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Research on Quantifiable Target Index System of Distribution Network Planning for Energy Internet

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ABSTRACT In order to improve the guidance and operability of the planning and construction of the distribution network, ensure the safe, reliable and stable operation of the distribution network, and enhance the sustainable development and comprehensive competitiveness of China's power system. Taking the distribution network planning target indicators as the research object, combined with the characteristics of ''energy internet'', this paper constructs a more objective and comprehensive distribution network planning target indicator system facing energy Internet from multiple dimensions. Firstly, the selection principle and application scope of the index system are determined. Secondly, for enterprises, users, equipment, load, benefits and other factors, a quantifiable distribution network planning target index system for energy Internet covering 50 indicators are constructed from the six dimensions of safety and reliability, clean and low-carbon, efficient interaction, ubiquitous interconnection, intelligent openness and economic benefits Finally, an example is given to verify the effectiveness and operability of the planning target index system.

INDEX TERMS Energy internet, distribution network planning, index system, clean and low carbon, economic performance.

I. INTRODUCTION

With the continuous development of the economy, the demand for electricity load has gradually increased. At the same time, it is accompanied by the ''energy internet'' (the product of the deep integration of the energy field with automatic control, information processing, network communication and other fields) and the construction of new power systems. It puts forward higher requirements for power grid structure, power quality, economic efficiency, clean and low carbon, intelligent interaction, etc. [1]–[8]. Since the main grid of the power grid plays a decisive role in the stable supply of power in the region, the research on its planning target index system is relatively standardized and mature. However, with the rapid development of society, the importance of the distribution network is no less than that of the main network [9], [10], and the distribution network has become an important part of the power system. Its safety and reliability will directly affect the development of the national economy and people's living standards [11], [12]. With the continuous increase of the construction of distribution network, the planning target index system has also attracted the attention of power grid companies [13], [14]. Therefore, in order to improve the scientific rationality of distribution network planning, it is urgent to carry out the research on quantifiable distribution network planning target index system for ''energy internet''.

At present, more and more experts and scholars have carried out research on the target index system of distribution network planning. Although the constructed index system is not the same, the vast majority of literatures consider three aspects of power grid technology, economic benefits and environmental benefits [15]. In reference [16], considering reliability, economy, land occupation, environment and adaptability, the evaluation index system of distribution network planning scheme is constructed from these four aspects. Reference [17] establishes the evaluation index system of power grid planning from five aspects of power supply safety, reliability, economy, adaptability and coordination. Reference [18] constructs a comprehensive evaluation index system from five aspects of enterprise economic benefit, environmental benefit, social benefit, power grid technical

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performance and risk evaluation. It is demonstrated in [19] that comprehensively evaluates the distribution network from four aspects: technical rationality, operation safety, power supply quality and reliability, and maintenance level. This paper mainly studies the technical indicators of distribution network operation, without considering the indicators of distribution network construction. Reference [20] considered the energy-saving effect of implementing demand-side management, and constructed a post-evaluation index system for energy-saving measures of demand-side management from four aspects: economic benefits, social benefits, customer response and sustainability. Reference [21] constructs a comprehensive evaluation index system of smart grid from six aspects of firmness, efficiency, reliability, interactivity, economy and environmental friendliness, and puts forward indexes closely related to distribution network technology. It is demonstrated in [22] that establishes a comprehensive evaluation index system of smart grid from five aspects: development flexibility and coordination, reliability and voltage quality, economy, equipment utilization, technical equipment level and social benefits.

The above literatures are all about the construction of comprehensive target index system for traditional distribution network. However, with the proposal of ''double carbon target'' and the wide application of intelligence [23], more factors need to be considered when constructing the target index system of distribution network planning. Therefore, compared with other planning target index systems, combined with the characteristics of distribution network construction in China, this paper reconstructs a quantifiable distribution network planning target index system for ''energy internet'' from the six dimensions of safety and reliability, clean and low-carbon, efficient interaction, ubiquitous interconnection, intelligent openness and economic benefits. Further promote the innovation and practice of distribution network planning methods and means, promote the refinement and accuracy of distribution network planning, and constantly meet the new requirements of economic and social development for distribution network construction and development under the new situation.

II. SELECTION PRINCIPLE AND APPLICATION SCOPE OF INDEX SYSTEM

A. INDEX SYSTEM SELECTION PRINCIPLE

The distribution network is at the bottom of the whole power grid and closely connected with users. It has the characteristics of many points, wide range and long line. In order to establish a scientific and reasonable target index system of distribution network planning, the practicability and operability of the index system should be ensured on the basis of fully considering the influencing factors of distribution network construction. In terms of index selection, it should be accurate, standardized and comparable. As for the source of index data, it should be true and reliable. In terms of index results, it should be objective and comprehensive. Specifically, the establishment of distribution network planning target index system follows the principles shown in Figure 1.

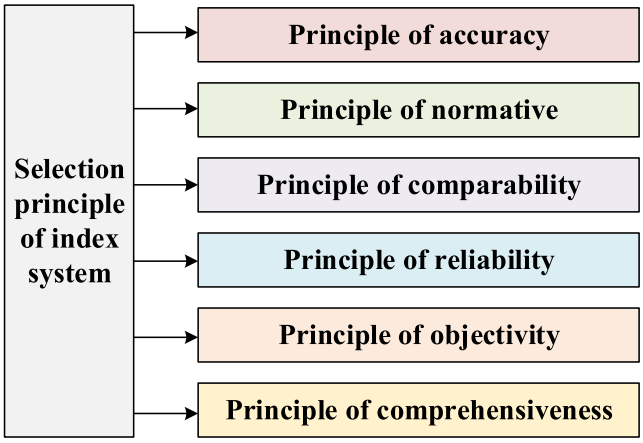

FIGURE 1. Selection principle of target index system for distribution network planning.

In Figure 1, the target index system of distribution network planning established in this paper mainly follows the six principles of accuracy, standardization, comparability, reliability, objectivity and comprehensiveness. The detailed description of each principle is as follows:

(1) Principle of accuracy. The connotation and denotation of the evaluation index are exactly defined, and the statistical caliber is unambiguous. In the development of the index system, we need to pay attention not to collect duplicate data information and try to avoid repeated calculation. In the selection of indicators, try to ensure their scientificity and relevance. If there is repeated calculation of index data, there should be a high degree of consistency.

(2) Normative principle. The indicators should have clear standards and norms. There should be unified normative requirements in the classification of evaluation indicators, measurement units, calculation methods, and questionnaire formulas. The systemicity and standardization of the entire evaluation system should be ensured, so that it can be promoted and applied in practical work.

(3) Principle of Comparability. The evaluation index should facilitate the comparison of distribution network planning and construction between different regions and in the same region at different time. In view of the different distribution network, it can highlight the distinct guiding effect.

(4) Principle of Reliability. The evaluation index should have reliable statistical data channels and be operable and practical. For the indicators that can't be counted for the time being and are very necessary, they can be set first and then counted with the improvement of the company's information system.

(5) Principle of objectivity. Evaluation indicators should be able to truly reflect the statistical objects. On the basis of objectively understanding and grasping the actual operating status of the distribution network. The statistical data is unambiguous, and the indicators are consistent with the

TABLE 1. Evaluation index of domestic and international power grid.

European Energy Regulatory Commission regulatory indicators	British Electricity Regulatory Agency Regulatory Indicators
● Power supply continuity: system average outage time (SAIDI). ● Service standard category for individual users: failure recovery time related to a single customer. ● Voltage quality category: voltage quality indicators related to relevant standards.	● Performance incentive: index of power cut times of users (CI). ● Investment incentive: accuracy and stability of investment forecast. ● Operation efficiency incentive: unit CSV controllable operation cost. ● Line loss incentive index: line loss electricity cost.
Zhejiang "World Class" Index	**Jiangsu "World Class" Index**
● Power supply reliability: average annual power outage time for urban users. ● Sustained development: clean energy access ratio. ● Service quality: third-party customer satisfaction. ● Operating efficiency: return on assets. ● Asset efficiency; average life of assets.	● Resource allocation capability: power shortage probability (LOLP) ● Sustainable development: average outage duration index (SAIDI) ● Risk resistance: customer complaint rate ● Service support capability: transformation capacity per unit power

actual situation. Only by ensuring the objectivity of evaluation indicators can the objectivity of grid planning be ensured.

(6) Principle of comprehensiveness. The entire structure of the evaluation index should cover all operating links of the distribution network. There is no blind zone in the comprehensive and systematic determination of the range of individual indicators and the entire indicator system to be expressed.

B. APPLICATION SCOPE OF INDEX SYSTEM

The distribution network planning target index system established in this paper is mainly for 110kV, 35kV high-voltage distribution network and 10kV medium voltage distribution network (the system structure diagram of distribution network is shown in Figure 2). The index system is mainly applied to the distribution network planning evaluation of provincial companies to prefecture and municipal companies and prefecture and municipal companies to county-level companies. Considering the differences of regional development, county-level companies can refer to the formulation of corresponding distribution network planning target index system and detailed rules to evaluate the township distribution network planning.

III. INDEX SYSTEM CONSTRUCTION

Select developed countries and regions that can represent the ''world-class level'' of urban power grids, such as Britain, Germany, and France, for research. It is found that these countries and regions have selected indicators related to power supply reliability, economic efficiency and customer satisfaction as the core indicators to measure their construction and operation levels, but they are different in the selection of specific indicators. Domestic units that started international benchmarking earlier, such as State Grid Zhejiang Electric Power Company and State Grid Jiangsu Electric Power Company, have also carried out the collection and summary of relevant indicators in the practice of striving to be first-class. In view of the reliability of power supply, operating efficiency, service quality, etc., the screening results of key indicators of world-class urban power grids are presented, as shown in Table 1.

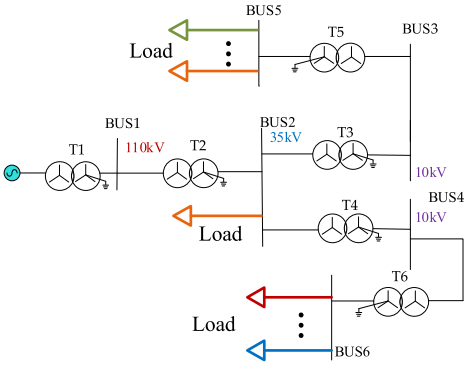

FIGURE 2. The system structure diagram of distribution network.

Through the investigation and analysis of the world's advanced urban power grid and some domestic power grids, and the research on the existing target index system. This paper comprehensively analyzes the factors affecting distribution network planning and construction from the six dimensions of safety and reliability, ubiquitous interconnection, clean and low-carbon, efficient interaction, intelligent openness and economic benefits (as shown in Figure 3). And use the interval reciprocal judgment matrix method to determine the index weight [24]. Finally, a quantifiable distribution network planning target index system for ''energy internet'' is constructed. Realize the transformation from single index to single and compound index, from pure terminal index management to the combination of terminal index and process index management.

A. SAFE AND OBJECTIVE

Safe and reliable power supply is the first priority and the most basic element of urban power grid to serve the society. Safe and reliable urban power grid can provide sufficient power supply for the smooth and stable development of all walks of life. The instability of power supply system will bring huge losses to the national economy and social development. Therefore, in the process of building a new generation of distribution network, we must put 'safety and reliability''

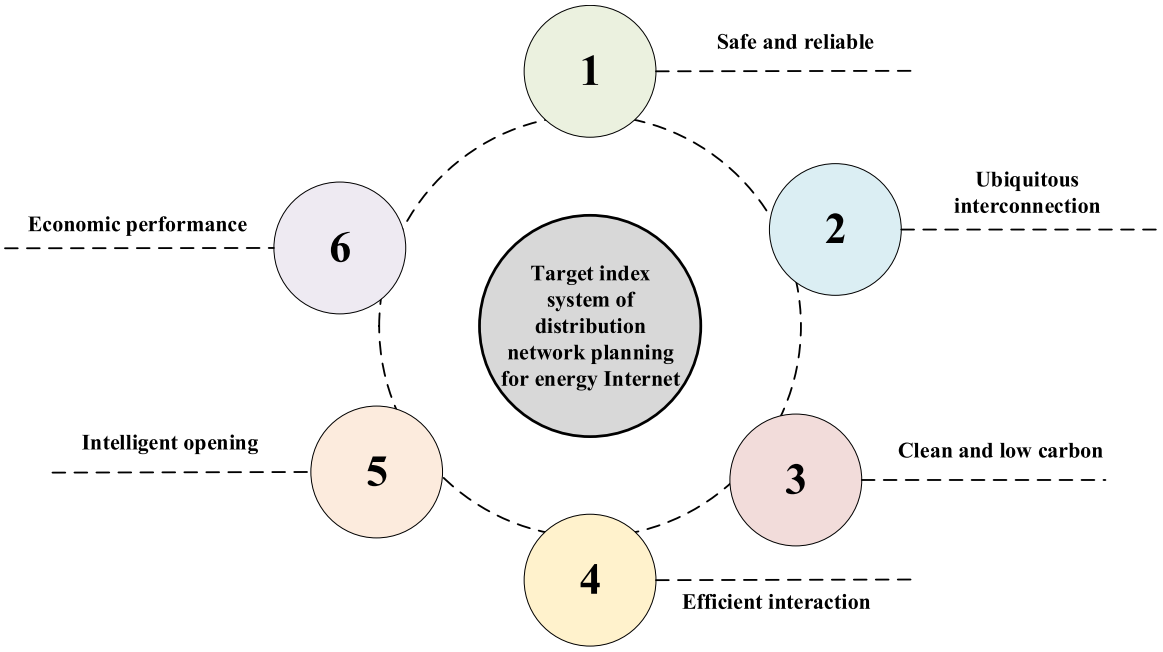

FIGURE 3. Distribution network planning index system based on six dimensions.

TABLE 2. Support index of grid structure.

Serial number	Support name	Definition and description of supporting indicators	Weights
1	N-1 pass rate of 110kV main transformer (%)	The N-1 passing rate of 110kV main transformer is the percentage of the ratio between the number of 110kV main transformers meeting N-1 and the total number of 110kV main transformers. The calculation formula is as follows: 110kV main transformer N-1 pass rate = number of 110kV main transformer units that meet N-1 / total number of 110kV main transformer units×100%	10%
2	N-1 pass rate of 35kV main transformer (%)	The N-1 passing rate of 35kV main transformer is the percentage of the ratio between the number of 35kV main transformers meeting N-1 and the total number of 35kV main 35kV main transformer N-1 pass rate = number of 35kV main transformer units that meet N-1 / total number of 35kV main transformer units×100%	10%
3	N-1 pass rate of 110kV line (%)	The pass rate of 110kV line N-1 is the percentage of the ratio of the number of 110kV lines meeting N-1 to the total number of 110kV lines. Calculated as follows: 110kV line N-1 pass rate = number of 110kV lines meeting N-1 / total number of 110kV lines×100%	15%
4	N-1 pass rate of 35kV line (%)	The pass rate of 35kV line N-1 is the percentage of the ratio of the number of 35kV lines meeting N-1 to the total number of 35kV lines. Calculated as follows: 35kV line N-1 pass rate = number of 35kV lines meeting N-1 / total number of 35kV lines×100%	15%
5	N-1 pass rate of 10kV line (%)	The pass rate of 10kV line N-1 is the percentage of the ratio of the number of 10kV lines meeting N-1 to the total number of 10kV lines. Calculated as follows: 10kV line N-1 pass rate = number of 10kV lines meeting N-1 / total number of 10kV lines×100%	20%
6	10kV line connection rate (%)	Refers to the ratio of the number of 10kV lines that are connected to the total number of 10kV lines. Calculated as follows: 10kV line connection rate = number of connected 10kV lines/10KV line total number×100%	20%
7	Average power supply radius of 10kV line (km)	Refers to the average value of the power supply radius of all 10kV lines within a region. Calculated as follows: Average power supply radius of 10kV line = sum of power supply radius of all 10kV lines/10kV line total number×100%	10%

TABLE 3. Supporting indicators of power supply capacity.

Serial number	Support name	Definition and description of supporting indicators	Weights
1	110kV capacity load ratio (%)	It refers to the ratio of the total capacity of the public substation equipment and the corresponding load of the 110kV power grid in the planning area. It is a macro index used to evaluate the adequacy of power supply capacity of regional power grid of this voltage level. The calculation formula is as follows: 110kV capacity load ratio = the sum of the maximum load of 110kV network supply in the planning area / the main transformer capacity of 110kV public substation×100%	5%
2	35kV capacity load ratio (%)	It refers to the ratio of the total capacity of the public substation equipment and the corresponding load of the 35kV power grid in the planning area. It is a macro index used to evaluate the adequacy of power supply capacity of regional power grid of this voltage level. The calculation formula is as follows: 35kV capacity load ratio = the sum of the maximum load of 35kV network supply in the planning area / the main transformer capacity of 35kV public substation×100%	5%
3	Proportion of heavy load (overload) of 110kV main transformer	It refers to the proportion of the number of 110kV heavy load main transformers in the total number of 110kV main transformers. Among them, 110kV heavy load main transformer refers to the 110kV main transformer with maximum load rate greater than 80% and single time lasting more than 2 hours. The calculation formula is as follows: Proportion of 110kV heavy load main transformer = number of 110kV heavy load main transformer / total number of 110kV main transformer×100%	10%
4	Proportion of heavy load (overload) of 35kV main transformer	It refers to the proportion of the number of 35kV heavy load main transformers in the total number of 35kV main transformers. Among them, 35kV heavy load main transformer refers to the 35kV main transformer with maximum load rate greater than 80% and single time lasting more than 2 hours. The calculation formula is as follows: Proportion of 35kV heavy load main transformer = number of 35kV heavy load main transformer / total number of 35kV main transformer×100%	10%
5	Average value of maximum load rate of 10kV line (%)	It refers to the average value of the maximum load rate of all 10kV lines under normal operation mode. Among them, the maximum load rate of a single 10kV line is the percentage of the ratio of the annual maximum load (MW) of a single 10kV line to the rated transmission power (MW) of a single 10kV line. The calculation formula is as follows: Average value of maximum load rate of 10kV line = sum of maximum load rate of all 10kV lines / total number of 10kV lines×100%	15%
6	Proportion of 10kV line heavy load (overload)%	It refers to the proportion of the number of 10kV heavy haul lines in the total number of 10kV lines. Among them, 10kV heavy haul line refers to the 10kV line with the maximum load rate greater than 80%. The calculation formula is as follows: Proportion of 10kV heavy haul lines = number of 10kV heavy haul lines / total number of 10kV lines×100%	15%
7	Average value of maximum load rate of 10kV distribution transformer	It refers to the average value of the maximum load rate of all 10kV distribution transformers. Among them, the maximum load rate of a single 10kV distribution transformer is the percentage of the ratio between the annual maximum load of a single 10kV distribution transformer and the rated transmission power of a single 10kV distribution transformer. The calculation formula is as follows: Average value of maximum load rate of 10kV distribution transformer = sum of maximum load rate of all 10kV distribution transformers / total number of 10kV distribution transformers (sets)×100%	15%
8	Proportion of 10kV distribution transformer heavy load (overload) (%)	It refers to the proportion of the number of 10kV heavy load distribution transformers in the total number of 10kV distribution transformers. Among them, 10kV heavy load distribution transformer refers to the 10kV distribution transformer whose maximum load rate is more than 80% and single time duration is more than 2 hours. The calculation formula is as follows: The proportion of 10kV heavy load distribution transformer = the percentage of the ratio of the number of 10kV heavy load distribution transformer to the total number of 10kV distribution transformer×100%	15%
9	Average household distribution capacity (kVA / household)	It refers to the ratio of the total capacity of 10kV public distribution transformer to the number of households. The formula is as follows: Average household distribution transformer capacity = total capacity of 10kV public distribution transformer / number of residential households×100%	10%

TABLE 4. Power supply quality support indicators.

Serial number	Support name	Definition and description of supporting indicators	Weights
1	Power supply reliability rate (RS-1) (%)	Refers to the ratio of the total hours of effective power supply to users (excluding planned blackouts) during the statistical period to the hours during the statistical period. The formula is as follows: Power Supply Reliability = (8760-Average Power Outage Time for Users)/8760×100%	25%
2	Average annual power outage time of users (h)	Refers to the average number of hours of power outage for power users during the statistical period. The formula is as follows: Average user outage time = ∑ (duration of each outage × number of users per outage)/total number of users	10%
3	Comprehensive voltage qualification rate (%)	Refers to the percentage of the cumulative running time of the actual running voltage deviation within the limit to the corresponding total running statistical time. Calculated as follows: Comprehensive voltage qualification rate=V=0.5×VA+0.5×(VA+VB+VC)/3 Among them, the qualification rate of VA--A monitoring points; the qualification rate of VB--B monitoring points; the qualification rate of VC--C monitoring points; the qualification rate of VD--D monitoring points	25%
4	Low voltage distribution transformer ratio (%)	Refers to the proportion of low voltage distribution stations to the total number of transformers. The formula is as follows: Low Voltage Distribution Ratio = Number of Low Voltage Distribution Units/Total Number of Tolerances×100%	10%
5	Proportion of low-voltage users (%)	Refers to the proportion of end users with "low voltage" phenomenon to the total number of users. Calculated as follows: Percentage of users with "low voltage" = number of users with "low voltage" phenomenon/total number of users (households)×100%	10%
6	Average number of power outages by users (times)	Refers to the average number of power outages experienced by a user in a unit time. The calculation formula is as follows: the average number of power outages by users = the total number of power outages per user per unit time / the total number of users in the supply area	10%
7	Average duration of scheduled outage (h)	Refers to the planned average duration of a power outage within a single pre-outage on the grid side. Calculated as follows: Average duration of scheduled outage = Σ (pre-arranged outage time)/pre-arranged outage times	10%

in the first place, so as to ensure reliable, stable and safe power supply to users in various industries and support social and economic development.

This paper decomposes and analyzes the safety and reliability index from four power grid business modules: grid structure, power supply capacity, power supply quality and equipment level. The four categories of support indicators account for 25% of the weight of safety and reliability indicators.

1) GRID STRUCTURE

Grid structure plays a fundamental and critical role in the overall situation of distribution network construction. It is the basic guarantee for regional expansion and development. By building a robust, orderly, flexible and reliable distribution network architecture to serve the urbanization construction, the prominent problems such as heavy overload and low voltage are fundamentally solved. Differentiation improves power supply reliability and distribution network flexibility. The grid structure is mainly analyzed from two aspects of grid structure standardization and N-1 passing rate.

As far as high voltage is concerned, it mainly reflects the transfer capacity of the power grid at the same level and the next level when any element (main transformer and line) in the power grid is out of service through the N-1 passing rate of main transformer and line. Medium voltage mainly considers line connection rate, N-1 passing rate, power supply radius and other indicators. The line connection rate and N-1 passing rate are based on the consideration of power supply security. The former examines the structural support capacity of the medium voltage distribution network for the superior power grid, while the latter is at any section of the power supply. For a group of anticipated faults, the ability of power grid to maintain normal and continuous power

TABLE 5. Correspondence table of *G* value coefficent.

Serial number	Support name	Definition and description of supporting indicators	Weights
1	110kV old and old main transformers (%)	Refers to the proportion of the 110kV equipment that has reached or exceeded 80% of the design life and the status is evaluated as abnormal or serious to the total number of 110kV equipment. Calculated as follows: The proportion of 110kV old equipment = the number of 110kV equipment that has reached or exceeded 80% of the design life and the state is evaluated as abnormal or serious / the total number of 110kV equipment×100%	10%
2	The proportion of 35kV old and old main transformers (%)	Refers to the proportion of 35kV equipment whose operation has reached or exceeded 80% of the design life and the status is evaluated as abnormal or serious. Calculated as follows: The proportion of 35kV old equipment = the number of 35kV equipment that has reached or exceeded 80% of the design life and the status is evaluated as abnormal or serious / the total number of 35kV equipment×100%	10%
3	10kV old lines (%)	Refers to the ratio of the number of 10kV lines whose operation has reached or exceeded 80% of the design life and the status is evaluated as abnormal or serious to the total number of 10kV lines. Calculated as follows: Percentage of 10kV old lines = the number of 10kV lines that have reached or exceeded 80% of the design life and the status is evaluated as abnormal or serious/10kV lines×100%	20%
4	The proportion of 10kV old and old transformers (%)	Refers to the proportion of 10kV distribution variables that have reached or exceeded 80% of the design life and whose status is evaluated as abnormal or serious to the total number of 10kV distribution variables. Calculated as follows: Percentage of 10kV old distribution transformers = 10kV distribution variables that have reached or exceeded 80% of the design life and whose status is evaluated as abnormal or serious/10kV total number of distribution transformers×100%	20%
5	Overhead insulation rate of 10kV lines (%)	Refers to the ratio of the length of the overhead insulated line of 10kV line to the total length of the overhead line of 10kV line. Calculated as follows: Insulation rate of 10kV overhead lines = the sum of the lengths of all 10kV overhead lines / the ratio of the total length of all 10kV overhead lines×100%	15%
6	Cabling rate of 10kV lines (%)	Refers to the ratio of the length of the 10kV line cable to the total length of the 10kV line. Calculated as follows: 10kV line cable rate = 10KV line cable length (km)/total length of all 10kV lines (km) ratio×100%	15%
7	The proportion of 10kV high loss distribution variants (%)	This indicator is used to reflect the implementation of energy conservation and consumption reduction policies. Calculated as follows: High-loss distribution transformer ratio = S7 (including S8) and the following model number of distribution transformers/total number of distribution transformers×100%	10%

supply to load is investigated. The supporting indexes of grid structure are shown in Table 2.

2) POWER SUPPLY CAPACITY

The distribution network is a terminal power network which directly supplies power to users, and its structural features include multiple voltage levels. Whether each voltage level of distribution network can supply power safely and reliably will directly affect the quality of power supply to users. Moreover, with the increasing proportion of distributed generation connected to the distribution network, the structure and trend of power flow will be changed. The original structure of single source radiation has become a network structure with two or more power supply terminals, and the direction of power flow has changed from single source to load to reverse flow of power flow, which has a certain impact on power quality, power supply safety and power grid planning of distribution network. The fluctuation of load and the inaccuracy of load forecasting require the distribution network to be flexible to the future load and to be adaptive to the expectation of

TABLE 6. Ubiquitous interconnection support indicators.

Serial number	Support name	Definition and description of supporting indicators	Weights
1	Smart meter coverage (%)	Refers to the proportion of the number of smart meters installed at settlement and metering points in the area to the total number of electricity meters at the settlement and metering points in the evaluation area. Calculated as follows: Smart meter coverage = the number of smart meters installed at the settlement and metering points in the area/the total number of meters installed at the settlement and metering points in the area×100%	20%
2	Distribution automation coverage rate (%)	Refers to the proportion of the number of 10kV lines equipped with distribution automation terminals in the area to the total number of 10kV lines in the area, denoted as DAR-1. Calculated as follows: Distribution automation coverage rate = the number of 10kV lines equipped with distribution automation terminals in the area/the total number of 10kV lines in the statistical area×100%	20%
3	Feeder communication network coverage rate (%)	Refers to the ratio of the number of feeder terminals covering the communication network to the total number of feeder terminals. Calculated as follows: Feeder communication network coverage ratio = number of feeder terminals covering 10kV communication access network/total number of feeder terminals×100%	20%
4	Station communication network coverage rate (%)	Refers to the ratio of the number of station terminals covering the communication network to the total number of station terminals. Calculated as follows: Station communication network coverage = number of station terminals covering 10kV communication access network/total number of station terminals×100%	20%
5	Distribution transformer information collection rate (%)	Refers to the ratio of the number of distribution transformers that realize information collection to the total number of distribution transformers. Calculated as follows: Distribution transformer information collection rate = number of distribution transformer units that realize information collection/total number of distribution transformer units×100%	20%

load growth. The economic, reliable and stable operation ability of distribution network is reflected by capacity load ratio, main transformer heavy load (overload) ratio and average household distribution transformer capacity. Improve the flexibility and adaptability of the system in an all-round way, improve the grid's ability to accept distributed energy, and ensure the adaptability and sustainability of the development of distribution network. The supporting indexes of power supply capacity are shown in Table 3.

3) POWER SUPPLY QUALITY

The power supply reliability of distribution network is the reliability of continuous power supply to users on the premise of meeting the power supply security criteria of power grid. Voltage quality is an important symbol to reflect the management level of power supply enterprises and the power quality of users, which is mainly measured by voltage level. To meet the requirements of power supply reliability and voltage quality is one of the main tasks of distribution network construction. When planning the distribution network, in order to meet the power demand of users, the power grid operation needs to meet the characteristics of safety and stability, so as to avoid the collapse or damage of voltmeters and other equipment. At the same time, it is also necessary to improve the load bearing capacity of the power grid and reduce the failure rate of the power grid.

Relevant indexes reflecting the reliability and quality of distribution network mainly include power supply reliability rate, average annual power outage time of users, comprehensive voltage qualification rate, low voltage distribution ratio, low voltage user ratio, etc. Power supply quality support indicators are shown in Table 4:

4) EQUIPMENT LEVEL

Distribution network equipment utilization efficiency and technical equipment level are important attributes reflecting distribution network assets. Comprehensively promote the standardized configuration of power distribution network equipment, drive the transformation and upgrading of upstream and downstream industries, and realize the level upgrade of power distribution network equipment and energy saving and consumption reduction, which is conducive to

TABLE 7. Clean low carbon support indicators.

Serial number	Support name	Definition and description of supporting indicators	Weights
1	Proportion of electric energy in terminal energy consumption (%)	Refers to the proportion of electricity in the total energy consumption of the terminal, the calculation formula is as follows: Terminal electrification rate = total power consumption/total terminal energy consumption×100%	25%
2	Proportion of renewable energy in power generation (%)	Refers to the proportion of renewable energy in electricity generation. Calculated as follows: Renewable energy power accounted for power generation = renewable energy power/total power generation×100%	25%
3	Utilization rate of renewable energy power generation (%)	Refers to the percentage of the actual power generation from renewable energy to the theoretical power generation. Calculated as follows: Renewable energy power generation utilization rate = actual renewable energy power generation/theoretical power generation×100%	15%
4	Penetration rate of distributed generation (%)	Refers to the proportion of the installed capacity of distributed power sources in the annual maximum load of the region. Calculated as follows: Distributed power penetration rate = installed capacity of distributed power/regional annual maximum load×100%	10%
5	Energy consumption per unit GDP (tons of standard coal/10000yuan)	Refers to the ratio of total primary energy supply to GDP. Calculated as follows: Comprehensive energy consumption per 10,000yuan output value = total primary energy supply/gross domestic product×100%	15%
6	Comprehensive line loss rate (%)	Refers to the ratio of the difference between the power supply of the distribution network of 110kV and below and the electricity sold to the power supply of the distribution network of 110kV and below. Calculated as follows: Comprehensive line loss rate = (110kV and below distribution network power supply-difference between sales power)/110kV and below distribution network power supply×100%	10%

ensuring the safe and reliable operation of the power grid. Among them, the utilization efficiency of distribution network equipment is an important manifestation of the overall operation efficiency of the distribution network, and it is also an important marker to make full use of its own value during the life of distribution assets. The related indexes include the load rate and its distribution of the main transformer, the load rate and its distribution of the distribution transformer, the line load rate and its distribution, etc. Distribution network technology and equipment level is the main means to achieve high-quality power supply and improve service efficiency of enterprises. Relevant indicators include the proportion of old and old main transformers, line overhead insulation rate, etc. The equipment level support index is shown in Table 5:

B. UBIQUITOUS INTERCONNECTION

The integration of cloud computing, big data, internet of things, mobile applications and other key technologies provides strong technical support for the development of distribution network. The digital construction of power grid such as data center and business center promotes the lean of distribution network planning and construction, equipment management and decision support. Strong smart grid characterized by informatization, automation, interaction and intelligence has become the development trend of power grid in the future.

Improve the cloud service capability of storage, computing, network and other resources by building and improving the infrastructure cloud platform. Promote the construction of the Internet of things, build an intelligent perception and data collection system, and improve the perception and data collection ability of intelligent devices. Build a wide area coverage, high-speed broadband, safe and reliable, moderately advanced and technologically advanced power communication network. Optimize the power communication network architecture, meet the communication needs of smart grid, and improve the coverage level of power communication optical cable. Make full use of public network communication resources to build an economic, flexible, two-way, real-time, safe, reliable and all-round power distribution and

TABLE 8. High efficiency interactive support indicators.

Serial number	Support name	Definition and description of supporting indicators	Weights
1	Comprehensive energy utilization efficiency (%)	The comprehensive utilization efficiency of energy refers to the ratio of energy effectively used by a system (country, region, enterprise or single energy consuming equipment) to actual energy consumption. It is a comprehensive index reflecting the level of energy consumption and the effect of utilization, that is, the effective utilization of energy. The calculation formula is as follows: Energy comprehensive utilization efficiency = energy used effectively/actual energy consumption×100%	25%
2	Source-network-load-storage collaborative service index (%)	Reflects the ability of the power grid to interact with users, which can be measured by adjusting the proportion of the load and the proportion of the station area that implements energy optimization. Calculated as follows: Source network load-storage intelligent interactive service index = user-side demand response resource library maximum adjustable load capacity / maximum power load of the grid×60%+number of energy optimization implemented in public stations/total number of public stations×40%	25%
3	Customer service satisfaction (%)	Reflect the extent to which the services provided by the company meet the psychological expectations of users.	30%
4	Service radius of electric vehicle charging facilities (km)	In order to introduce this indicator to reflect the coverage of electric vehicle charging facilities, the service radius should be as small as possible.	10%
5	Electric vehicle charging pile vehicle ratio (%)	Refers to the ratio of the number of electric vehicle charging piles to the number of electric vehicles in the area. Calculated as follows: The ratio of electric vehicle charging piles to vehicles = the number of electric vehicle charging piles in the area/the number of electric vehicles in the area×100%	10%

TABLE 9. Supporting indicators of intelligent open class.

Serial number	Support name	Definition and description of supporting indicators	Weights
1	Digital development index (%)	It is a comprehensive index reflecting the application level of information technology such as business online rate. Online rate of energy service business refers to the ratio of online services of energy construction services, energy consumption services and energy value-added services to the total service forms. The calculation formula is as follows: Online rate of energy service business = three online service/total service forms of energy service business: energy construction service, energy consumption service and energy value-added service×100%	60%
2	Comprehensive energy services business development index (%)	It reflects the overall development level of the company's comprehensive energy business, which can be measured by the target completion rate of comprehensive energy service business income and comprehensive energy efficiency. The calculation formula is as follows: Comprehensive energy service business development index = comprehensive energy business revenue completion value/revenue target value × 60%+energy consumption per unit of GDP/target value of energy consumption per unit of GDP×40%	40%

consumption communication network. Strengthen the coverage level of optical cable in distribution network, and effectively support the reliable operation of distribution automation remote control and power consumption information collection business. Strengthen the power grid operation monitoring and control ability to realize the observable and controllable distribution network.

Through the distribution automation coverage, smart meter coverage, feeder communication network coverage, station communication network coverage, distribution transformer

TABLE 10. Supporting indicators of economic benefits.

Serial number	Support name	Definition and description of supporting indicators	Weights
1	Increased supply load by unit investment (kW/10,000yuan)	Refers to the ratio of the difference between the maximum power supply load at the end of the period and the maximum power supply load at the beginning of the period to the grid investment during the statistical period. Calculated as follows: Increased load of unit investment = difference between the maximum load of power supply at the end of the period and the maximum load of power supply at the beginning of the period (kW)/grid investment during the statistical period (10,000yuan) × 100%	50%
2	Increased power supply per unit investment (kWh/10,000yuan)	Refers to the ratio of the difference between the power supply at the end of the period and the power supply at the beginning of the period to the grid investment during the statistical period. Calculated as follows: Increased power supply per unit investment = difference between power supply at the end of the period and the power supply at the beginning of the period (kwh)/grid investment during the statistical period (10,000 yuan) × 100%	50%

information collection rate and other indicators to reflect the intelligent level of distribution network development. And meet the business needs of improving power supply reliability, improving power supply quality and improving the management level of distribution network. The supporting indicators of ubiquitous interconnection are shown in Table 6.

C. CLEAN AND LOW CARBON

Wind energy and solar energy develop rapidly and are widely used. The development and utilization of water energy, wind energy, solar energy, biomass energy and other clean energy has greatly alleviated the demand for energy in the rapid economic and social development. While reducing carbon dioxide emissions, we should deal with global warming and environmental pollution, and promote economic and social development to a certain extent. Therefore, in the distribution network planning for ''energy internet'', clean energy supply occupies an extremely important position. It is necessary to cooperate with power development and power grid construction, actively do a good job in various types of non-fossil energy grid services, and improve the support level of power side for system security and stability.

The related indicators mainly include the proportion of electric energy in terminal energy consumption, the proportion of renewable energy in power generation, and the energy consumption per unit GDP. The clean and low carbon support indicators are shown in Table 7.

D. EFFICIENT INTERACTION

To meet the needs of smart city development, build a comprehensive energy service system with energy efficiency as the core. It is necessary to promote the construction of integrated energy network infrastructure based on smart grid. At the same time, we should strengthen the interconnection of various types of networks and promote the deep integration of energy and information and communication infrastructure. And support flexible conversion, efficient storage and intelligent collaboration of various energy forms such as electricity, cold, heat, gas and hydrogen to improve the comprehensive utilization efficiency of energy. At the same time, smart home, smart community and other residential side smart power, as well as electric vehicle charging and swapping infrastructure supporting power grid construction and transformation. It puts forward higher requirements for the flexibility and adaptability of urban distribution network planning and the realization of efficient interaction between load and storage of source network.

The related indicators mainly include energy comprehensive utilization efficiency, source network load storage collaborative service index, customer service satisfaction, service radius of electric vehicle charging facilities, pile to car ratio of electric vehicle charging pile, etc. The supporting indicators of high efficiency interaction are shown in Table 8.

E. EFFICIENT INTERACTION

The Internet plus smart energy concept will enhance the public participation and create an open, inclusive and win-win environment for innovation, and promote the interconnection and interconnection of multi energy complementary energy networks. And support energy big data integration and sharing, business model innovation. Jointly promote the construction of information symmetry, open and shared energy Internet system, which provides a variety of operation modes and commercial value for the future distribution network. Through the digital development index, comprehensive energy service business development index, business model innovation index and other indicators to reflect the openness and sharing of distribution network business development, and promote the development of power grid to energy interconnection and sharing. The supporting indicators of intelligent open class are shown in Table 9.

F. ECONOMIC PERFORMANCE

Economic benefit is the internal power and external requirement to promote the healthy development of distribution network. Through the economic evaluation of the construction scheme of the distribution network, it can improve the

TABLE 11. Planning target table of distribution network in wuhan city, hubei province.

First level indicator	Secondary indicators	Indicator name	Current value in 2020	Target value at the end of the "14th Five-Year Plan" period	2030 target value	Vision Year Target Value
Safe and reliable	Grid structure	N-1 passing rate of 110kV main transformer (%)	92.26	100	100	100
		N-1 passing rate of 35kV main transformer (%)	91.46	100	100	100
		N-1 passing rate of 110kV line (%)	91.06	100	100	100
		N-1 passing rate of 35kV line (%)	94.12	100	100	100
		N-1 passing rate of 10kV line (%)	91.17	100	100	100
		10kV line connection rate (%)	94.41	100	100	100
		Average power supply radius of 10kV line (km)	3.41	2.98	2.49	2
	Power supply capacity	110kV capacity load ratio	1.86	1.84	1.8	1.8
		35kV capacity load ratio	2.05	1.82	1.8	1.8
		Proportion of heavy load (overload) of 110kV main transformer	11.90	0	0	0
		Proportion of heavy load (overload) of 35kV main transformer	3.66	0	0	0
		Average value of maximum load rate of 10kV line (%)	38.01	30	42.5	55
		Proportion of 10kV line heavy load (overload)%	9.44	0	0	0
		Average value of maximum load rate of 10kV distribution transformer (%)	21.23	40	47.5	55
		Proportion of 10kV distribution transformer heavy load (overload) (%)	4.76	0	0	0
		Average household distribution capacity (kVA/household)	3.73	3.66	4.08	4.5
	Power quality	Power supply reliability (RS-1) (%)	99.9597	99.9874	99.9909	99.9954
		Average annual outage time of users (h)	3.53	1.10	0.8	0.4
		Comprehensive voltage qualification rate (%)	99.9980	99.9990	99.9995	99.9999
		Proportion of low voltage distribution transformer	1	0	0	0
		Proportion of low voltage users (%)	4	0	0	0
		Average number of power outages by users (times)	0.5	0.37	0.12	0.05
		Average duration of scheduled outage (h)	3.22	1.03	0.77	0.3
	Equipment level	Proportion of 110kV old main transformer (%)	13.99	0	0	0
		Proportion of 35kV old main transformer (%)	12.2	0	0	0
		Proportion of 10kV old lines (%)	7.16	0	0	0
		Proportion of 10kV old distribution transformer	0.17	0	0	0
		Overhead insulation rate of 10kV line (%)	72.14	85	92.5	100
		10 kV line cabling rate (%)	47.69	55	57.5	60
		Proportion of 10kV High Loss Distribution Transformer (%)	2.98	0	0	0
Clean and low-carbon	Clean consumption	Proportion of electric energy in terminal energy consumption (%)	30	45	50	58
		Proportion of renewable energy in power generation (%)	44	50	60	80
		Utilization rate of renewable energy power generation (%)	100	100	100	100
		Penetration rate of distributed generation	16.5	16	24	44
	Green and low-carbon	Comprehensive energy consumption per 10,000yuan output value (ton of standard coal/10,000yuan)	0.55	0.40	0.35	0.28
		Comprehensive line loss rate (%)	4.65	3.65	2.575	1.5
Ubiquitous interconnection	Intelligent Internet of things	Smart meter coverage rate (%)	100	100	100	100
		Distribution automation coverage rate (%)	100	100	100	100
		Feeder communication network coverage rate (%)	100	100	100	100
		Communication network coverage rate of stations and substations (%)	100	100	100	100
		Distribution transformer information collection	100	100	100	100

TABLE 11. *(Continued.)* **Planning target table of distribution network in wuhan city, hubei province.**

		rate (%)				
Efficient interaction	Efficient service	Energy comprehensive utilization efficiency (%)	39	45	60	80
		Source network load storage collaborative service index (%)	5	15	25	35
		Customer service satisfaction (%)	92	98	99	100
	Green transportation	Service radius of electric vehicle charging facilities (km)	3	2.5	1.5	小于 1
		Electric vehicle charging pile to vehicle ratio (%)	1:11	1:5	1:3.5	1:2.5
Smart and open	Business innovation	Digital development index (%)	72	96	98	99
		Comprehensive energy services business development index (%)	100	100	100	100
Economic benefit	Investment benefit	Additional load per unit investment (kW/10,000 yuan)	2.75	2.52	3.51	4.5
		Increased electricity supply per unit investment (kWh/10,000 yuan)	3100	11800	12400	13000

TABLE 12. **Quantitative evaluation results of distribution network in wuhan, hubei province.**

First level indicator	Secondary indicators	2020 single indicator quantitative evaluation results	Quantitative assessment results of weighted indicators in 2020	Quantitative assessment results of single indicators at the end of the "14th Five-Year Plan" period	Quantitative evaluation results of weighted indicators at the end of the "14th Five-Year Plan" period	Results of single-indicator quantitative assessment in 2030	Quantitative assessment results of weighted indicators in 2030	Quantitative assessment results of single indicators in the long-term year	Quantitative assessment results of weighted indicators in the long-term year
Safe and reliable	Grid structure	83.6	42.6	90.3	43.1	90.2	44.3	90.2	45.4
	Power supply capacity	13.1		11.0		14.1		17.1	
	Power quality	51.2		50.2		50.2		50.1	
	Equipment level	22.4		21		22.5		24	
Clean and low-carbon	Clean consumption	51.2	76.2	50.9	75.9	50.6	75.6	50.4	75.4
	Green and low-carbon	25		25		25		25	
Ubiquitous interconnection	Intelligent Internet of things	38.2	38.2	41.9	41.9	46.5	46.5	56.5	56.5
Efficient interaction	Efficient service	38.6	38.9	44.4	44.7	51	51.1	58.8	58.8
	Green transportation	0.3		0.3		0.2		0.1	
Smart and open	Business innovation	83.2	83.2	97.6	97.6	98.8	98.8	99.4	99.4
Economic benefit	Investment benefit	1551.36	1551.36	5901.3	5901.3	6201.8	6201.8	6502.3	6502.3

scientific rationality and economy of the decision-making of the distribution network construction project, reduce the profit and loss rate of the power grid, give full play to the economic benefits of the project, and ensure the economic

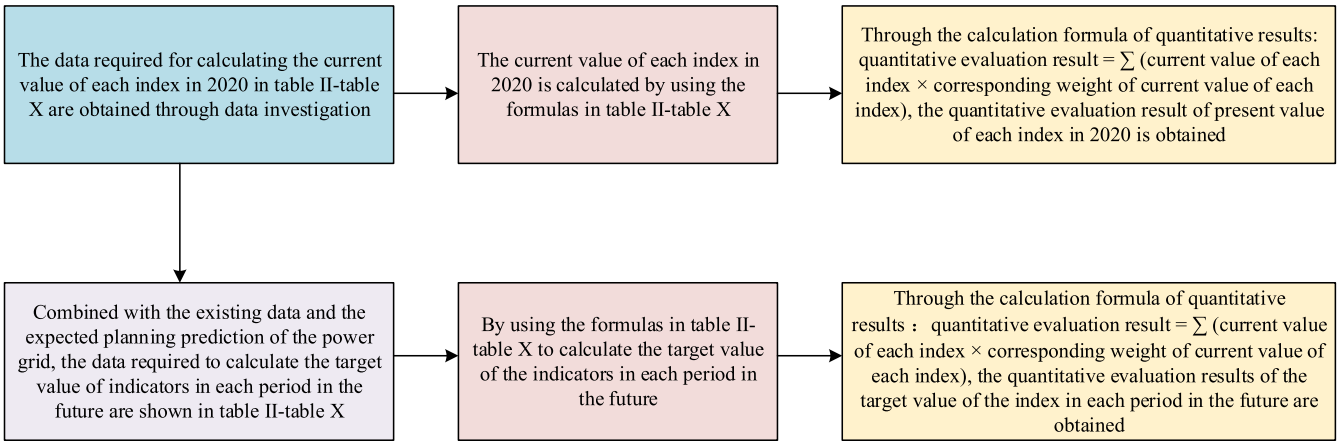

FIGURE 4. Operation flow chart.

vitality of the power supply enterprise. The index of increased power supply invested by users reflects the investment benefit and economic benefit of distribution network, as shown in table 10.

IV. CASE ANALYSIS

Refer to the results of distribution network differentiation classification in Wuhan, Hubei Province. Based on the goal of the average value in the past, combined with the development experience of domestic advanced cities, it is linked with the calculation results of various indicators in the early stage of the ''13th Five Year Plan''. Based on the calculation of the growth rate or decline rate of each index at the end of the ''13th Five Year Plan'', this paper analyzes the growth or decline of each index at the end of the ''14th Five Year Plan'' and in the future years, and forecasts the planning value of each index. So as to verify the effectiveness and operability of the quantifiable distribution network planning target index system for ''energy internet''.

By 2020, the power supply area of Wuhan City in Hubei Province is 1577.29km^2. The power consumption of the whole society is 61.546 billion kWh, the maximum load of the whole society is 13447.94 MW, the number of users is 5.2367 million, the average distribution and transformation capacity is 3.73 kVA, and there are 318 important users above the second level. Taking the distribution network of Wuhan City in Hubei Province as an example, the case analysis has strong reference value.

According to the index system constructed in this article, it starts from the six dimensions of safety and reliability, clean and low-carbon, efficient interaction, ubiquitous interconnection, intelligent openness, and economic benefits.

The current value and target value of each indicator are obtained through calculation and prediction (as shown in Table 11), and the quantitative evaluation result is obtained through the calculation formula of the quantitative evaluation result (as shown in Table 12). The operation flow is shown in Figure 4.

According to the quantitative evaluation results in Table 12, with the rapid development of China's ''energy internet'', compared with the 2020, the end goal of the ''14th Five-Year Plan'', the target value of 2030 and the vision year not only make the indicators of safety, reliability, ubiquitous interconnection, efficient interaction, intelligent openness and economic benefits rise rapidly, but also achieve lower and lower carbon and environmental protection. And through the analysis of each index quantity of distribution network in Wuhan, Hubei Province, it can fully show that the planning target index classification system proposed in this paper is comprehensive, innovative and effective. The classification system can help the long-term development of China's power grid.

V. CONCLUSION

This paper studies the quantifiable distribution network planning target index system for ''energy internet'', and obtains the following conclusions:

(1) Compared with the existing classification system, this paper takes the distribution network planning target indicators as the research object. And combined with the characteristics of ''energy internet'', and constructs a quantifiable distribution network planning target indicator system for ''energy internet'' covering 50 indicators from the six dimensions of safety and reliability, clean and low-carbon, efficient interaction, ubiquitous interconnection, intelligent openness and economic benefits. The distribution network planning target index system constructed in this paper is more comprehensive, safe and reliable, and has strong innovation.

(2) Taking Wuhan distribution network in Hubei Province as an example, it not only verifies the effectiveness and operability of the distribution network planning target index system constructed in this paper. It also shows that the distribution network planning target index system constructed in this paper provides a systematic index basis for scientific planning of the development status of distribution network.

It has important guiding significance for distribution network planning and management and accurate investment.

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