

Selection and Evaluation of Priority Domains in Global Energy Internet Standard Development Based on Technology Foresight

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Abstract. The selection and evaluation of priority domains in Global Energy Internet standard development will help to break through limits of national investment, thus priority will be given to standardizing technical areas with highest urgency and feasibility. Therefore, in this paper, the process of Delphi survey based on technology foresight is put forward, the evaluation index system of priority domains is established, and the index calculation method is determined. Afterwards, statistical method is used to evaluate the alternative domains. Finally the top four priority domains are determined as follows: Interconnected Network Planning and Simulation Analysis, Interconnected Network Safety Control and Protection, Intelligent Power Transmission and Transformation, and Internet of Things.

1. Introduction

Since the 21st century, with the continuous growth of the world's total energy consumption, environment pollution caused by the potential huge energy demand and fossil energy consumption has become increasingly prominent, threatening the people's livelihood, world peace and sustainable development of mankind. In that context, the Global Energy Internet (GEI) [1-2] came into being, providing an effective solution for the efficient deployment of clean energy resources around the world.

Construction of the GEI is an unprecedented, super-complex huge systems engineering, while interconnection at all levels face serious challenges. Therefore, the establishment of a technical standard system and selecting the standard development priority domains become the urgent strategic work of GEI construction. Giving priority to develop the domains of technology and standardization of urgent need can provide strong support to the following technology research and development, demonstration applications, construction and operation and industrial development of GEI.

Technology foresight, as a tool to select the technical domains that will be given priority to develop, explore strategic research field and choose the science and technology with greatest contribution to economic and social benefits through the systematic study of science, technology, economic and social future development trend. Gerami M considers the mean of technology foresight and surveys



movement from science and technology policy towards innovation policy in Iran (Reference [3]). Furthermore, Kang T H analyzes the development of Group Decision Support System and how it is utilized in technology foresight, and determines whether the methods used in global technology foresight is appropriate for the internet (Reference [4]). In this paper, the technology foresight of GEI standard development priority domains is taken for an example, the process of which will be empirically studied, in order to achieve the best allocation of social resources.

2. GEI standard development priority domains technology foresight process

2.1. GEI standard development priority domains Delphi method

Faced with the opportunities and challenges brought by the rapid development of high-tech and its industry, the United States, Japan, Germany, South Korea and other countries take the qualitative analysis of technology foresight to explore the future development direction of science and technology to determine the priority of the strategic focus of development [5], among which, the Delphi method, as an effective tool, is most commonly used in large-scale technology foresight [6]. Combined with the actual situation of GEI technical and standardized development construction, drawing lessons from domestic and foreign experience, the technology foresight of GEI standard development priority domains uses the Delphi method as well, and the specific implementation steps are as follows:

(1) Propose GEI standard alternative priority domains. According to the GEI standard architecture, a set of candidate priority domains was identified through standardization of literature analysis and expert consultation, which covers 13 technical domains in 4 major directions, as shown in table 1.

Table 1. GEI standard development professional direction and alternative domains

No.	Professional Direction	Alternative Domains
1	Smart Grid	Intelligent Power Transmission and Transformation Intelligent Switchgear Intelligent Power Large-scale Energy Storage Internet of Things
2	UHV and New Transmission	UHV Transmission HVDC and DC Grid New Transmission
3	Clean Energy	Clean Energy Generating Plant and System Clean Energy Synchronization and Operation Control
4	Interconnected Network	Planning and Simulation Analysis Safety Control and Protection Dispatch and Transaction

(2) Conduct an expert survey, and obtain feedback. Select technological backbones from the power enterprises, universities and research institutes of the first line and authority workers who are familiar with and active in the formulation of industry, corporate, national or international standards. A three-round survey is conducted to provide questionnaires to experts. During the transition period of three rounds of investigation, the results of the questionnaire collected in the last round are reflected in the next round of questionnaire, and the opinions of the different experts will be unified through three rounds of questionnaire feedback.

(3) Organize expert seminars for comprehensive evaluation. In accordance with the principles and guidelines for the selection of priorities in the field of GEI standards, and on the basis of comprehensive analysis and induction of survey data in various fields, the evaluation index system is designed and the priority domains for GEI standards are formulated.

2.2. Evaluation Index System Framework

The evaluation indicators include five first-level indicator, which are the current development of the domain, the demand of the standard of the domain, the differences between standards development

requirements and existing standards of the domain, the future influence of the domain and the restriction factor of the domain. There are a number of secondary and tertiary indicators. Detailed index system and specific assignment of the indicators are shown in table 2.

Table 2. Evaluation Index System and Indicator Assignment

1 st level indicator	2 nd , 3 rd level indicator	Weight	Indicator Assignment
Current Development	Technology Trends Compliance	0.2	①Fully ②Mostly ③Basically ④Rarely ⑤Inconformity
	Technology Relative Developmental Level		①5-10 years leading ②5 years leading ③Equal level ④5 years behind ⑤ 5-10 years behind
	Threats to International Alternative Technologies		①Small ②Lesser ③Medium ④Major ⑤Large
	Top Experts Technical Committees Influence		①Large ②Major ③Medium ④Lesser ⑤Small
Demand Degree	Complete Situation of Relevant Domestic Standards	0.3	①Fully ②Mostly ③Basically ④Rarely ⑤Incompleteness
	Current Degree of Technical Demand		①Large ②Major ③Medium ④Lesser ⑤Small
Difference Degree	Current Degree of Standardization Demand	0.3	①Large ②Major ③Medium ④Lesser ⑤Small
	Differences Between Standards Development Requirements and Existing Standards		①Large ②Major ③Medium ④Lesser ⑤Small
Influence of the Next 5 Years	Number of Standards to be Revised	0.1	①Over 20 ②10~20 ③Below 10
	The Degree of Promoting the Development of Relevant Domains of Technology		①Large ②Major ③Medium ④Lesser ⑤Small
	The Degree of Promoting International Cooperation in Energy Standards		①Large ②Major ③Medium ④Lesser ⑤Small
Development Constraints	The Degree of Promoting Energy Internet Industry Development	0.1	①Large ②Major ③Medium ④Lesser ⑤Small
	Policy		①Small ②Lesser ③Medium ④Major ⑤Large
	Capital		①Small ②Lesser ③Medium ④Major ⑤Large
	Human		①Small ②Lesser ③Medium ④Major ⑤Large

2.3. Statistical analysis method

2.3.1 The Calculation Method of Value of Each Indicator: The evaluation method was based on 5-point fuzzy evaluation. The mixed weighting coefficient averaging method is used to evaluate the index of each domain, and the calculation formula is as follows:

$$Indicator_{i,j} = \left(\frac{\alpha_j}{N_{total}} + \frac{\beta_j}{N_{i,j}} \right) \cdot \left(\sum_{k=1}^{n_j} score_k \cdot \frac{5}{n_j} \cdot N_{i,j,k} \right) \tag{1}$$

$$score_k = n + 1 - k \quad (2)$$

$$\alpha_j + \beta_j = 1, 0 \leq \alpha_j, \beta_j \leq 1 \quad (3)$$

Where, $Indicator_{ij}$ refers to the j^{th} indicator of the i^{th} standard domain; n_j refers to the number of subcategories of the j^{th} indicator; $score_k$ refers to the corresponding score of the k^{th} grade; $score_k \frac{5}{n_j}$ refers to the corresponding score of the k^{th} grade which converted to a 5-point scale; $N_{i,j,k}$ refers to the voting number of the k^{th} grade of the the j^{th} indicator in the i^{th} standard domain.

Since the total number of votes for each evaluation indicator is different, normalization is performed when the evaluation value is given. α_j reflects the preference for the weighted average of the total number of indicators j , β_j reflects the preference for the weighted average of the number of respondents who responded to indicator j .

2.3.2 Comprehensive Indicator Calculation Method. Based on the results of the evaluation of each indicator in section 2.3.1, standardize the five categories of 15 indicators, and use the weighted average method to calculate the comprehensive index. The weight of each indicator is shown in table 2, and the comprehensive indicator is calculated as follows:

$$CompositeIndicator_i = \sum_{j=1}^{N_{ind}} \gamma_j \cdot Indicator_{i,j} \quad (4)$$

Where, $CompositeIndicator_i$ refers to the comprehensive indicator of the i^{th} standard domain; N_{ind} refers to the total number of indicators; γ_j refers to the weighting factor of the j^{th} indicator.

3. Empirical Study on the Selection of Priority Domains in GEI Standards

3.1. Primary selection of GEI standard alternative priority domains

Through the analysis of the status of GEI construction, use standardized literature survey and expert meeting to settle the plan of the construction of GEI standard system. Combined with the current technology trends and the development of relevant standards at home and abroad in each area [7], a list of 13 priority domains was prepared. After the first round of the survey, 1 additional item was added based on expert advice and a second round of survey was conducted towards 14 domains. For the results of the second round survey, an expert seminar was held. The evaluation domains and evaluation indicators were classified, merged, deleted, added and summarized according to expert opinions. Finally, the list of candidate domains for the third round of the questionnaire was determined as the following 6 domains: Intelligent Power Transmission and Transformation, Large-scale Energy Storage, Internet of Things, UHV Transmission, Interconnected Network Planning and Simulation Analysis and Interconnected Network Planning Safety Control and Protection.

3.2. Statistical analysis of indicators

Sort out the results of expert survey, and calculate the size of each indicator in each domain according to the evaluation index system and evaluation method in section 1, to make fully decision-making use of technical foresight in order to prioritize the development of alternative domains.

3.2.1 Evaluation of Current Development. The survey results show that in terms of technology, China's large-scale energy storage technology and UHV transmission technology is close to the world's leading national level, of which China's pumped storage technology is mature. According to the total installed capacity, China currently ranks first in the world with 32.1GW [8]. The technological development of the remaining four domains are behind the world's leading level of 1 to 2 years, of which Internet of Things has the largest gap with the world leading level [9]. The technologies in all six domains are in line with the accepted trends in technology development and have broad prospects for development. China's UHV transmission technology occupies a completely dominant position among the world, for not only owns independent intellectual property rights, but also the intellectual property is unique worldwide. Therefore, the international threat of alternative

technology of UHV transmission is far less than the other five domains. Overall, UHV transmission technology at this stage has the highest level of development, and the remaining five areas are of uneven development levels.

In terms of standardization, according to the authority degree of experts and technical committees of standard development in six domains, as well as the completeness score of domestic standards in each area, the equal-weighted average method is used to calculate the comprehensive indicator of the current development, the result of which is shown in table 3.

Table 3. Current Development Comprehensive Analysis of Six Domains

No.	Professional Direction	Alternative Domains	Domain No.	Top Experts / Technical Committees Influence	Complete Situation of Relevant Domestic Standards	Comprehensive Indicator
1	UHV and New Transmission	UHV Transmission	D4	4.82	4.89	4.855
2	Smart Grid	Large-scale Energy Storage	D2	4.78	4.72	4.75
3		Intelligent Power Transmission and Transformation	D1	4.75	4.68	4.715
4		Internet of Things	D3	4.73	4.61	4.67
5	Interconnected Network	Planning and Simulation Analysis	D5	4.35	4.56	4.455
6		Safety Control and Protection	D6	4.23	4.52	4.375

As showed in table 3, the development of UHV transmission technology in standardization is well ahead of the rest of fields, and the international standards in this domain are mostly from IEC and IEEE, while the domestic standards are very complete. The development of Interconnected Network standards slightly lag behind, some national standards are directly translated from the IEC and IEEE standards, and the others are formulated by their own, which are of less completeness.

3.2.2 Demand Assessment. Demand assessment, starts with two aspects of technical needs and standardization needs, first of all analyze the need for key technology supporting the construction of the GEI, and then propose requirements for the standardization of key technology domains. The results of evaluation are shown in figure 1.

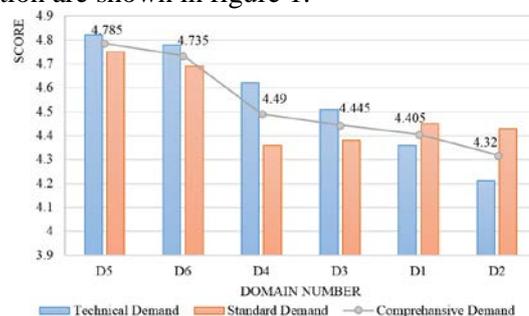


Figure 1. Demand evaluation result

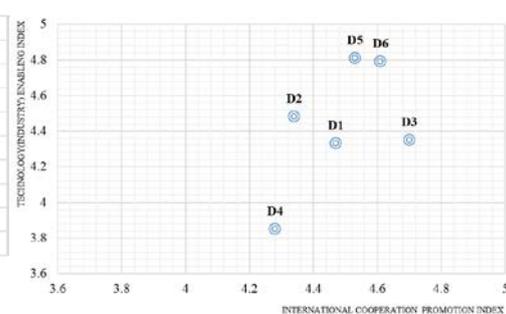


Figure 2. Influence assessment result

As can be seen from figure 1, the degree of demands for technology and standards in two domains of Interconnected Network ranks first, the reason of which is that GEI involves national interconnection intercontinental interconnection and global interconnection, the difference of different national grid brings huge barriers to technology and standardization of grid interconnection[10].

China's large-scale energy storage technology leads international level, the current standard of which is relatively complete, resulting in minimum demand for technology development and standardization.

3.2.3 Difference Evaluation. Difference evaluation is to face the demand, review the existing relevant technical standards and analyze the differences between requirement and existing standards, after which the lack of relevant standards can be identified, and then put forward and statistical the quantity of standards need to be revised. The evaluation results of six alternative domains are shown in table 4.

Table 4. Difference Evaluation Results

Domain No.	Professional Direction	Alternative Domains	Difference Analysis	Standards Need to be Revised	Comprehensive Index
D4	UHV and New Transmission	UHV Transmission	higher demand on the power transmission capacity, transmission distance and the grid structure	①operation and maintenance ②equipment and experiments ③construction	4.15
D2		Large-scale Energy Storage		①energy storage electrical safety ②electrical compatibility	4.35
D1	Smart Grid	Intelligent Power Transmission and Transformation	lack communication standards; some standards not compatible	Transmission: ①transmission line condition monitoring ②flexible AC transmission Transformation: standards of equipment, system and station control layer	4.62
D3		Internet of Things		①Intelligent sensing ② transmission network communication technology ③access network communications technology	4.53
D5		Planning and Simulation Analysis	Current standards are independent, not united; The simulation domain standard is lagging behind; Relay protection exists difference worldwide	①planning program ②standards of supporting interaction of simulation domain	4.85
D6	Interconnected Network	Safety Control and Protection		①relay protection ②stability control	4.76

As can be seen from table 4, difference evaluation results are similar to the ones of demand evaluation, in which the difference between the two alternatives is the largest in the direction of the Interconnected Network, while the variance in the UHV transmission field is the smallest.

3.2.4 Influence Assessment. The influence assessment of the GEI standards development priority domains, is mainly based on the degree that standardization work in the alternative domain promote the development of technology, international cooperation and industrial development to calculate the

influence comprehensive index. Technology development can bring strong support for scale development of industry, and thus there is a causal relationship between the impact for technology and industry development, as a result of which, they have similar score trend. The specific results of influence assessment are shown in figure 2.

In figure 2, the closer to the upper right corner the dot distributes the stronger influence the standard setting of the domain represented by the dot owns. It can be seen from the figure that the standardization work in the domain of Interconnected Network has obvious potential to promote its related technology development, industrial development and international cooperation. While the standardization work in the domain of UHV Transmission has the least impact on advancing international cooperation, which is because the domain of UHV Transmission has a strong Chinese characteristic, the technology and standards covered are mostly in China.

3.2.5 Development Constraints Analysis. Constraints on the development of GEI standards include policy factors, financial factors and human factors. The results of the survey on the factors above in six selected domains are shown in table 5. The result indicates that experts believe that capital is the main factor restricting the technical research and standard setting in various fields. The two domains in the direction of the Interconnected Network have the greatest constraints of human factor, with the remaining four areas at the middle level. There are three domains where policy factors are most influential, accounting for 50 percent of all alternative fields. Therefore, if the Government is willing to provide adequate policy support and increase financial and human input, will help promote the technical research and standard-setting in all areas of the implementation.

Table 5. Development Constraints Analysis Results

Domain No.	Alternative Domains	Policy Factor	Capital Factor	Human Factor
D01	Intelligent Power Transmission and Transformation	medium	larger	medium
D02	Large-scale Energy Storage	medium	larger	medium
D03	Internet of Things	medium	larger	medium
D04	UHV Transmission	larger	larger	medium
D05	Planning and Simulation Analysis	larger	larger	larger
D06	Safety Control and Protection	larger	larger	larger

3.3. Comprehensive index calculation and analysis

Based on previous analysis, the five categories of 15 indicators is standardized. And then according to the weight of each indicator in table 1, the comprehensive index is calculated by weighted average method and sorted in descending order to get the ranking result of GEI standard setting priority domains, which is shown in figure 3. The top four priority domains are determined as follows: Interconnected Network Planning and Simulation Analysis, Interconnected Network Safety Control and Protection, Intelligent Power Transmission and Transformation, and Internet of Things. Among them, the evaluation of each indicator of Intelligent Power Transmission and Transformation and Internet of Things is in the upper level. While the two fields of the Interconnected Network are in the leading position in many fields with higher technical and standardization requirements, larger difference between existing standards and requirements and higher international influence upon the international standard-setting work in the corresponding fields.

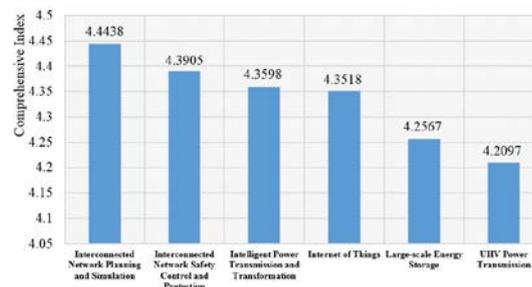


Figure 3. GEI standards priority list

4. Conclusion

Firstly, this paper analyzes the background of the construction of the GEI standard system and the necessity of the selection of the priority areas of standard development. Secondly, Delphi's investigation process based on technology foresight is put forward, the evaluation index system of priority field is constructed, which includes 15 indicators, and the calculation method of comprehensive index is determined. In the empirical analysis of the choice of priority domains, statistical analysis is used to analyze and evaluate the alternative domains. Finally, the comprehensive indexes of the alternative domains are sorted in descending order, and the top four priority fields are obtained.

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