The Interpretative Structural Model of Influencing Factors of the New-type Town Distribution System

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***Abstract*- An Interpretative Structural Model (ISM) of influencing factors of the new-type town distribution system is proposed in this paper. The weight of each influencing factor in the ISM is obtained by extended Analytic Hierarchy Process (AHP). The main influencing factors are analyzed. It provides reference for the development and construction of China's new-type town distribution system. First, the influencing factor set of new-type town distribution system is put forward and the interaction relation between each two factors is analyzed to form the Reachable Matrix. According to the Reachable Matrix, the ISM of influencing factors of the new-type town distribution system is constructed. In order to directly show the impact of each factor on the new-type town distribution system, an extended AHP method to calculate the weight of each factor is proposed in this paper. Finally, the analysis of two examples verifies the practicability and adaptability of the proposed method.**

***Key words*- New-type town; Distribution system; Influencing factor; Interpretative Structural Model (ISM); Analytic Hierarchy Process（AHP）**

I. INTRODUCTION

In order to cope with energy shortage, ecological environment deterioration and other problems, countries around the world are exploring new development mode actively. China has proposed a development concept for New-type Urbanization Construction [1] including the following concepts: intensive, intelligent, low-carbon and green. The new-type town is characterized by diversification, region individualization, ecology and livability. Distribution system guarantees the energy supply for new-type urbanization. There are many differences in natural environment, economic situation and social form among different regions. Since different new-type towns have their own characteristics in development foundation, type, scale, direction and so on, the modes of their distribution systems are not the same. The development speed, quality and other aspects of new-type town distribution system are constrained by various internal and external factors. Therefore, it is necessary to construct a model of influencing factors in order to formulate measures, make plans reasonably and promote the development of the new-type town distribution system.

At home and abroad，analysis of influencing factors of distribution system mainly focus on providing technical support for stable operation, consumption of new energy and the influences of Distributed Generation (DG) on voltage level and power quality [2]. At present, many scholars have studied the influences of grid-connected DG on a certain aspect of distribution system. For example, lots of papers have explained influences of grid-connected DG on the relay protection of distribution system[3]-[7]. The influences of DG on the reliability of distribution system are also studied in [8]-[10]. The problems of security and stability brought by Photovoltaic are analyzed [11]. There are also many scholars did research on the influencing factors of distribution system load forecasting. Some of them especially considered the impact of non-meteorological factors on summer cooling load[12]. A series of voltage problems such as over-voltage, voltage sags and voltage quality have been discussed in [13]-[17]. Some scholars also studied the influences of DG and electric vehicles on distribution system design and other aspects. Obviously, all of these studies focus on the effect of distributed power access on one aspect of the distribution system. The influences of grid-connected DG on distribution system are studied in some papers[18]-[19], which mainly includes the planning, power quality, relay protection, reliability, fault recovery and other aspects of distribution system. Furthermore, not only the influences of DG on distribution system are studied, but also the related measures are proposed by some researchers[20]-[21]. It is worth noting that the core of the research is mainly about DG, whether the influences of DG (including electric vehicles) on a particular aspect or many aspects of the distribution system. All in all, current researches focus on two aspects. One aspect is "Many-to-One" and the other aspect is "One-to-Many" in this paper. "One-to-Many" means that one aspect of distribution system is affected by a variety of factors. Similarly, "One-to-Many" means that one factor affects many aspects of distribution system. The influences of other factors except for DG on the distribution system and influencing factor models of developing new-type town distribution system are very few in both domestic and foreign research.

In this paper, an Interpretative Structural Model（ISM）of influencing factors of the new-type towns distribution system is proposed and the main factors influencing the development and construction of new-type town distribution system are analyzed. An influencing factor set of the new-type town distribution system is put forward and the interaction relation between each factor is analyzed to form the Reachable Matrix. Based on the Reachable Matrix, the ISM of influencing factors of the new-type town distribution system can be constructed. In order to directly show the impact of each factor on the distribution system, an extended AHP method is proposed in this paper to calculate the weight of each influencing factor.

II. INTERPRETATIVE STRUCTURAL MODEL OF INFLUENCING FACTORS OF THE NEW-TYPE TOWN DISTRIBUTION SYSTEM

A. Interpretative Structural Model (ISM)

Interpretative Structural Model (ISM) describes the relation between each two elements of a complex system by using a matrix representation of the graph and a simple logical operation. ISM is proposed by the United States Professor J. Warfield in 1973 and it is aiming at analyzing and solving complex system modeling problems [22].

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After more than 40 years continuous development, the systematic and operable analysis method have been formed. ISM plays an important role in the study of related problems of complex system. The characteristic of ISM is that the complex systems are decomposed into several subsystems and that the multilevel hierarchical structure model is constructed using related knowledge, experience and computer-aided.

(1)Determination of the influencing factor set

According to the professional knowledge, research papers and practical experience relative to the complex system, influencing factors of the system are analyzed and the influencing factor set is determined.

(2)Construction of the Consciousness Empirical Model

The system and its influencing factors are analyzed based on professional theory and practical experience of the system studied in order to form a preliminary structure about the influencing factors and their correlations.

(3) Establishment of the Connection Matrix

We should determine whether there is a direct impact between two influencing factors or not before expressing all the direct relationship by the Connection Matrix as follows.

$$A = (a_{ij})_{m \times n}$$

When $i \neq j$, if there is direct influencing relation between the factor e_i and e_j, $a_{ij} = 1$; if there is not direct influencing relation between the two factors, $a_{ij} = 0$.

(4) Establishment of the Reachable Matrix

The Reachable Matrix M can be calculated by (1) and (2).

When $k < n-1$,

$$\text{if} \quad (A+I) \neq (A+I)^2 \neq \cdots \neq (A+I)^k = (A+I)^{k+1} = L \qquad (1)$$

then

$$M = (A + I)^{k+1} \qquad (2)$$

I is the identity matrix in (2), and the matrix multiplication satisfies the Boolean algebra algorithm.

(5) Hierarchical allocation of each factor

The following sets are calculated according to Matrix M.

$$\begin{cases} P(e_i) = \{e_i | m_{ij} = 1\} \\ Q(e_i) = \{e_j | m_{ji} = 1\} \end{cases} \qquad (3)$$

$P(e_i)$ in (3) represents the set of all influencing factors that can be reached from the factor e_i. It is called Reachable Set. $P(e_i)$ can be obtained by searching for a factor corresponding to a column with the value 1 in row i of the Reachable Matrix. $Q(e_i)$ is the set of all the factors that can reach the factor e_i. It is called Advance Set. It can be obtained by searching for the factors corresponding to a row with the value 1 in column i of the Reachable Matrix M. And then, the set L_1 can be obtained based on $P(e_i)$ and $Q(e_i)$. Elements in set L_1 are satisfying (4).

$$L_1 = \{e_i | P(e_i) \cap Q(e_i) = P(e_i)\} \qquad (4)$$

Factors in the set L_1 can be reached from other factors, but other factors cannot be reached from these factors. It means the factors are at the highest level (Level 1). The new matrix M' is obtained by deleting the rows and columns in the original Reachable Matrix M corresponding to the factors in the set L_1.

Factors at the second level L_2 can be determined by the same operation on M'. All the factors can be assigned to their corresponding levels by repeating all above procedures.

(6) Construction of Hierarchy Structure Diagram

According to the Matrix M, a Hierarchical Structure Model is constructed using a canonical or practical method. The model is expressed by a multi-level hierarchical directed graph.

(7) Analysis and explanation of Hierarchy Structure Diagram

Based on the relevant theoretical knowledge and practical experience, the Hierarchy Structure Diagram is analyzed and interpreted to obtain the ISM.

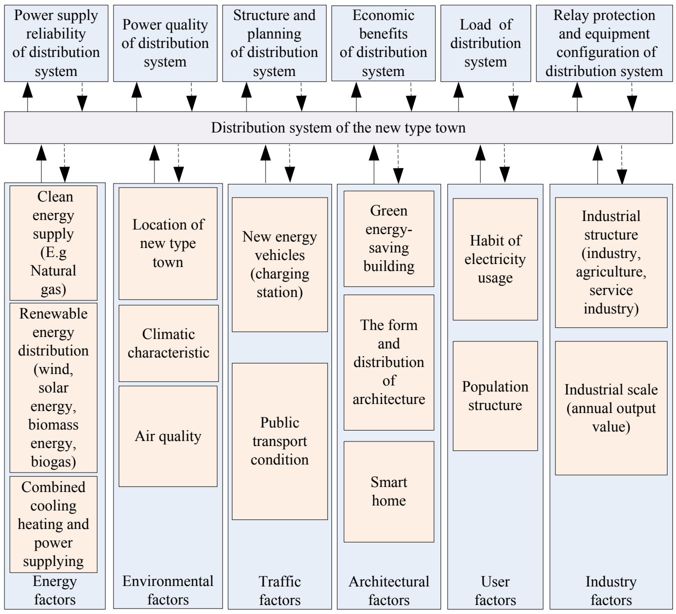

Fig. 1. Knowledge model of influencing factors of the new-type town distribution system

Comparing the ISM with the existing empirical consciousness model, if there is any serious discrepancy, researchers should return to step (2) and correct the influencing relation between the relevant factors.

B. ISM of Influencing Factors of the New-type Town Distribution System

(1) The Knowledge Model of influencing factors of the new-type town distribution system should be built before determining influencing factor set as shown in Fig. 1.

The object of this paper is new-type town distribution system, which is denoted as factor S_0.

Based on a large number of relevant literatures, combined with the Knowledge Model of influencing factors of the new-type town distribution system shown in Figure 1, this paper summarized the existing research results about influencing factors of the distribution system, and put forward the following specific factors.

Energy factors: types, distribution and percentage of clean energy denoted as factor S_1, conventional fuel consumption denoted as factor S_2, total energy utilization efficiency denoted as factor S_3, clean energy distributed generation denoted as factor S_4, cooling coefficient of combined cooling heating and power supplying denoted as factor S_5, storage capacity of combined cooling heating and power supplying denoted as factor S_6, clean energy penetration denoted as factor S_7.

Environmental factors: latitude and longitude of new-type town denoted as factor S_8, weather in new-type town denoted as factor S_9, climate type of new-type town denoted as factor S_{10}, PM10 index (including PM2.5) denoted as factor S_{11}.

Traffic factors: number of new energy vehicles denoted as factor S_{12}, number and distribution of electric vehicle charging stations denoted as factor S_{13}, number of buses per 10000 people and highway mileage denoted as factor S_{14}, number of non-clean energy vehicles denoted as factor S_{15}.

User factors: load characteristic curve denoted as factor S_{16}, percentage of resident population and population composition denoted as factor S_{17}, residents' lifestyles and energy use habits denoted as factor S_{18}.

Industry factors: total GDP of new-type town denoted as factor S_{19}, proportion structure of various industries denoted as factor S_{20}, distribution of various industries denoted as factor S_{21}, annual output value of industries denoted as factor S_{22}.

Architectural factors: quantity and distribution of green building denoted as factor S_{23}, total energy saving of green building denoted as factor S_{24}, percentage of green energy-saving buildings denoted as factor S_{25}, morphology and uses of architecture denoted as factor S_{26}, the number of users and the percentage of smart home denoted as factor S_{27}.

Besides, electricity sales of the new-type town denoted as factor S_{28}, the power supply reliability of distribution system denoted as factor S_{29}, the power quality of distribution system denoted as factor S_{30}, the structure and planning of distribution system denoted as factor S_{31}, the load of distribution system denoted as factor S_{32}, the relay protection and equipment configuration of distribution system denoted as factor S_{33}, the economic benefits of distribution system denoted as factor S_{34}.

It should be noted that S_{29}, S_{30}, S_{31}, S_{32}, S_{33}, S_{34} and S_0 are different from other factors because it is not necessary to determine the weights of them. S_0 is the core of the problem to be studied. S_{29}, S_{30}, S_{31}, S_{32}, S_{33} and S_{34} are six aspects of the problem which is needed in the process that determining the weights of other factors.

(2) For the ISM of influencing factors of the new-type town distribution system studied in this paper, after determining the influencing factor set, it is necessary to find out the factors that directly affect other factors and to establish the direct relation between factors and the consciousness empirical model. All above is the basis for next step to establish the Connection Matrix. According to the characteristics of new-type town, the existing literatures and experts' experience are combined to determine the factors that directly influence on other factor as shown in Table I.

The influencing factors of the new-type town distribution system are divided into several levels by (3) and (4):

$L_1=\{S_0\}$;

$L_2=\{S_{29}, S_3, S_{31}, S_{32}, S_{33}, S_{34}\}$;

$L_3=\{S_3, S_7, S_{13}, S_{20}, S_{21}, S_{24}, S_{28}\}$;

$L_4=\{S_4, S_5, S_6, S_{16}, S_{25}\}$;

$L_5=\{S_9, S_{11}, S_{23}, S_{26}, S_{27}\}$;

$L_6=\{S_2\}$;

$L_7=\{S_{12}, S_{15}, S_{18}, S_{19}\}$;

$L_8=\{S_1, S_{10}, S_{14}, S_{17}, S_{22}\}$;

$L_9=\{S_8\}$.

TABLE I

RELATION OF THE INFLUENCING FACTORS

factor	factors directly affected	factor	factors directly affected	factor	factors directly affected
S_0	-	S_{12}	S_2 S_{13}	S_{24}	S_{34}
S_1	S_{12} S_{23}	S_{13}	S_{30} S_{31} S_{33}	S_{25}	S_{24}
S_2	S_{11}	S_{14}	S_{15}	S_{26}	S_{16}
S_3	S_{34}	S_{15}	S_2	S_{27}	S_{16}
S_4	S_7 S_{31} S_{32} S_{33}	S_{16}	S_{28} S_{31} S_{32}	S_{28}	S_{34}
S_5	S_3	S_{17}	S_2 S_{15} S_{19}	S_{29}	S_0
S_6	S_3	S_{18}	S_2 S_{16}	S_{30}	S_0
S_7	S_{29} S_{30} S_{33}	S_{19}	S_2 S_{28}	S_{31}	S_0
S_8	S_1 S_{10}	S_{20}	S_{30} S_{32}	S_{32}	S_0
S_9	S_4 S_{16} S_{29}	S_{21}	S_{31} S_{32}	S_{33}	S_0
S_{10}	S_9 S_{18} S_{26}	S_{22}	S_{19}	S_{34}	S_0
S_{11}	S_4	S_{23}	S_{24} S_{25} S_{31} S_{32}		

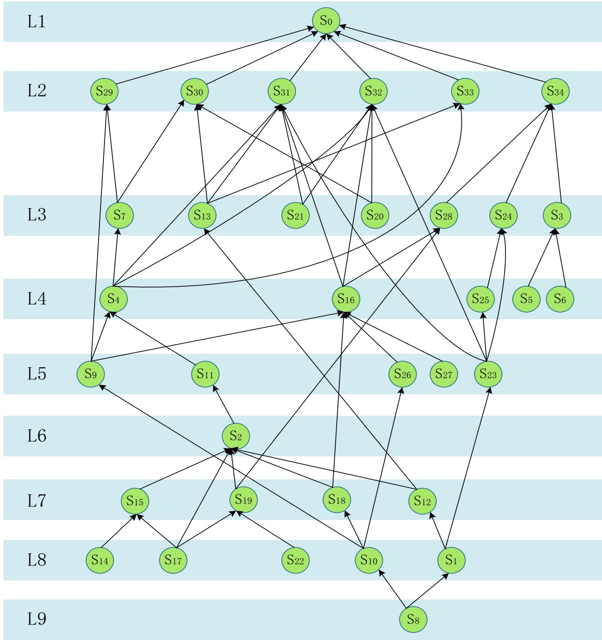

Fig.2. Hierarchical Structure Diagram of influencing factors of the new-type town distribution system

The Hierarchical Structure Diagram of influencing factors of the new-type town can be obtained as shown in Fig. 2.

III. WEIGHT DETERMINATION OF INFLUENCING FACTORS OF THE NEW-TYPE TOWN DISTRIBUTION SYSTEM

Analytic Hierarchy Process (AHP) can use less information to make the process of decision-making mathematical. Traditional AHP model consists of target layer, criterion layer and scheme layer [23]. In this paper, it is improved to calculate the weight of factors by extending the three layers. In the ISM, the influencing factors are distributed at the level L_i (i=0, 1, 2⋯). But the factors in set L_i are not always at the same level in AHP method. Assuming that there are n elements in the ISM, for the factor S_p, if the elements in the Reachable Matrix M satisfy

$$M_{pq} = 1 \;(\; p\leqslant n, \quad q\leqslant n) \tag{5}$$

then S_p is a factor that directly affects factor S_q. Thus all the m ($0\leqslant m\leqslant n$) factors that directly affect S_q can be found.

If m = 0, there is no factor directly influencing the factor S_q in the influencing factor set; If m = 1, the weight of S_p is equal to the weight of S_q, that is, $w_{pq} = w_q$; If m> 1, the weight w_{pq} of S_p can be calculated as follows.

Construct the Judgment Matrix $A_{m\times m}$ of all the m factors. Calculate the Maximum Eigenvalue λ_{max} and its Normalized Eigenvector W with positive components. Then use the weight coefficient equation (6) to calculate the weight of each factor.

$$W = \frac{\sqrt[m]{\prod_{j=1}^{m} a_{ij}}}{\sum_{i=1}^{m} \sqrt[m]{\prod_{j=1}^{m} a_{ij}}} \tag{6}$$

a_{ij} is the element in the Judgment Matrix A. W=[w_{1q}, w_{2q},⋯, w_{pq},⋯, w_{mq}] is the Eigenvector. The relevant weight of each factor on the evaluation target S_q can be obtained by W. The Maximum Eigenvalue λ_{max} can be obtained from (7).

The results should be tested for consistency using (8), in which m is the order of the Judgment Matrix A. If $C.I$ < 0.10, it means the results are passed consistency test.

$$AW = \lambda_{max} W \tag{7}$$

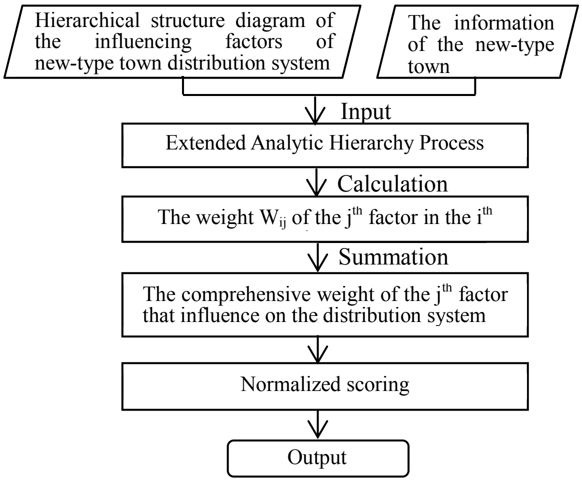

Fig.3. Weight calculation flowchart

$$C.I=\frac{\lambda_{max}-m}{m-1} \quad (8)$$

$$W_{ik}=\sum W_{kq} \quad (9)$$

W_{kq} in (9) is the weight of S_k at L_i level influencing on S_q.

In this way, the weights of the factors at level L_i (i=0, 1, 2,⋯) can be obtained. And then the comprehensive weight of factor S_k is calculated by (10).

$$W_k=\sum W_{ik} \quad (10)$$

IV. Analysis Of Examples On Weight Calculation Of Influencing Factors Of The New-type Town Distribution System

The new-type town A in East China is located in the East Asian monsoon region. Its annual average temperature is 15.7℃, annual average precipitation is 1160 mm and annual average sunshine time is about 2020 hours. It is famous for silk and rice. There are two national AAA-level tourist attractions. The population of the town is about 90,000. Recently, the government issued a series of energy-saving and emission reduction policies. These policies especially the subsidy policy of PV power generation has promoted the development of local distributed PV power generation.

The climate of new-type town B in Northeast China is the temperate continental climate. Its annual average temperature is 7℃, annual average precipitation is 607.5 mm. B town is rich in mineral resources and the heavy industry was once the pillar of economic development. The population of B town is about 40,000. With the development of green ecological agriculture, comprehensive utilization of biogas has been popularized and applied. Using the method proposed in this paper, the influencing factors of distribution system of A town and B town are analyzed and the weight of each factor is calculated. The results are shown in Table II and Table III.

TABLE II
WEIGHTS LIST 1 OF INFLUENCING FACTORS

	New-type town A(tourism-leading)		New-type town B (industry-leading)	
	factors	weight	factors	weight
1	S_{29}:power supply reliability	0.3750	S_{29}:power supply reliability	0.2778
2	S_{30}:power quality	0.1250	S_{30}:power quality	0.1642
3	S_{31}:structure and planning	0.1250	S_{32}:load	0.1414
4	S_{32}:load	0.1250	S_{33}:relay protection and equipment configuration	0.1414
5	S_{33}:relay protection and equipment configuration	0.1250	S_{34}:economic benefits	0.1414
6	S_{34}:economic benefits	0.1250	S_{31}:structure and planning	0.1338

TABLE III
WEIGHTS LIST 2 OF INFLUENCING FACTORS

	Influencing factor	New-type town A		New-type town B	
		Comprehensive weight	Normalized score（%）	Comprehensive weight	Normalized score（%）
S_1	types, distribution and percentage of clean energy	0.2389	5.91	0.0866	2.94
S_2	conventional fuel consumption	0.0327	0.81	0.0348	1.18
S_3	total energy utilization efficiency	0.0223	0.55	0.0223	0.76
S_4	clean energy distributed generation	0.2619	6.48	0.2085	7.07
S_5	cooling coefficient of combined cooling heating and power supplying	0.0056	0.14	0.0056	0.19
S_6	storage capacity of combined cooling heating and power supplying	0.0167	0.41	0.0167	0.57
S_7	clean energy penetration	0.1822	4.51	0.1292	4.38
S_8	latitude and longitude of new-type town	0.9064	22.43	0.5854	19.84
S_9	weather in new-type town	0.6145	15.21	0.4664	15.81
S_{10}	climate type of new-type town	0.6675	16.52	0.4988	16.91
S_{11}	PM10 & PM2.5	0.0327	0.81	0.0348	1.18
S_{12}	number of new energy vehicles	0.2066	5.11	0.0533	1.81
S_{13}	number and distribution of electric vehicle charging stations	0.2051	5.08	0.0519	1.76
S_{14}	number of buses per 10000 people and highway mileage	0.0006	0.01	0.0005	0.02
S_{15}	number of non-clean energy vehicles	0.0033	0.08	0.0029	0.10
S_{16}	load characteristic curve	0.1403	3.47	0.0816	2.77
S_{17}	percentage of resident population and composition	0.0270	0.67	0.0356	1.21
S_{18}	residents' lifestyles and energy use habits	0.0310	0.77	0.0196	0.66
S_{19}	total GDP of new-type town	0.0812	2.01	0.0969	3.28
S_{20}	proportion structure of various industries	0.0735	1.82	0.1648	5.59
S_{21}	distribution of various industries	0.0556	1.38	0.1086	3.68
S_{22}	annual output value of various industries	0.0677	1.68	0.0727	2.46
S_{23}	quantity and distribution of green building	0.0323	0.80	0.0333	1.13
S_{24}	total energy saving of green building	0.0088	0.22	0.0115	0.39
S_{25}	percentage of green energy - saving buildings	0.0022	0.05	0.0029	0.10
S_{26}	morphology and uses of architecture	0.0220	0.54	0.0128	0.43
S_{27}	number of users and the percentage of smart home	0.0083	0.21	0.0048	0.16
S_{28}	electricity sales of the town	0.0939	2.32	0.1076	3.65

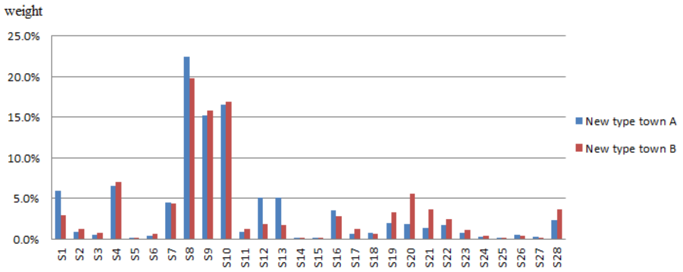

Fig.4 Influencing factors weights comparison of distribution system of A town and B town

As shown in Table II, the requirement of the new-type town distribution system on reliability of power supply is the highest. The result is inevitable. For the tourism-leading town, it is easy to cause confusion, resulting in security threats in scenic spots, shopping areas and so on once the power supply interrupted. For industry-leading town, it not only requires high reliability of power supply, but also requires high power quality of the distribution system. Because the decline of power quality will lead to reducing of efficiency and power factor, increasing of loss, equipment life shortens, product quality descends and many other results that do harm to normal operation and development of industry. We can get the following conclusions through the analysis of all above results as shown in Fig. 4.

(1) The trends of the weights of A and B are generally the same. The meteorological factors are still important factors that affect the new-type town distribution system. No matter the tourism-leading town like A or the industry-leading town like B, the influences of wind, thunderstorms, line icing and other adverse weather should be paid more attention. During design and planning of distribution system, installation location and configuration of lines and equipment should be paid special attention to and chosen carefully.

(2) Different from the traditional distribution system, the new-type town distribution system is greatly affected by clean energy. On the one hand, clean energy utilization reduces the load pressure of distribution system. On the other hand, grid-connected DG produces the bi-directional current in the distribution system. Because of the bi-directional current, many aspects such as planning, design, operation, control and device configuration of new-type town distribution system should adjust to the new situation in order to adapt to future development of distribution system. As a tourism-leading town, the acceptance of clean energy DG of new-type town A is greater than the acceptance of B town. Large numbers of distributed photovoltaic power generation connecting to distribution system makes load forecasting more difficult. Therefore, the impact of clean energy utilization on distribution system should be fully considered and reasonable configured for new-type town A and other towns that are similar to A during planning and designing of the distribution system, especially on security and other aspects.

(3) The influence of industrial factors on new-type town distribution system is relatively great. Moreover, the impact on the industry-leading town is much greater than the tourism-leading town. Combined the result with actual situation, there isn't any heavy industry in new-type town A. The economic growth of A town mainly depends on the tourism industry. The new-type town B is industry-leading but also combined with ecological agriculture. The industry structure and changes of the output value are easier to influence the distribution system. GDP, industry distribution and other factors mainly influence load growth of the new-type town distribution system. Therefore, during planning of new-type town distribution system, the potential of its economic development and the demand of load growth should be taken into consideration in order to meet the development requirements.

V. CONCLUSION

First, influencing factor set of the new-type town distribution system is summarized and put forward in this paper. Secondly, an ISM method applicable to analyze influencing factors of the new-type town distribution system is proposed, which determine the weights of factors using extended AHP method. The weights of factors during the process are added to obtain the comprehensive weight of each influencing factor. At last, the weights of all the influencing factors are normalized to get the final weights. The final weights intuitively show the impact degree of every factor on the distribution system. Especially for the lack of data, using of the proposed model and algorithm can draw a conclusion with practical significance. Based on the proposed model and algorithm, the weights of influencing factors were calculated for two kinds of new-type town, which are industry-leading and tourism-leading.

The validity of the model is verified by analyzing the results and comparing with the actual results. It provides a new way of thinking for the analysis of influencing factors and the determination of the weights of influencing factors of the new-type town distribution system. And it also provides reference for the development and construction of the new-type town distribution system in China.

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