated as open loops and one feeder used as public backup, two-branch and two-zone feeders, loop feeders, three-zone and single-zone feeders in overhead network.

(8) Results of economic evaluation: reliability-based cost-benefit analysis and the idea of life cycle cost are adopted. The results of economics from good to bad are three-zone and single-zone feeders in of overhead network. In cable network the results are orderly Two-branch and two-zone, three feeders operated as open loops and one feeder used as public backup, loop feeders and double-loop feeders.

The transition development from status arrangements to objective configurations

In overhead network, radial feeders could be interconnected near the substation to improve reliability and can be turned into single-zone feeders (two paths from the same substation or different substations). While single-zone feeders (two paths from the same substation) can be turned into single-zone feeders (two paths from different substations) under proper conditions.

In cable network, radial feeders (a single path) could be interconnected with overhead feeders to improve reliability and should be turned into loop feeders as the growth of network. Radial feeders (two paths from the same substation) should avoid to be destroyed by external force and could be turned into radial feeders (two paths from different substations) or double-loop feeders.

CONCLUSION

The objective configurations of MV distribution are not only able to improve capability and reliability of power supply, simplify HV distribution configurations, but also meet the development requirements of smart grid in the future, so objective configurations of MV distribution should meet the following requirements:(1) standard and reasonable configurations, flexible operation, adequate capability of power supply, strong load transfer capability and providing contingency capability to "cover" outages at a higher level; (2) adapt for the growth and development of all kinds of load, DG, electric vehicle charging facilities and other DER and ease of load integration and expansion; (3) secure and reliable equipment and facilities, strong protective properties and ability of withstanding contingencies and natural disasters; (4) reasonable and reliable protection configurations; (5) facilitating the implementation of distribution automation and effectively guarding against failure to expand in chain; (6) meeting corresponding reliability of power supply, coordination with the social environment and reasonable construction and operation costs.

REFERENCES

[1] H. Lee Willis, 2004, "*Power Distribution Planning Reference Book (Second Edition, Revised and Expanded)*". Marcel Dekker Inc., Raleigh, U.S.A., 400-420.

[2] Fan Mingtian, Zhang Zuping, 2008, *Research on related issues about development strategy of distribution network in China*. China Electric Power Press, Beijing, China, 76-80.

[3] Fan Mingtian, Zhang Zuping, 2010, "Research for network planning during pre-smart-grid". *Distribution & Utilization*, 27(6): 1-4 (in Chinese).

[4] Bian Xuehai, Zhang Wei, Xu Qi, 2001, "On target frameworks of power system for nation-wide interconnection". *Power System Technology*, 24(2): 74-81(in Chinese).