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Research on Differentiated Classification System of Distribution Network Based on Grading and Zoning

BIN ZHOU[1], SHAOPING DENG[2], JIZHOU HU[1], AND YUNFEI ZHENG[1]
[1]State Grid Hubei Electric Power Corporation Ltd., Wuhan 430077, China
[2]POWERCHINA Hubei Electric Engineering Corporation Ltd., Wuhan 430040, China
Corresponding author: Jizhou Hu (748897264@qq.com)

ABSTRACT In order to cope with multiple pressures such as ensuring the safe operation of the distribution network, promoting market-oriented operation, and satisfying rigid investment needs, power grid companies must implement a lean management approach. In response to the lack of systematic classification and evaluation methods for the distribution network in precise investment and future planning, this paper proposes a multi-dimensional hierarchical sub-regional distribution network differentiation classification system covering provinces, cities (counties), urban power supply units, towns, and villages. In the dimensions of provinces and cities (counties), based on the data fitting analysis of per capita electricity consumption, the classification method of the development stage of the power grids is obtained, and the provinces and cities (counties) are classified into pioneering benefits, steady improvement, and excellence three stages; in the dimension of urban power supply units, based on the combination of ''top-down'' and ''bottom-up'', the urban power supply units are divided into three categories: A+, A, and B; in the dimensions of towns and villages, according to characteristics indicators and construction models, proposed classification schemes for towns and villages. Finally, the results of an example analysis show that the differentiated classification system proposed in this paper can achieve an accurate assessment of the current development status of the distribution network, and provide important guidance for the precise investment of the distribution network in the future.

INDEX TERMS Distribution network, differentiated classification, grading and zoning, multi-dimensional assessment, precise investment.

I. INTRODUCTION

With the integrated development of energy revolution and digital revolution and the promotion of energy Internet in recent years, the development mode of distribution network is also very different, with diversified and personalized characteristics [1]–[4]. As an important part of power grid, distribution network is an important platform to connect transmission network and users and support demand side response management [5]–[8]. In order to meet the new requirements of economic, social and reform and development, and cope with multiple pressures such as ensuring the safe operation of power system, promoting market-oriented operation and meeting rigid investment demand, the rational planning and accurate control of distribution network project planning and construction is one of the basic conditions for whether the power network can supply high reliability and high quality power [9]. In view of the demand for lean management and accurate investment decision-making of distribution network, the differentiated classification and evaluation method of distribution network as the key link of its future development investment and decision-making [10], [11] has gradually become a research hotspot carried out by scholars.

At present, experts and scholars have carried out relevant research on the classification system of distribution network, but there is still a lack of systematic and applicable evaluation methods for distribution network construction projects, which is difficult to effectively evaluate the standardization and effectiveness of distribution

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network project construction, which brings many uncertainties to the realization of distribution network construction scheme and expected planning objectives. At the same time, the distribution network form index system is huge, the coupling relationship between indicators is complex, which increases the difficulty of the whole classification process [12].

There are many methods in the classified evaluation of distribution network. The qualitative methods include analytic hierarchy process, fuzzy comprehensive evaluation method, Delphi method, etc., and the quantitative methods include entropy weight method and data envelopment analysis method [13]–[16]. At present, for the distribution network, most of them carry out classified evaluation of reliability and comprehensive benefits of planning schemes. The index system only focuses on operating costs and benefits [17]–[19]. In order to evaluate the development form, the main characteristics of future distribution system architecture and pattern should be additionally considered in the process of selecting indicators, so as to show the operation status and highlight the advanced level of distribution network development. Literature [20] solves the problem of the uncertainty of the original data and mentions the accuracy of the planning and evaluation of the distribution network. Literature [21], [22] studied the risks in the operation of the distribution network, and proposed an index system suitable for evaluating the operation risk of the distribution network. Literature [23] classifies and evaluates the urban distribution network from the perspective of safety and economy, and carries out a conceptual introduction to the development of power grids. It lacks a quantitative analysis from the perspective of the evolution of power grid development. Literature [24] only covers power grids. The two major indicators of self and economic development do not consider strategic factors such as energy development.

To sum up, at present, there is a relatively perfect comprehensive evaluation index system for the development level of distribution network, but the content of the index system is relatively limited. Only the relevant indexes of power grid are considered, and the impact of other influencing factors on the development of distribution network is not considered. Therefore, this paper aims at the systematic evaluation and classification of the development status of the distribution network, and proposes the theory of the differentiated classification system of the hierarchical and sub-regional distribution network by considering the differences in the development of the distribution network. Combined with qualitative and quantitative classification methods, the development level of the target distribution network is classified and evaluated, the distribution network form is divided, and the form level of the current distribution network is defined, so as to provide a new theoretical guidance for the systematic evaluation of the current development level of the distribution network and accurate investment in the future.

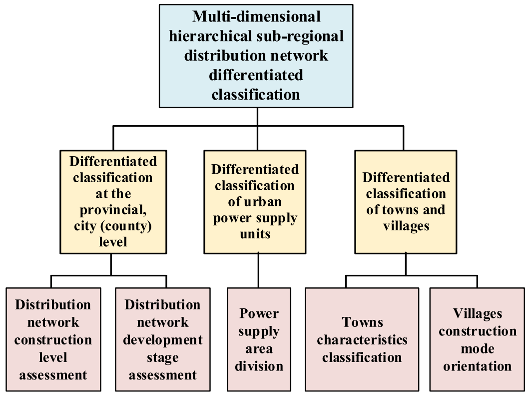

FIGURE 1. Schematic diagram of differentiated classification system for distribution network.

II. DISTRIBUTION NETWORK DIFFERENTIATION CLASSIFICATION ARCHITECTURE

The differentiated classification system architecture of the distribution network proposed in this paper is shown in Figure 1.

The differentiated classification system of distribution networks proposed in this paper includes multiple dimensions of provinces, cities (counties), urban power supply units, towns and villages. In the dimension of provinces and cities (counties), the Logistic function is used to fit and analyze the per capita power consumption to obtain the classification results of the development stage of the province and each city's distribution networks. Based on the evaluation of distribution networks development stage and construction level, provinces and cities (counties) are classified into four stages: basic operation stage, development benefit stage, steady improvement stage and striving for excellent stage. In the dimension of urban power supply units, based on the combination of ''top-down'' and ''bottom-up'' methods, the urban power supply units are divided into three categories: A +, A and B, and the power supply areas in typical power supply modes of distribution network are subdivided into 28 types. In the dimension of villages and towns, through the multi-objective evaluation system, the towns are divided into five types: industry oriented type, commercial trade type, tourism development type, agriculture-led type, comprehensive type. The villages are divided into four types: industrial development type, leisure tourism type, Traditional farming type and livable comprehensive type.

III. DIFFERENTIATED CLASSIFICATION OF PROVINCES, CITIES (COUNTIES) DISTRIBUTION NETWORK

A. DISTRIBUTION NETWORK DEVELOPMENT STAGE ASSESSMENT

The change of investment demand of distribution network is closely related to the development stage of power network. From the typical experience, the annual investment demand of power grid basically presents the situation of ''low at

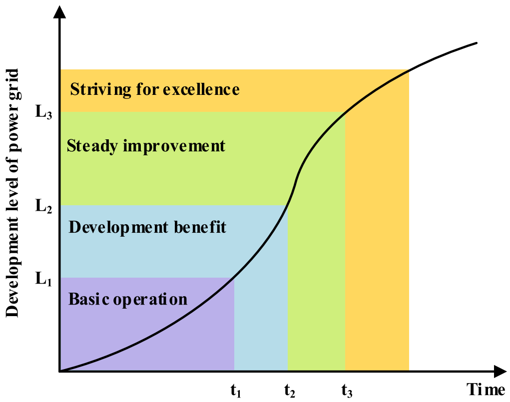

FIGURE 2. Schematic diagram of distribution network development stages based on logistic function.

both ends and high in the middle''. The law of changes in electricity demand in developed countries such as Germany, Japan, and Britain after entering the advanced economic stage also confirms this law. The US electricity data collected by the Energy Information Administration over the years also proved the existence of this trend.

This paper uses the Logistic growth model to analyze the change trend of the distribution network development level over time t, which is expressed as:

$$L(t) = \frac{c}{1 + e^{a-bt}} \tag{1}$$

where $L(t)$ is the development level of distribution network; c is the saturation value of distribution network development; a and b are parameters; t is time.

From the graphical characteristics of the Logistic curve in Figure 2, it can be seen that the development of the distribution network presents a typical S-shaped characteristic, and its development stage is divided by the change of the curve tangent. The development speed and acceleration of the distribution network are both small in the initial stage. With the passage of time, the speed of development has gradually increased, and the acceleration has gradually increased. In the later stages of development, the construction of the distribution network has gradually become saturated, and the speed of development has gradually become flat. In this paper, the development of distribution network is divided into four stages, and evaluated from three aspects: development scale, technical level and benefit. The characteristics of each development stage of the distribution network and the investment priorities in different stages are shown in Table 1.

B. DISTRIBUTION NETWORK CONSTRUCTION LEVEL ASSESSMENT

In this paper, by constructing a two-dimensional classification model of ''power consumption per capita—power grid development adaptability'', the classification results are used to evaluate the development and construction level of power supply companies in various provinces and cities, and are

TABLE 1. characteristics of distribution network development stages and investment priorities in different stages.

Development stage	Scale aspect	Technical aspect	Benefit aspect	Development focus
Basic operation stage	The focus is on establishing a preliminary grid structure as soon as possible, and the development speed is slow.	The technical level of power grid is limited, which can not fully meet the requirements of distribution networks reliability.	Efficiency improvement is not its main focus, and there is a loss-making operation.	Establish a preliminary grid structure.
Development benefit stage	Pay attention to the rapid expansion of the grid scale to meet the demand for electricity. Due to the development law of diminishing marginal costs, economies of scale appear.	The development of distribution network has accumulated a certain fixed cost, and the technical level has been improved to a certain extent.	The level of efficiency has initially improved, but given the characteristics of its public utility companies, it still cannot meet the requirements of marketization.	Rapidly expand the scale of the grid.
Steady improvement stage	The scale of distribution networks continues to expand, but the investment, operation, management and other aspects of power grid have disadvantages due to the rapid expansion of power grid scale, and the possibility of diseconomy of scale increases.	The operation, control and automation level of power grid is improving day by day, which basically guarantees the power supply reliability of distribution networks.	There is a development bottleneck in the improvement of power grid operating efficiency. Overcoming this bottleneck depends on the coordinated development of grid scale, technical level and management level.	Pay attention to the transformation of power grid development and overcome the bottlenecks that hinder the scale effect.
Striving for excellent stage	The scale development tends to be stable, and the leap forward development of power grid depends on the emergence of a new round of major changes in energy technology.	With the continuous improvement of informatization, automation and intelligence of power grid, the speed of technology updating is accelerated, and the power supply reliability of distribution networks is fully met.	The distribution networks development strategy focuses on the coordination and improvement of multi-level benefits.	Improve the efficiency of distribution networks at multiple levels.

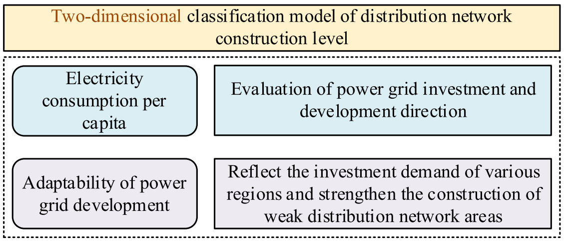

FIGURE 3. Schematic diagram of two-dimensional classification model of distribution network construction level.

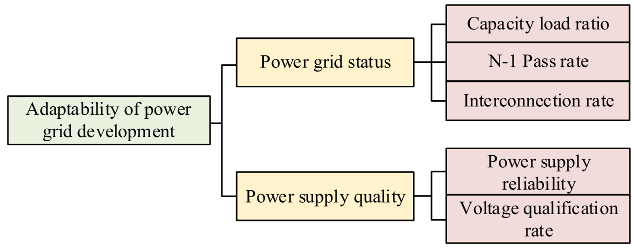

FIGURE 4. Evaluation index system of power grid development.

used to guide the determination and allocation of future power grid development investment, and to clarify the investment of power supply companies in various provinces and cities. The structure of two-dimensional classification model of distribution network construction level is shown in Figure 3.

In this paper, the selection indicators and specific analysis steps of the two-dimensional classification model of ''power consumption per capita—adaptability to grid development'' are as follows:

(1) Electricity consumption per capita. The actual income is the product of the electricity sales and the power transmission and distribution price, and attention should be paid to the investment intensity of incremental investment in areas where the electricity stimulus effect is obvious. Therefore, development investment should be tilted towards regions where the growth of electricity is relatively stable or there is room for higher growth. The electricity consumption of each city is evaluated by two indicators: per capita electricity consumption and per capita electricity consumption. Comprehensive evaluation of per capita electricity consumption in various regions.

$$S = 0.4\bar{E}_L + 0.6\bar{E} \tag{2}$$

where S is the comprehensive evaluation score of electricity consumption per capita; $\bar{E}_L$ is the electricity consumption per capita; $\bar{E}$ is the electricity consumption per capita.

(2) Adaptability of distribution network development. The development status of the distribution network is an important indicator that reflects the investment needs of various regions. For regions where the grid is weak, especially the distribution network, which requires a large amount of capital investment, these regions should be tilted when the investment arrangements for the transformation and upgrading of the distribution network are made.

The paper analyzes the asset quality of distribution network from the following two aspects: distribution network status (index: capacity-load ratio, N-1 pass rate, interconnection rate), power supply quality (index: power supply reliability rate, voltage qualification rate). The evaluation index system of distribution network development status is shown in Figure 4.

Comprehensive evaluation of the adaptability of regional power grid development, the main indicators include power grid status and power supply quality. The comprehensive evaluation scores of grid development adaptability are as follows:

$$\text{Fitness} = \alpha_1 G_s + \alpha_2 G_q \tag{3}$$

$$G_s = \beta_1 D_{clr} + \beta_2 D_{pr} + \beta_3 D_{ir} \tag{4}$$

$$G_q = \gamma_1 D_{psr} + \gamma_2 D_{vqr} \tag{5}$$

where the power grid state is G_s, the power supply quality of the distribution network is G_q, D_{clr} is the capacity load ratio of the distribution network, D_{pr} is the N-1 passing rate, D_{ir} is the interconnection rate of the distribution network, D_{psr} is the power supply reliability rate of the distribution network, D_{vqr} is the voltage qualification rate of the distribution network, and a_1, a_2, β_1, β_2, β_3, γ_1, γ_2 are the weight factors.

IV. DIFFERENTIAL CLASSIFICATION OF URBAN POWER SUPPLY UNITS

In this paper, according to the dimension differentiation classification of urban power supply units, the combination of ''top-down'' and ''bottom-up'' is adopted. ''Top down'' refers to the power supply area defined by the technical principles of distribution network, and takes several application scenarios set by typical power supply mode of power grid as reference. The ''bottom-up'' approach is based on the actual work of the provincial unit system planning, taking into account the results of the completed unit system division of power supply enterprises in each city and the actual situation of saturated load density in the province, and putting forward the demand for the division of power supply units. Through the combination of the two methods, differentiated power supply units in various power supply areas are formed.

A. POWER SUPPLY AREA DIVISION

The division of power supply regions is mainly based on the load density of the administrative level or planning level, and can also be determined with reference to other factors such as economic development, user importance, power consumption level, GDP, etc. The specific power supply region divisions in this article are shown in Table 2.

Based on the division of A+∼E power supply areas, according to the current status and development positioning of the distribution network in different regions, different functional divisions (administrative districts, business districts, residential areas, development areas, high-tech areas, etc).

TABLE 2. Power supply area division.

Power supply area		A+	A	B	C	D	E
Administrative level	Municipality	Downtown or σ≥30	City proper or 15≤σ<30	City proper or 6≤σ<15	Town or 1≤σ<6	Village or 0.1≤σ<1	/
	Provincial capital cities, cities separately listed in the state plan	σ≥30	Downtown or 15≤σ<30	City proper or 6≤σ<15	Town or 1≤σ<6	Village or 0.1≤σ<1	/
	Prefecture level city (autonomous prefecture, League)	/	σ≥15	Downtown or 6≤σ<15	City proper, town or 1≤σ<6	Village or 0.1≤σ<1	Agricultural and pastoral areas
	County (county-level city, flag)	/	/	σ≥6	Village or 1≤σ<6	Village or 0.1≤σ<1	Agricultural and pastoral areas

Note 1: σ is the load density of the power supply area (MW/km^2)
Note 2: The area of power supply area is generally not less than $5km^2$.
Note 3: When calculating the load density, the 110 (66) kV dedicated line load and the area of invalid power supply such as mountains, gobi, deserts, waters, and forests should be deducted.

Considering the technical indicators such as the planned area load density, power supply reliability rate, comprehensive voltage qualification rate, transfer capacity, etc., determine the target grid structure suitable for regional development, select appropriate standardized facilities, and ensure the reliable access of different types of power sources and users. Form a typical power supply mode of the distribution network adapted to the development of different regions. The power supply area in the above-mentioned typical power supply mode of the distribution network is further refined as shown in Table 3.

V. DIFFERENTIATION CLASSIFICATION OF TOWNS AND VILLAGES

A. DIFFERENTIATED CLASSIFICATION OF TOWNS

(1) Town classification index selection principles. The principle of scientificity: the new type of urbanization selected should be considered to be based on traditional urbanization and fully reflect the scientific connotation and characteristics of the new urbanization process. Principle of completeness and hierarchy: First, it is necessary to fully consider the indicators that can reflect the development situation, requirements and key issues of new urbanization, and avoid errors, omissions and repetitions; second, it is necessary to be logical and clear in organization and hierarchy, so as to lay a solid foundation for completeness. Operability principle: the practicality of the indicators should be considered, and the indicators that are not easy to operate should be selected as suitable alternatives or discarded.

(2) Town differentiated classification index system. According to the characteristics of towns under different economic development models and the results of the research on the differentiated classification of township power grids, this paper selects some indicators with different types of characteristics for calculation, so as to complete the classification of different types of townships. The classification index system of township areas is shown in Table 4.

Considering the actual operation environment of the index system and the difficulty of the actual operation, this part will use a function to calculate the corresponding index calculation method. The specific implementation is to use the two points of a function to determine the characteristics of a line, and select the appropriate value as the full score of 100 points and the passing score of 60 points. The corresponding index calculation formula is given. Delphi method is mainly used to determine the weight, and the numerical calculation method and weight calculation results are shown in Table 5.

(3) Differentiation classification method of towns. The towns differentiation classification is mainly to calculate the corresponding score of characteristic industry according to the relevant indicators of each characteristic town. The higher the score is, the higher the degree of characteristic industry is, indicating that the town is closer to this characteristic industry. According to the score of each industry, the type of towns can be judged.

In information theory, entropy is a measure of the degree of chaos in a system, while information is a measure of the degree of order. The absolute values of the two are equal, but the signs are opposite. In the process of calculation, the greater the degree of data dispersion, the smaller the information entropy, the greater the amount of information it provides, the greater the impact of the index on the comprehensive evaluation, and the greater its weight; On the contrary, the smaller the difference of each index value is, the greater the information entropy is, the smaller the amount of information it provides, the smaller the impact of the index on the evaluation results, and the smaller its weight should be.

TABLE 3. Refinement of power supply area of typical power supply mode of distribution network.

Serial number	Power supply zoning	Typical power supply mode	Functional zoning	Main user load types
1	A+	A+-1	Business district	Administrative office, commercial finance, service industry, residents
2		A+-2	Comprehensive district	Administration, business, culture, residents
3		A+-3	Financial business district	Administrative office, business, finance and service
4		A+-4	Commercial business district	It is mainly composed of administrative district and commercial district complex, supplemented by financial district and residential district
5		A+-5	Business district	Administration, commerce, finance, services
6	A	A-1	Comprehensive district	Administration, business, culture, residents, urban industry
7		A-2	Business district	Administrative office, business, finance and service
8		A-3	Comprehensive district	Business district and residential area are the main areas, supplemented by administration and finance
9		A-4	Business district	Administration, commerce, finance, services
10	B	B-1	Comprehensive district	Administration, commerce, culture, residents, industry
11		B-2	Industrial, high-tech park, commercial and residential	Industrial, administrative office, teaching and research and residential area
12		B-3	Comprehensive district	Mainly in administrative, commercial, industrial and residential areas
13		B-4	Comprehensive district	Commercial, residential
14		B-5	Business district	Administrative office, business, finance, service and residential area
15		B-6	Mixed commercial and residential district	Administration, commerce, finance, services, housing
16		B-7	Industrial district	Glass manufacturing, machining, etc
17	C	C-1	Commercial and residential-oriented	Commercial tourism and residents' life
18		C-2	Suburb or central town dominated by industrial district and residential housing	Residents, industries
19		C-3	County and important town	Residents, business
20		C-4	County and important town	Government organizations and other enterprises and institutions, commerce, service industry, residential
21		C-5	City complex	Residents, business, catering, entertainment
22	D	D-1	Agricultural production district	Agricultural electricity and residents' life
23		D-2	Town and village	Residents, farmland irrigation
24		D-3	Town district	Small industrial users, small workshop production users, ordinary small business users
25		D-4	Town or village district	Agricultural electricity and residents' life
26		D-5	County district	Administrative office, business, service, medical
27	E	E-1	Agricultural and pastoral district	Forest farms, residents
28		E-2	Agricultural and pastoral district	residents

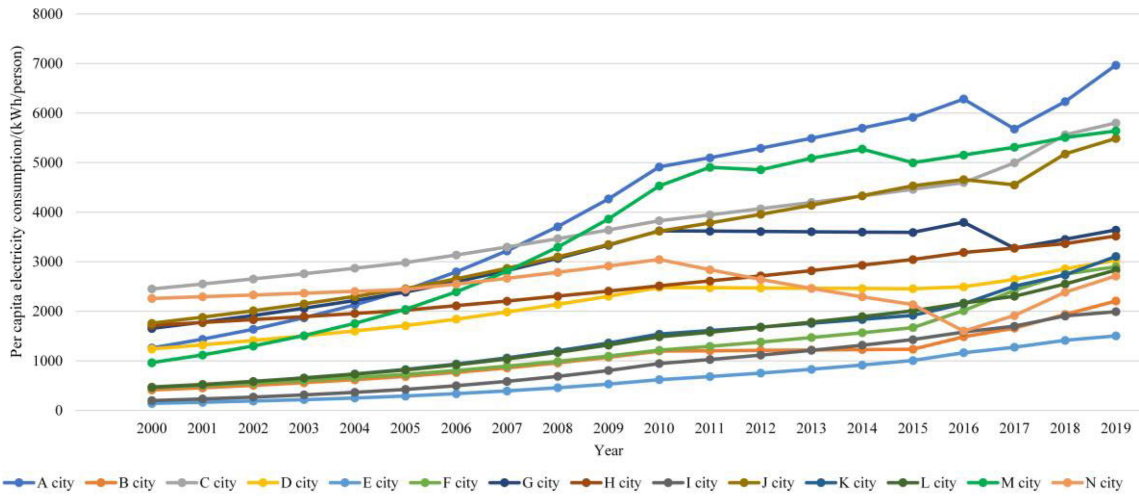

FIGURE 5. Electricity consumption per capita in all cities and provinces in X province from 2000 to 2019.

TABLE 4. Classification index of town area.

Index classification	Index content
Industry oriented type	Proportion of secondary industry (%)
	Proportion of industrial power consumption (%)
Commercial trade type	Proportion of tertiary industry (%)
	Proportion of commercial and residential electricity consumption (%)
Tourism development type	Proportion of tourism and residents' life (%)
	Number of grade A scenic spots(individual)
Agriculture-led type	Proportion of primary industry (%)
	Proportion of residential electricity consumption and primary electricity consumption (%)
Comprehensive type	/

According to the secondary classification factors of index classification in Table 5, the classification indexes of each town are calculated.

$$\begin{cases} c_1 = \mathrm{B}_{11}\mathrm{C}_{11} + \mathrm{B}_{12}\mathrm{C}_{12} \\ c_2 = \mathrm{B}_{21}\mathrm{C}_{21} + \mathrm{B}_{22}\mathrm{C}_{22} \\ c_3 = \mathrm{B}_{31}\mathrm{C}_{31} + \mathrm{B}_{32}\mathrm{C}_{32} \\ c_4 = \mathrm{B}_{31}\mathrm{C}_{31} + \mathrm{B}_{32}\mathrm{C}_{32} \end{cases} \tag{6}$$

Calculate the entropy value of the classification index c_1-c_4. When the entropy value is greater than 0.9, the index has no outstanding characteristics, and the town is considered to be a comprehensive type:

$$\begin{cases} P_i = \dfrac{c_i}{\sum\limits_{i=1}^{4} c_i}, (i = 1, 2, 3, 4) \\ e = -\dfrac{1}{\ln(4)} \sum\limits_{i=1}^{4} P_i \ln(P_i) \end{cases} \tag{7}$$

When the entropy value is less than 0.9, the corresponding classification of P_i maximum value is taken as the classification of the evaluated towns. According to the calculation results, the differentiation classification results of towns distribution network proposed in this paper are shown in Table 6.

B. DIFFERENTIATED CLASSIFICATION OF VILLAGES

According to the differentiation of construction models, this paper divides rural areas into four types: industrial development villages, leisure tourism villages, traditional agriculture and animal husbandry villages, and livable comprehensive villages. The specific development characteristics and electricity consumption characteristics are shown in Table 7.

VI. CASE ANALYSIS

This paper selects X provinces containing 14 cities (numbered A-N) for example analysis to further verify the rationality of the differentiated classification method for distribution network constructed in this paper.

A. DATA RESEARCH

The electricity consumption of a region not only reflects the development level of the power grid in the region, but also reflects its economic and social development level. The per capita electricity consumption further excludes the influence of the scale of electricity consumption, which is more comparable. Therefore, existing studies generally use per capita electricity consumption as the main basis to study the characteristics of the development stage of the power grid. This paper summarizes the per capita electricity consumption statistics of X province, and obtains the per capita electricity consumption of various cities in X province from 2000 to 2019, as shown in Figure 5.

It can be seen from Figure 5 that the per capita power consumption of all cities in the X province is basically in a steady growth trend, and the per capita power consumption

TABLE 5. Index numerical calculation method and weight setting.

Index classification	index		Standard value	computing method	weight	
	Index content	identification			identification	Weight value
Industry oriented type (C_1)	Proportion of secondary industry（%）	C_{11}	60	$y=\begin{cases}0, & x=0\\ x+40, & 0<x\leqslant 60\\ 100, & x>60\end{cases}$	B_{11}	0.6
	Proportion of industrial electricity consumption (%)	C_{12}	50	$y=\begin{cases}0, & x=0\\ x+50, & 0<x\leqslant 50\\ 100, & x>50\end{cases}$	B_{12}	0.4
Commercial trade type (C_2)	Proportion of tertiary industry (%)	C_{21}	60	$y=\begin{cases}0, & x=0\\ x+40, & 0<x\leqslant 60\\ 100, & x>60\end{cases}$	B_{21}	0.6
	Proportion of electricity consumption by business and residents (%)	C_{22}	50	$y=\begin{cases}0, & x=0\\ x+50, & 0<x\leqslant 50\\ 100, & x>50\end{cases}$	B_{22}	0.4
Tourism development type (C_3)	Proportion of tertiary industry (%)	C_{11}	50	$y=\begin{cases}0, & x=0\\ x+50, & 0<x\leqslant 50\\ 100, & x>60\end{cases}$	B_{11}	0.4
	Proportion of tourism and residents' life (%)	C_{31}	50	$y=\begin{cases}0, & x=0\\ x+50, & 0<x\leqslant 50\\ 100, & x>50\end{cases}$	B_{31}	0.4
	Number of grade A scenic spots (individual)	C_{32}	3	$y=\begin{cases}0, & x=0\\ 20x+40, & 0<x\leqslant 3\\ 100, & x>3\end{cases}$	B_{32}	0.2
Agriculture-led (C_4)	Proportion of primary industry (%)	C_{41}	50	$y=\begin{cases}0, & x=0\\ x+50, & 0<x\leqslant 50\\ 100, & x>50\end{cases}$	B_{41}	0.6
	The proportion of residential electricity consumption and primary production electricity consumption (%)	C_{42}	50	$y=\begin{cases}0, & x=0\\ x+50, & 0<x\leqslant 50\\ 100, & x>50\end{cases}$	B_{42}	0.4

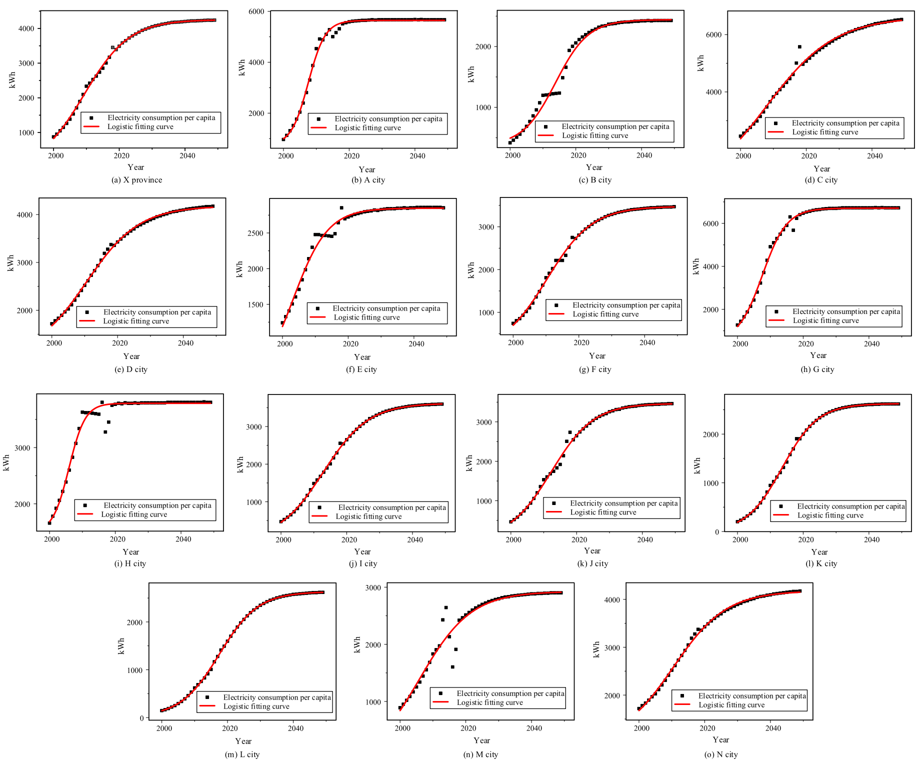

FIGURE 6. Schematic diagram of power grid development stages based on logistic fitting.

TABLE 6. Results of differentiation classification of town distribution network.

Differentiated Classification of Town Distribution Network	Industry characteristics	Electricity consumption characteristics
Industry oriented type	With industry as the leading industry, the GDP of the secondary industry accounts for more than 60% of the total GDP of towns	The proportion of industrial power consumption to total power consumption is more than 50%, the load of electricity is high, the seasonal fluctuation is small, and the requirements for voltage quality and power supply reliability are high
Commercial trade type	With commerce as the leading industry, the GDP of the tertiary industry accounts for more than 60% of the total GDP of villages and towns	The commercial and residential electricity consumption accounts for more than 50% of the total electricity consumption. The seasonal fluctuation of power load is small, and the peak valley difference between day and night is obvious. The requirements for voltage quality and power supply reliability are high
Tourism development type	With tourism as the leading industry, the GDP of the tertiary industry accounts for more than 50% of the total GDP of villages and towns	Tourism and residential electricity consumption account for more than 50% of the total electricity consumption. The seasonal characteristics of power load are obvious. The power load in tourism peak season is high, and the requirements for voltage quality and power supply reliability are high
Agriculture-led type	With planting and breeding as the leading industries, the GDP of the primary industry accounts for more than 50% of the total urban GDP	The electricity consumption of agriculture and animal husbandry and residents' living accounts for more than 50% of the total electricity consumption. The electricity load is greatly affected by the climate, environment, production cycle and other factors. The electricity consumption is large in key periods such as irrigation and drainage, harvest and cold, and the requirements for voltage quality and power supply reliability are high
Comprehensive type	Towns other than industry oriented, tourism oriented, commercial and trade oriented, and agriculture and animal husbandry oriented	The characteristics of industrial power consumption are not prominent, and there are high requirements for voltage quality and power supply reliability

of some prefectures and cities has experienced a short-term decline and then resumed an upward trend. As of the end of 2019, the per capita electricity consumption in City A was the province's highest at 6965.87 kWh, and the per capita electricity consumption in City E was the province's lowest at 1504.42 kWh.

B. RESEARCH AND JUDGMENT RESULTS OF DEVELOPMENT STAGE

In this paper, the logistic curve model fitting prediction is carried out based on the electricity consumption per capita of each city in X province, and the development stage of the power grid of each city in X province is studied, and the corresponding development investment trend is analyzed. The result of the fitted curve is shown in Figure 6.

By analyzing the fitting curve of per capita electricity consumption and combining the development stage classification of the distribution network proposed in this paper, it can be seen that only one city in X province is in the stage of excellence; eight cities are in the stage of steady improvement, and five are in the development benefit stage.

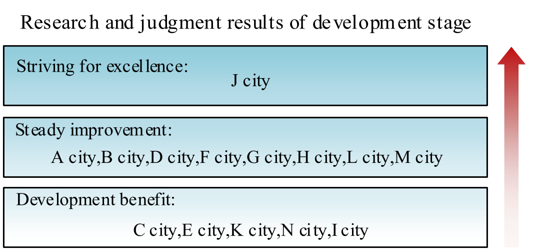

FIGURE 7. Research and judgment results of the development stage of the power grid.

The classification results of the specific development stages of each city are shown in Figure 7.

C. RESEARCH AND JUDGMENT RESULTS OF CONSTRUCTION LEVEL

Through the calculation and sorting of capacity load ratio, N-1 passing rate, interconnection rate, power supply reliability rate and voltage qualification rate of local cities in X province, the basic data onto distribution network development in X province is obtained, as shown in Table 8.

TABLE 7. Results of differentiation classification of villages distribution network.

Type of development	Development characteristics	Electricity consumption characteristics
Industrial development type	Driven by the development of township industry, villages adopt the cluster development of rural industries, encourage enterprises to invest in the countryside by integrating local resource elements in rural areas, and vigorously develop modern rural industries, forming a block of "one village, one industry" and "one village, one product".	With rural industry and household small processing electricity load, the electricity load is high and seasonal fluctuations are small, with industrial electricity consumption accounting for more than 50%.
Leisure tourism type	In villages with superior natural conditions and abundant water resources, as well as villages with cultural landscape features such as ancient villages, ancient buildings and ancient dwellings, rural tourism, accommodation, catering, leisure and entertainment are developed. The villages, which are not rich in rural tourism resources, material and cultural resources, have complete facilities, convenient transportation, and are close to cities, are suitable for leisure and vacation.	The load of commercial operations, such as catering and accommodation, sightseeing and excursions, is dominant, with a sudden increase in load during the tourist season and significant changes in seasonal load, with the volume of tourism and residential life accounting for more than 50%.
Traditional farming type	The main focus is on the development of agricultural crops and farm animal production, the realization of agricultural and livestock production aggregation, agricultural and livestock scale operation, relatively complete agricultural infrastructure such as farmland water conservancy, high rate of commercialization of agricultural products and agricultural mechanization, and abundant arable land resources per capita.	With modern agriculture, breeding industry, agricultural products processing electricity load, electricity load is low, agricultural sowing, harvesting and drainage and irrigation and other special time load surges, seasonal load changes are large, residential electricity consumption and electricity consumption of the first production accounted for more than 50%.
Livable comprehensive type	In villages with a larger number of people, larger scale, more concentrated residence and less prominent rural industrial development, we focus on solving the problems of poor rural living conditions, lagging infrastructure construction and serious environmental pollution to create habitable and environmentally beautiful villages.	The electricity consumption is mainly for residential use, and the electricity consumption load is low, influenced by air-conditioners, electric heaters and other temperature-regulating loads, with prominent time loads, and the electricity consumption ratio of each industry and residential consumption is relatively average.

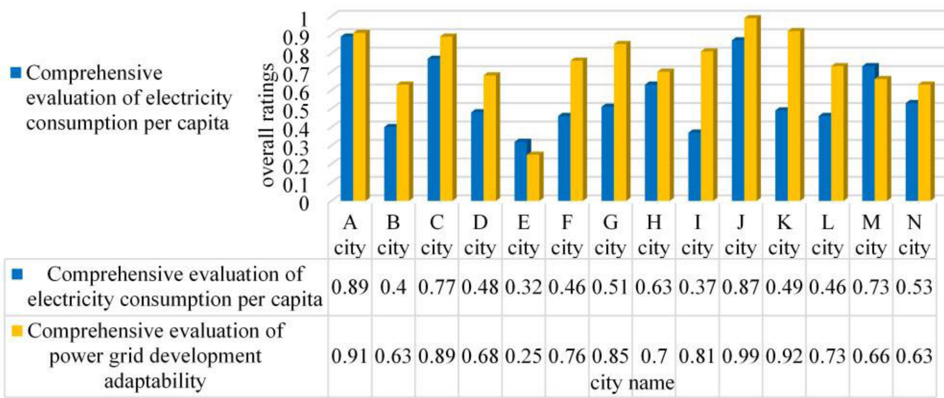

FIGURE 8. "Per Capita Electricity Consumption—Adaptability to Grid Development" Two-Dimensional Evaluation Chart.

According to the two-dimensional classification model of "power consumption per capita—adaptability to grid development" proposed in this paper, the construction level of the distribution network and the future investment

TABLE 8. Basic data on the development of the distribution network.

City	110kV Capacity-load ratio	35kV Capacity-load ratio	110kV Pass rate of substation N-1	110kV Line N-1 pass rate	35kV Pass rate of substation N-1	35kV Line N-1 pass rate	10kV Line N-1 pass rate	10kV Line interconnection rate	Power supply reliability rate	Voltage qualification rate
A city	2.04	2.16	96.15	98.44	100	100	54.87	64.29	99.878	99.9922
B city	2.15	2.12	69.09	92.25	86.64	71.3	41.27	53.32	99.7699	99.965
C city	2.71	2.8	97.92	99.12	91.67	100	57.19	65.11	99.905	99.821
D city	2.68	2.35	81.67	94.04	54.47	49.55	35.07	51.02	99.7871	99.959
E city	2.14	2.46	33.9	74.44	25.27	36.51	39.29	46.12	99.81	99.049
F city	2.22	2.33	97.58	100	84.75	84.71	61.74	72.65	99.8151	99.944
G city	2.28	2.13	56.58	92.86	57.28	88.89	35.77	41.76	99.8862	99.771
H city	1.99	1.72	72.88	89.3	89.1	85.2	35.05	56.79	99.795	99.978
I city	2.12	2.25	87.27	95.16	82.35	89.55	51.11	63.58	99.8317	99.949
J city	1.86	2.05	92.26	91.06	91.46	94.12	91.17	94.41	99.9597	99.998
K city	2.42	2.93	73.08	90.63	68.76	78.35	55.95	59.05	99.8943	99.912
L city	1.9	1.8	68.48	97.54	60.54	82.91	53.59	65.54	99.8078	99.925
M city	2.68	2.35	77.07	93.61	44.16	65.63	51.6	60.38	99.8178	99.688
N city	5.23	4.7	66.67	83.33	52.94	81.25	57.45	76.6	99.7845	99.842

positioning of the cities in X province are studied and judged. The specific evaluation results are shown in Figure 8.

It can be seen from Figure 8 that the comprehensive evaluation of per capita electricity consumption in cities A, C, and J is relatively high and the grid development ability low. Adaptability is relatively high, while the comprehensive evaluation of per capita electricity consumption in cities I and F is low, and the grid development adaptability is relatively high. City B, City D, City E, City G, City K, City L, City N have low comprehensive evaluation of per capita electricity consumption and low grid development adaptability, while cities H and M have a higher comprehensive evaluation of per capita electricity consumption and relatively high grid development adaptability low.

D. COMPREHENSIVE EVALUATION RESULTS

Comprehensive distribution grid development stage and construction level research and judgment, analysis to obtain the evaluation results of grid development positioning of cities in X province are shown in Table 9.

Considering the electricity consumption situation and grid structure comprehensively, based on the two-dimensional classification results of "per capita electricity consumption-grid development adaptability", it is clear that the investment positioning of power supply companies in various regions is as follows.

City A, City J, and City C belong to the first category of units, that is, the comprehensive evaluation of per capita electricity consumption is high, and the grid development adaptability is high. The overall investment positioning of this type of unit: should continue to maintain stable development, and it is recommended to try as much as possible meet the investment needs of such units.

Cities I and F belong to the second category of units, low comprehensive evaluation of per capita electricity

TABLE 9. Evaluation form for the development position of each city.

City	Development Positioning Score	Development and construction positioning
A city	0.90	Good foundation for development
B city	0.50	Poor development foundation
C city	0.81	Good foundation for development
D city	0.55	Poor development foundation
E city	0.30	Poor development foundation
F city	0.65	Good foundation for development
G city	0.59	Poor development foundation
H city	0.65	Good foundation for development
I city	0.60	Poor development foundation
J city	0.92	Good foundation for development
K city	0.57	Poor development foundation
L city	0.54	Poor development foundation
M city	0.67	Good foundation for development
N city	0.43	Poor development foundation

consumption and high adaptation to grid development. The overall investment of such units is positioned: there is a certain margin space in the grid, and investment benefit analysis can be conducted to improve the input-output ratio of grid investment according to the load development demand and the forecast of increased supply of electricity.

Cities B, D, E, G, K, L and N belong to the third category of units. low comprehensive evaluation of per capita electricity consumption and low adaptation to grid development. The overall investment orientation of such units: solve the current problems of the grid and try to meet the investment needs of such units involving electricity security.

City H and City M belong to the fourth category, high per capita electricity consumption and low adaptation to grid development. The overall investment position of these units is relatively weak, with problems in power supply capacity and reliability, but relatively good investment efficiency. The investment needs should be met from the target grid structure, equipment level, technology application.

VII. CONCLUSION

According to the needs of accurate investment and future planning of distribution network, this paper carries out hierarchical and subregional differentiation classification and evaluation. Based on the multi-dimensional distribution network differentiation classification system architecture, the research and judgment methods of distribution network development stage and distribution network construction level are proposed in the dimensions of province, city (county), in the dimension of urban power supply unit, the typical power supply mode of distribution network is divided into 28 categories, in the dimension of township and village, a classification method based on construction mode is proposed. Through the example analysis and verification, it can be seen that the distribution network differentiation classification system proposed in this paper can accurately evaluate the current development status of distribution network, give the key direction of future planning and investment by integrating various indicators, and provide solutions for the systematic evaluation and classification of distribution network.

The next research focus of this paper is to consider the quantifiable indicators such as distribution network cleanliness and low carbon, and further improve the distribution network classification and evaluation system proposed in this paper.

COMPETING INTERESTS

The authors declare that they have no competing interests.

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BIN ZHOU was born in November 1972. He received the bachelor's degree from North China Electric Power University, Beijing, China, in June 1996, the master's degree and the Ph.D. degree in power system and automation from Wuhan University, Hubei, China, in June 2002 and June 2016, respectively, mainly engaged in power grid planning research.

SHAOPING DENG was born in December 1967. He received the bachelor's degree in power system and automation from the Hubei Huazhong University of Science and Technology, in June 1989, mainly engaged in power grid planning, operation, and control research.

JIZHOU HU was born in January 1972. He received the B.S. degree from the Huazhong University of Science and Technology, Hubei, in June 1994, the M.S. degree from Wuhan University, Hubei, in June 2001, and the Ph.D. degree from the Huazhong University of Science and Technology, in June 2006, mainly engaged in power grid planning research.

YUNFEI ZHENG was born in October 1989. He received the master's degree in electrical automation from the Illinois Institute of Technology, in December 2014, mainly engaged in power grid planning research.