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Evaluation of Power Supply Capability of Urban Distribution Network

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Abstract: **Urban distribution network is an important link for users, and it is of great social and economic significance to carry out scientific evaluation on power supply capacity of urban distribution network. Firstly, this paper summarizes the concept of power supply capacity of urban distribution network, traditional evaluation method, and evaluation model. Secondly, the evaluation steps of power supply capability of urban distribution network are divided into three parts, which are building urban distribution network, power supply capability evaluation index system, evaluation index weights evaluation method. Summary analysis are carried on each steps and content. Lastly, the application prospect and research direction of power supply capacity assessment of urban distribution network are pointed out.**

Keywords: **Urban distribution network; Power supply; Evaluation methods**

1. INTRODUCTION

In recent y.ears, with the rapid development of China's economy, the growth of power load has accelerated significantly. Higher requirements have been placed on the power supply capacity, power quality, and power supply reliability of the urban distribution network. In order to adapt to the development of the city, the transformation and expansion of the power network have been fully developed [1]. As an important part of power system work, the evaluation of power supply capability of urban distribution network has great practical significance to correctly evaluate the current power network, optimize the structure of the network, improve the security and reliability of the power supply of urban grid, and improve the economic and social benefits of enterprises. Therefore, the evaluation of power supply capacity of urban distribution network is more focused by electric power enterprises, and the necessity of the evaluation method research is becoming more and more prominent.

At present, domestic and foreign scholars have carried out various researches on the assessment of power supply capacity of urban distribution networks and achieved certain research results. This paper will analyze and summarize the index system, weight determination method, and comprehensive evaluation method of urban distribution network power supply capacity, so as to facilitate readers' understanding of the process and progress of urban distribution network power supply capacity assessment, and to promote the in-depth development of the research.

2. POWER SUPPLY CAPACITY OF URBAN DISTRIBUTION NETWORK

2.1. CONCEPT OF POWER SUPPLY CAPACITY

Power supply capacity is the ability of the power grid in a certain power supply area to satisfy the maximum ability to meet the electricity consumption of users under the condition of N-1 [2]. The power supply capacity of the grid depends on the power supply capacity of the substation and the power transfer capacity of the grid. Therefore, the load capacity and the power transfer capacity are usually considered in the research of power supply capacity evaluation.

2.2. CONTENT OF URBAN DISTRIBUTION NETWORK CAPACITY ASSESSMENT

The content of power supply capacity evaluation of distribution network mainly includes the following aspects:

(1) Whether the power supply capacity meets the needs of the existing load and may adapt to the extent of load growth
(2) Reliability of power supply
(3) Voltage level at each node, voltage loss, and line loss during normal operation
(4) Possibility and necessity of upgrading the power supply equipment

By fully analyzing the overload situation of distribution lines and substations, the structure of the grid is analyzed with respect to the wiring mode and load situation of the distribution network Line solutions and transformation measures are proposed, and reasonable layout is made, with the aim of improving the reliability of the power supply and the safety of the system operation. Meanwhile, this provides technical support and services for the planning and investment plan of distribution network. Through the statistics, analysis and calculation of the power supply network of a distribution network in an urban area is carried out, the structure of the distribution network is evaluated, the main problems and weak links of the power network are identified, and the improvement measures and suggestions are put forward. These lay a good foundation for the planning and transformation of the urban distribution network and provide guarantee for the future investment planning to meet the needs of the development of the power market.

2.3. TRADITIONAL METHODS FOR ASSESSING THE POWER SUPPLY CAPACITY OF URBAN DISTRIBUTION NETWORKS

The main methods to evaluate the power supply capacity of traditional distribution network include trial method, capacity load ratio method, and maximum load multiple method.

The trial method is to assign a specified system load to each load point according to a certain load distribution coefficient, continuously increasing the system load and calculating the power flow until a small increase in load will cause the branch power to exceed the limit [3]. The method requires a clear overall grasp of the load level of the distribution network and its distribution at various load nodes, and relies more on engineering experience. The capacity load ratio method examines the power supply capacity of an object macroscopically by examining the ratio of its transformer capacity to its power supply load [4]. The power supply capacity was evaluated from a macroscopic point of view, and the method can reflect the power supply capacity of the distribution network in a simple and clear way, but it does not take into account factors such as network transfer capacity and power supply reliability. Some scholars have considered the wiring mode and the current load situation, and proposed the maximum load multiple method. Based on the existing load of the system, the maximum multiple of load method evaluates the power supply capacity of the network, and the adaptability to load changes by calculating the maximum multiple of load that the power grid can achieve [5]. The results of this evaluation are largely influenced by the existing load distribution of the network. The comparison of traditional evaluation methods is shown in **Table 1**.

There are also studies that include the assessment of grid supply capacity as a planning requirement. By using the method of network planning, a certain power supply network is simplified and transformed into the equivalent network, that is system state flow chart. According to the system state flow chart and the mathematical model for solving the maximum flow, the power supply capacity of the power grid can be obtained under normal and various fault conditions. This method is simple and reliable, easy

Table 1. Comparison of traditional assessment methods

Assessment method	Consideration factor	Advantages	Disadvantages
Capacity-loading ratio method	Substation capacity margin	Macro evaluation can simply and clearly reflect the power supply capacity of distribution network	The calculation method is complicated, and the result may not be accurate when the network is complicated
Maximum multiple method	Network influence factor	Considering the connection mode and the current load, the evaluation effect is significantly enhanced	There are still some errors between the analysis results and the actual situation
Actual computation based on interconnections	N-1 criteria and network constraints	The network migration capability is fully considered, and the calculation process is simple and effective	There are ideal assumptions, and the practical application needs to consider the power grid structure and equipment capacity constraints

to deal with complex constraints, and can obtain better results for the power supply capacity of local power grid, which is a very convenient engineering algorithm [6,7].

Jun [8] put forward the concept and method of distribution network planning based on maximum power supply capacity. It gives priority to improving the maximum power supply capacity to meet the load by optimizing the distribution network structure and operation mode. Then it considers adding power transformation capacity, so as to make full use of the existing network to absorb the new load, which is suitable for the planning of the current complex distribution network in urban built-up areas. Literature [9] discusses the new mode of distribution network construction planning and operation under the background of smart grid, applies the concept of efficient planning, construction, and operation of distribution system, as well as puts forward a new planning idea. The optimization of power supply capacity applicable to mature distribution networks is based on the large number of constructed and renovated distribution networks with a large amount of excavation space of power supply capacity. Chen [10] put forward a comprehensive power supply capacity evaluation method of distribution network regarding network reconstruction and daily load curve, taking into account two situations that all load interruptions can be reconfigured through the network, and daily load curves of different categories of customers. The applicability test results of the proposed model show that the proposed model is more accurate than the previously published model. This analysis method can be applied to a series of network planning studies.

Xin [11] evaluated the power supply capacity of DC distribution network, and proposed a probability circle sampling method based on distributed generation probability model, that is the improved Monte Carlo sampling method. The calculation and comparison of radial, ring, and grid DC distribution networks under different permeability are carried out, and the feasibility of this method is verified, and it is used as a reference for future research on power supply capacity of DC distribution networks. Based on the uncertainty of distributed generation (DG) output and the periodic change characteristics of power grid load, literature [12] proposed a real-time evaluation method of power supply capacity of distribution network based on distributed generation. This method takes into account the various types of DG complementary power generation in the distribution network, obtains the future load and DG output through forecasting technology, and gives the change curve of the power supply capacity of the distribution network in the future, so that the dispatcher can take corresponding measures in advance according to the evaluation results to ensure the safety and reliability of the grid operation. In order to supplement the lack of theoretical analysis in traditional distribution network planning for the selection of connection modes of medium voltage distribution network, literature [13] proposed a fine planning method for medium voltage distribution network framework based on power supply capability analysis. Based on the concept of power supply capacity, this paper compares and analyzes the “degree” of substation interconnection to form the construction method of network reasonable power supply architecture. Based on the principle of optimizing the power supply capacity of distribution network, the planning method of medium voltage feeder interconnection structure is established, which has positive guiding significance for distribution network planning.

3. POWER SUPPLY CAPACITY EVALUATION MODEL OF URBAN DISTRIBUTION NETWORK

Domestic and foreign scholars have done a lot of research on the power supply capacity evaluation model of urban distribution network, and built a power supply capacity evaluation model adapted to the current scene from different perspectives.

Gao [14] analyzed the influence of uncertain factors on the power supply capacity of active distribution system, modeled the uncertain factors, and based on scene generation and reduction technology, formed multiple scenarios for power supply capacity evaluation, and evaluated the short-term power supply capacity of active distribution system under multiple scenarios. By aiming at the distribution network with distributed generation and considering the characteristics of volatility and intermittence of distributed generation, the evaluation model of power supply capacity of distribution network is established based on the improved repetitive power flow method, and its effectiveness and feasibility are verified by the arithmetic example [15]. Li [16] proposed a probabilistic analysis model of power supply capacity based on the full probability theory according to the traditional power supply capacity assessment model, and analyzed the impact of intermittent energy penetration and volatility on power supply capacity with wind power as an example. Wu [17] determined the dominant switching station load of the line power based on the current tracking theory and established the power sharing multiple non-linear regression model between the line power and the dominant switching station load. On this basis, a model of maximum power supply capacity of ring distribution network is proposed, which takes the maximum sum of power of substation as the objective function. While the limit of substation main transformer capacity, line transmission capacity and switching station capacity under N-1 power supply safety criterion are the constraint conditions. Fan [18] proposed a new model to evaluate the power supply capacity of distribution network. According to the principle of load rate balance of main transformer, the load rate of substation is taken as the independent variable, the maximum power supply capacity of the system is taken as the objective function, and the load transfer under the constraint condition of N-1 fault does not exceed the transmission capacity of the contact line between substations and the capacity margin of the transformer. This evaluation method not only considers the full utilization of the capacity of the liaison line and transformer, but also considers the load balance of the substation, ensuring the safety of the system and the quality of the power supply. Wu [19] investigated the impact of grid integration of electric vehicle charging, discharging, and storage integrated power stations on the power supply capacity of the grid. Considering the grid operation and battery charge state, multi-scenario optimization of the integrated power station is carried out, and the comparison matrix method is applied to propose the assessment indexes of the grid power supply capacity containing the integrated power station, which is combined with the continuous tidal current method.

Under the new economic and technological conditions, such as the distributed power supply concept, the integration of charging, discharging, and storage power plants into the grid and the development of multi-scenario technology all have different degrees of influence on the power supply capacity assessment model of the distribution network from different aspects, as shown in **Table 2**.

Table 2. Impact of new economic and technological conditions on the evaluation model

Influencing factor	Objective function	Constraint condition	Impact on ease of solution
Distributed generation	The addition takes into account the volatility and intermittency of distributed power models for optimization	Significant impact on the flow constraints of the original distribution network power supply capacity assessment model	Increase the difficulty of solving
Grid-connected charging, discharging and storage integrated power plant	The model optimization of integrated power station with both source and load characteristics is also considered	Different operating states and access locations of power plants complicate current constraints	Increase the difficulty of solving
Multi-scene technique	Multi-scene generation technology is used for modeling	Tidal currents and component parameter constraints in multi-scenario environments	Increase the difficulty of solving

4. STEPS FOR ASSESSING THE CAPACITY OF URBAN DISTRIBUTION NETWORK

The evaluation process of power supply capacity of urban distribution network is mainly divided into three steps:

(1) Establish the evaluation index system of power supply capacity of urban distribution network
(2) Determine the weight of each evaluation index
(3) Determine the evaluation method

The flow chart of power supply capability evaluation of distribution network is shown in **Figure 1**.

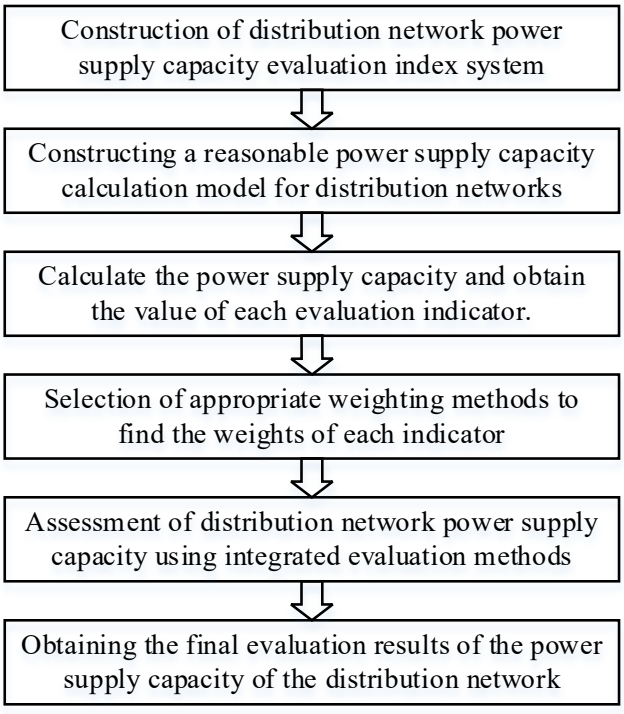

Figure 1. Flow chart of power supply capacity assessment of distribution network

4.1. EVALUATION INDEX SYSTEM OF POWER SUPPLY CAPACITY OF URBAN DISTRIBUTION NETWORK

As the basis of evaluation, the selection of evaluation index system plays an important role in the analysis object. In the process of establishing evaluation indicators, unreasonable situations may occur. For example, the structure of the index system is unreasonable, that is, the lack of understanding of the connotation of indicators, and the classification of indicators is not clear. Another example is that the index redundancy is too high, the direct or indirect influence between indicators is not considered, which results in the unreasonable determination of index weight. The shortcomings of insufficient comprehensiveness and strong subjectivity of indicators.

On the basis of full investigation and study of the operating characteristics of distribution networks, according to the "Guidelines for Planning and Design of Urban Power Grids" and "Guidelines for Security and Stability of Electric Power Systems," and combining with the specific conditions of distribution networks, we summarize the existing methods of establishing evaluation indexes, clarify the principles of constructing the evaluation index system, and construct a set of evaluation index system that can comprehensively reflect the power supply capacity of urban distribution networks on the basis of the original single assessment of distribution networks. On the basis of the original single assessment of distribution networks, a set of evaluation index system can be constructed to reflect the power supply capacity of urban distribution networks in an integrated and comprehensive way. It can be selected according to the following basic principles.

The first principle is systematic principle. The indicators of the evaluation index system must be able to reflect the technical characteristics and conditions of distribution network operation comprehensively and systematically from an overall perspective in cooperation with each other, and fully reflect the economy of distribution network operation.

The second principle is scientific principles. The indicators of the evaluation index system should be independent of each other and organically integrated. According to the interrelationship between the evaluation indicators, the degree of correlation between the indicators should be minimized, and overlapping cross-cutting areas between the indicators should be avoided or reduced.

Another principle is objectivity principle. In order to comprehensively and objectively reflect the economic situation of distribution network operation, the evaluation standard should be refined and perfected, and an objective, real, scientific, and effective evaluation index system of distribution network economic operation should

be established, so as to ensure the objectivity and fairness of the evaluation results.

Next is the principle of practicality. The construction of the evaluation indicator system should also take into account practicality and feasibility, and should be easy for relevant personnel to operate and use, and the indicator data should be easy to collect and expressed in a way that is easy to understand.

The evaluation index of power supply capacity can be divided into two aspects, which are load capacity and transfer capacity. Load capacity can include line heavy load ratio, capacity load ratio, and distribution heavy load ratio. The transfer capacity can include indicators such as the line meeting the N-1 ratio, line liaison rate, and the liaison line ratio of different substations. The evaluation indicators are reasonably designed according to the actual grid scenario. The meanings of some indicators are as follows.

(1) Capacity-load ratio refers to the ratio of the total capacity of the substation equipment to the maximum load of the power supply area in a certain power supply area.

(2) The line meets the N-1 ratio. The N-1 ratio refers to the ratio of the number of lines that meet the N-1 safety standard to the total number of lines.

(3) Line connection rate refers to the ratio of the number of connected lines to the total number of lines.

The communication includes that between different bus terminals of the same substation, and the communication between different substation terminals.

4.2. METHOD TO DETERMINE THE WEIGHT OF EACH EVALUATION INDEX OF POWER SUPPLY CAPACITY OF URBAN DISTRIBUTION NETWORK

The rationality of weight determination directly affects the correctness of the whole assessment process. There are many methods to determine the weights, such as Delphi method, hierarchical analysis, principal component analysis, entropy weight method, and the combination of the above methods to determine the method [20,21]. Choosing the best method for assigning weights to indicators is the key to comprehensive evaluation.

4.2.1. SUBJECTIVE WEIGHTING METHOD

Subjective weighting method is a method based on decision-makers to directly give preference information, such as analytic hierarchy process, Delphi method, and least sum of squares method, etc. However, subjective weighting method has shortcomings such as insufficient theoretical evidence and large subjective arbitrariness. The following is a brief introduction to several subjective empowerment methods.

(1) Delphi Method. It is also known as expert consultation method. This method first needs to hire a number of experts and scholars in related fields of the evaluated object to independently judge the relative importance of the evaluation indicators, analyze the weighted results of the experts through certain mathematical statistics methods, and finally determine the weight coefficient of each indicator.

(2) Analytic Hierarchy Process. Using the Analytic Hierarchy Process, the weight, according to the indicator level, constructs a two-by-two comparison of the judgment matrix, that is, the same level of indicators on the upper level of the relative importance of a particular indicator. Then the judgment matrix calculates the weight of the indicators and consistency test. The advantage of this method is that the level of indicators is clear and less quantitative data are needed, while the disadvantage is that there are many qualitative components, which affects the reasonableness of the weight.

4.2.2. OBJECTIVE WEIGHTING METHOD

Objective weighting method is based on decision matrix information, such as principal component analysis, entropy weight method, and multi-objective optimization method, but the weight determined method sometimes contradicts the actual importance of the index. The following is a brief introduction to several objective weighting methods.

(1) Principal Component Analysis (PCA). Principal component analysis is a multivariate analysis method. Principal component analysis reduces the number of indicator dimensions through data transformation, and maintains the characteristics of the data transformation of each indicator data with the largest contribution to each other's

difference, transforms and categorizes the heavy indicators into a few comprehensive indicators, and ensures the comprehensiveness of the indicator system after the data transformation.

(2) Entropy evaluation method. Entropy was originally a concept in physics to characterize the state of disorder of a system. It was later widely used in evaluation and decision theory. In information theory, entropy is used to determine the amount of information uncertainty. The larger the amount of information, the smaller the uncertainty, and the smaller the entropy. Conversely, the smaller the amount of information, the larger the uncertainty, and the larger the entropy.

4.2.3. COMBINED WEIGHTING METHOD

In recent years, considering the shortcomings of subjective and objective weighting methods, combined weighting methods have received more and more attention. Through the compromise and optimization of the index weights determined by the subjective and objective weighting methods, the final evaluation index weights are determined according to the specific conditions of the evaluated objects. This method not only reflects the subjective tendency of decision-makers to a certain extent, but also ensures the objectivity of index weight by using objective quantitative mathematical model and original data, and the weight of evaluation index is more reasonable.

4.3. COMPREHENSIVE EVALUATION METHOD OF POWER SUPPLY CAPACITY OF URBAN DISTRIBUTION NETWORK

Many domestic and foreign experts and scholars have studied the comprehensive evaluation of power grids. Comprehensive evaluation refers to the fact that according to different evaluation purposes, people choose corresponding evaluation forms, accordingly select multiple factors or indicators, and through certain evaluation methods, transform multiple evaluation factors or indicators into information that can reflect the overall characteristics of the evaluation object.

According to the theoretical basis of each evaluation method, the comprehensive evaluation methods are generally divided into four categories. The first category is expert evaluation methods. The second type is based on operations research and other mathematical theories, such as fuzzy comprehensive evaluation method, data envelopment method, etc. The third category is new evaluation methods, such as artificial neural network method [22], and gray comprehensive evaluation method. The fourth category is the hybrid approach, that is, the simultaneous use of several different evaluation methods in solving the same problem, such as principal component analysis plus fuzzy comprehensive evaluation [23], and fuzzy neural network evaluation [24]. The following is a brief introduction to several comprehensive evaluation methods.

(1) Fuzzy comprehensive evaluation

The fuzzy comprehensive evaluation method based on fuzzy mathematics theory is according to the principle of fuzzy relation synthesis, which quantitatively analyzes some influential factors with unclear boundaries and difficult to quantify, and comprehensively evaluates the subordination level of the evaluated things from multiple factors [25,26]. As a comprehensive evaluation method, fuzzy comprehensive evaluation has the following advantages. Firstly, fuzzy comprehensive evaluation deals with fuzzy evaluation objects by quantitative method, which can make the evaluation more scientific and reasonable, and can deal with fuzzy data close to reality. Secondly, the result obtained by fuzzy comprehensive evaluation is a vector rather than an exact value, which contains more information, is able to describe the evaluation object more accurately, can be further processed, and has more information reference value.

(2) Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) is a multidisciplinary cross-cutting field with a scientific and theoretical background that includes mathematics, operations research, mathematical economics, and management science, etc. In 1978, A. Charnes, W.W. Cooper, and E. Rhodes gave a C^2R model for the relative validity of the decision evaluation units as an initial model for DEA [27]. The DEA evaluation process is the

use of mathematical planning models to evaluate the relative validity between decision units with multiple inputs and outputs. It is very sensitive to the validity of the data provided and therefore has some limitations on the application of data envelopment analysis method.

(3) Grey Relational Analysis. Grey Relational Analysis is an effective method for mining the internal laws of data, and its basic idea is to compare and analyze the similarity degree of data sequence geometric relationship and curve geometry, and take the size of the similarity degree between the curves as a measure of the degree of correlation [28,29]. The process of grey relational analysis is to obtain the difference information between the sequences first, to establish the space of the difference information. Then the grey relational degree of the difference information is calculated, so as to establish the sequential relationship between factors, which is characterized by low requirements for sample data and low computational volume.

(4) TOPSIS

Technique for order preference by similarity to an ideal solution (TOPSIS) was first proposed by C.L. Wang and K. Yoon in 1981 that the method of ranking a limited number of evaluation objects according to their proximity to the idealized target is to evaluate the relative merits of existing objects [30]. By constructing the ideal value and making the participating schemes approximate to the ideal solution, the TOPSIS method is a judgmental ranking method, which only requires that the utility function of each indicator has monotonically increasing or decreasing nature.

Considering the evaluation indexes comprehensively, this paper determines the comprehensive assessment method of power supply capacity indexes of distribution network, evaluates the status quo network, comprehensively reflects the operation of the distribution network through the evaluation results. It also finds out the factors affecting the power supply capacity of the distribution network, and provides theoretical guidance for carrying out the renovation of the power grid, and improving the power supply capacity of its operation.

5. CONCLUSION

This paper summarized the current research status of the traditional urban distribution network power supply capability evaluation content, evaluation method and model, and summarized and analyzed the three steps of urban distribution network power supply capability evaluation, namely, establishing the evaluation index system of urban distribution network power supply capability evaluation, determining the weight of each evaluation index, and determining the evaluation method. However, with the expansion of the scale and complexity of the power grid, the assessment of the power supply capacity of the urban distribution network will face new challenges, and it is necessary to adapt to the distribution network under the new environment. In addition, the weak links of the distribution network found in the assessment should be reasonably demonstrated in the power grid planning and transformation technology. The power supply quality and reliability of the grid should be improved to bring greater social benefits.

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DISCLOSURE STATEMENT

The authors declare no conflicts of interest.

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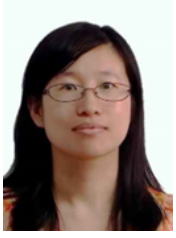

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