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Construction of the Indicator System Applied to Evaluate Basic Capabilities of Smart Meter Enterprises on NQI

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Abstract. In order to quantitatively evaluate the basic capabilities of smart meter enterprises on National Quality Infrastructure（NQI） and continuously improve the quality level of smart meter enterprises, this paper, profited from China’s NQI capability index system and the Delphi method, with representiveness of indicators as the starting point, and based on repeated screening and expert demonstration, chooses the most representative indicators devised for NQI factors such as measurement, standardization, certification & accreditation, inspection & testing and quality management in the production of smart meters, and constructs an indicator system applied to evaluate the basic capabilities of smart meter enterprises on NQI, which includes 5 first-level indicators, 8 second-level indicators and 30 basic indicators. With construction of this system, we can quantitatively evaluate the basic quality and technology capabilities of smart meter manufacturers and continuously improve deficiencies of enterprises on their NQI. And, the State Grid can also apply this system as a technical specification to evaluate the quality level of smart meter enterprises.

1. Introduction

Nowadays, China's economic and social development has entered the "quality era", and the strategic position of quality in national development has become more prominent. The overall quality level is still the key bottleneck restricting our international competitiveness, where low level of NQI technology serves as the root cause. Under the smart grid standard, the industry of smart watt-hour meter is mature with an integrated system and developing towards information interaction and intelligent power consumption, which provides a solid foundation for the research and application of NQI. However, most of the smart meter manufacturers implement the quality compliance strategy at low cost with varied construction of quality infrastructure, which has become an obstacle for enterprises to improve product quality.

In order to take the lead in advocating "craftsman spirit" in smart grid measurement industry to reverse the image of low price and low quality showed by Chinese products, give full play to the support and leading role of NQI, implement NQI construction to smart meter enterprises, and improve the overall quality of the industry, this paper, starting with the construction of a quantitative indicator system that can be used to evaluate and quantify the comprehensive situation of the quality technology base of smart meter enterprises, studies and refines the key technical indicators representing factors involved in smart meter enterprises such as measurement, standardization, authentication & approval, test & inspection and quality management and their relationship, in a way to promote the application of the evaluation indicator system aiming at basic quality technology capabilities in the development of the meter industry, improve developmental quality and efficiency of the meter industry, and provide theoretical support for the structural change of the meter industry in China.

2. Domestic and foreign research status

In terms of NQI capability evaluation, UNIDO firstly established the indicator system for national basic capabilities on quality technology in the Trade Standards Compliance Report (2010)[1], and further enriched and improved the system in the Trade Standards Compliance Report (2015)[2], which mainly includes standardization capability indicator, measurement capability indicator, accreditation capability indicator, testing capability indicator, detection capability indicator and authentication capability indicator. Referring to the construction of the UNIDO Trade Standards Compliance Capability Indicator, we constructed an evaluation indicator system for basic national capabilities on NQI in line with China's national conditions and work needs[3], including 5 first-level indicators of " metrological capability", "standardization capability", " Certification and accreditation capability", "inspection & testing capability", "quality management capability", 15 second-level indicators, 34 third-level indicators and 45 basic indicators, which are used to measure the relative level of the national quality technology base and quality technology base of 31 provinces (regions, municipalities) in different time and space.

In regard to smart grid evaluation, developed countries occupy a dominant position in construction, operation and maintenance of grid for historical reasons. Especially in the evaluation of power grid, a lot of empirical data have been obtained. A variety of comprehensive smart-grid evaluation systems have been put forward, including smart grid revenue assessment system of EU[4], smart grid development evaluation indicator system formulated by US Department of Energy (DOE)[5], IBM[6][7] smart grid maturity model, evaluation indicators for smart grid construction proposed by American Academy of Electrical Sciences (ERPI)[8] and etc. The domestic power industry has put forward many suggestions on the construction and planning of smart grid, such as "dual-type" power grid indicator system, power grid development indicator system and other evaluation systems[9]. In recent years, pilot projects of smart grid have been carried out nationwide, which provides a practical basis for the further implementation of smart grid in China.

Through the analysis and research on the indicator system for NQI evaluation of smart meter at home and abroad, we found that there is no evaluation indicator system aiming at NQI capability of smart meter enterprises at present. The trade standard conformity indicator system proposed by the United Nations Industrial Development Organization and the system of indicators about basic quality technology capabilities proposed by the author are both the evaluation of national and regional NQI capabilities. The selection of indicators mainly reflects the development capability and level of NQI at the macro level, which lays a good reference for extracting the general NQI indicators of watt-hour meter enterprises, but does not involves characteristic indicators in the production and manufacturing process of watt-hour meter enterprises. Most of the studies on the evaluation indicator system of smart meter industry at home and abroad have placed focus on the comprehensive evaluation of smart grid construction, where the evaluation is mainly carried out from the aspects of benefit, performance and development, emphasizing the overall and macro-evaluation, but lacking the indicators about the professionalism and uniqueness of smart meter industry. Yet, they have laid a foundation for further understanding the connotation, characteristics and development trend of smart meter industry.

For the first time, this paper applies the evaluation of basic capability on NQI to smart meter enterprises, constructs an indicator system for comprehensive evaluation of basic capability on NQI of smart meter enterprises, which provides an implementation framework for the evaluation of NQI capability of smart meter enterprises in China, and also provides a theoretical basis for the construction of detailed indicators in the future.

3. Construction method of NQI capability indicators for smart meter enterprises

Referring to the national NQI capability indicator system, and combining with the development status of smart meter enterprises in China, this paper will focus on the key technical indicators and their relationships representing measurement, standards, authentication & accreditation, detection & testing and quality management of smart meter enterprises, and extract the first-level indicators representing the NQI capability of smart meter enterprises. Moreover, using the Delphi method for reference, from the perspective of indicators' representativeness, we designed a questionnaire survey and calculated the representative coefficients of various indicators, so as to construct a quantitative indicator system for evaluating the comprehensive situation of quality technology base of smart meter enterprises.

3.1 Building of the indicator framework
Measurement, standardization, authentication and accreditation, detection and testing are the internationally recognized core elements of the quality technology base. Therefore, the indicator framework for evaluation of NQI capability of smart meter enterprises shall be also constructed from these aspects. However, in view of the production characteristics of meter enterprises themselves, each production link covers different requirements on measurement, standards, authentication and accreditation, detection and testing, and some links do not necessarily cover all NQI factors. Thus, we extracted the key quality control points in the production process of smart meters to find out the focus and the most obvious stage characteristics of each link which can best represent the NQI capability of smart meters, applied them as an indicator to evaluate the NQI capability of enterprises, and constructed an indicator system framework for evaluation of the NQI capability of smart meter enterprises.

3.2 Design of the indicator system
Drawing on the Delphi method, we invited experts of watt-hour meter industry, representative enterprises, statistics, mathematics and economics to conduct multi-round investigation and consultation. On the basis of the indicator framework that has been built, we selected the second-level indicators that best represent the first-level indicators, sorted out the indicators selected by experts, and carried out repeated screening for many rounds. Finally, we constructed the indicator system for evaluation of NQI capability of smart meter enterprises.

3.3 Indicator screening
Delphi method is a way that survey experts anonymously expressing opinions to questions contained in the questionnaire, under which experts are not allowed to discuss with each other. After many rounds of repeated consultation and revision, the consensus of experts is summarized and used as the result of prediction. Brainstorming is the most obvious advantage of such a method, which is very important to improve the accuracy of prediction. The whole prediction process of Delphi method is scientific, reasonable, simple and easy to implement, which can realize the scientific decision-making as far as possible.

In this paper, we adopted the Delphi method for reference and consulted with relevant experts based on the representation of indicators in the production process of smart meters, where the specific steps are as follows:

(1) First round of investigation: Initial set of indicators

Organize N（$N\geq 20$） experts to consult, introduce the background and framework of the indicator system to experts, set up questionnaires according to structure of the indicator system, and let experts list specific indicators in their opinion that can best represent measurement, standardization, authentication & accreditation, detection & testing and quality management in the production process of smart meters. We collate and summarize the results of the first round investigation to determine the initial set of indicators $P=\{p_1, p_2, \ldots p_m\}$.

(2) Second round of investigation: Primary screening

Based on the initial set of indicators P, organize N（$N\geq 20$）experts to consult, and each expert, such as the k（$1\leq k\leq N$） expert, arbitrarily select t（$1\leq t\leq m$） indicators from the initial, which he thinks best represents the NQI capability of smart meter enterprises. Thus, the result selected by the expert k constitutes a subset of the initial set P $\mathrm{P}^{(k)}=\left\{p_1^{(k)},\ p_2^{(k)},\ldots p_t^{(k)}\right\}(k=1,2,\ldots N)$.

Define the function $y_i(p_i)=\begin{cases}1, p_i \in P^{(k)} \\ 0, p_i \notin P^{(k)}\end{cases}$, which represents whether the indicator p_i in the original set of indicators is selected by the k expert.

Thus, the representative coefficient of p_i in the original set of indicators can be expressed by $f(p_i)=\sum_{k=1}^{N} y_k(p_i)(i=1,2,...N)$.

Preliminary screening shall be done by comparing the values of $f(p_i)$. Smaller value of $f(p_i)$, indicates that the indicator is selected for fewer times. And this indicator has a lower level of representativeness, which shall be omitted.

Define a standard value ρ （$0\leq \rho \leq N/2$）, if $f(p_i)\geq \rho$, p_i shall be selected into the primarily-screened set as a primarily-screened indicator, if $f(p_i) < \rho$, p_i shall be selected into controversial set of indicators R as a controversial indicator.

(3) Third round of investigation: Re-screening

In order to make the indicator system more scientific and objective, the second round of investigation will be repeated for the indicator set under primary screening Q.

In order to gather the opinions of experts and reach to a unified view, this round of investigation will be repeated many times.

Taking a positive integer h_k（$1\leq h_k \leq m$）as the initial value, let each expert select the indicator according to the following steps:

Step 1: Select h_k indicators from Q which he thinks the most representative, and get the subset $Q_{1,k}=\{p_{1,k,1}, p_{1,k,1}, \dots p_{1,k,hk}\}$;

Step 2: Select $2h_k$ indicators from Q which he thinks the most representative, and get the subset $Q_{1,k}=\{p_{2,k,2}, p_{2,k,2}, \dots p_{2,k,2hk}\}$;

Step sk: Select $s_k h_k$ indicators from Q which he thinks the most representative, and get the subset $Qs_{k,k}=\{ps_{k,k,}s_k, fs_{k,k,}s_k, \dots p_{1,}k_{,}s_{khk}\}$.

If the natural number s_k satisfies $s_k h_k + r_k = m(0\leq r_k \leq h_k)$, then the k（$1\leq k\leq N$）expert ends the selection process from the indicator set under initial screening, and get s_k subsets.

The representative coefficient of the re-screening indicator is expressed by the function $f(p_i)=\sum_{k=1}^{N}\sum_{j=1}^{s_k} y_{jk}(p_i)(i=1,2,K,m)$,

in which $y_{jk}(p_i)=\begin{cases}1, p_i \in Q_{jk} \\ 0, p_i \notin Q_{jk}\end{cases}$ $(j=1,2,K,s_k; k=1,2,K,N)$.

Define a standard value ρ （$0\leq \rho \leq N/4$）, if $f(p_i)\geq \rho$, p_i shall be selected into the final set as a final indicator, if $f(p_i) < \rho$, p_i shall be selected into controversial set of indicators R as a controversial indicator.

(4) Fourth round of investigation: Indicator confirmation

For the controversial set R, expert opinions are solicited for further discussion and screening. Each expert is required to re-evaluate each indicator in R and repeat the steps of the third round until $f(p_i)$=0, then the indicator shall be deleted. The originally-selected indicators shall be included into the final set S, when the final NQI indicator system for smart meter enterprises can be obtained.

4. Composition of indicator system for NQI capability of smart meter enterprise

Through screening and expert demonstration, the NQI indicator system for smart meter enterprises can be obtained, which includes 5 first-level indicators, 8 second-level indicators and 30 third-level

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indicators, where the specific constitution is shown in Table 1.

The NQI capability indicators of smart meter enterprises are divided into three levels: The first is the basic level, i.e. the first-level indicator, which evaluates the five elements that constitute NQI, including capabilities on measurement, standardization, authentication & accreditation, detection & testing and quality management. The second level contains the second-level indicators, which evaluates the efficiency of each factor of the first level in the production process of smart meters, chooses the indicators from the comprehensive level, output benefit and other aspects of each capability, and takes into account the characteristics of smart meter manufacturers, regards the management capability of key quality control points in the production process as an important second-level indicator to reflect the efficiency of quality management capability enjoyed by the meter enterprise in the production process. The third level contains the basic indicators. According to each of the eight secondary indicators, through expert consultation and demonstration, this level chooses specific representative indicators to reflect the capability effect of each secondary indicator. There are 30 basic indicators in total.

Table 1. NQI Capability Indicator System of Smart Meter Enterprise.

First-level indicator	**No.**	**Second-level indicator**	**Basic indicator**
Measurement capability	1	Comprehensive measurement level	1. Quantity of measurement personnel
			2. Quantity of measurement certificates
			3. Types of measuring instruments
	2	Productive measurement level	4. The maximum standard number of measurement established in enterprise
			5. On-time achievement rate of traceability of standard measurement equipment
Standardization capability	3	Comprehensive standardization level	6. Number of participation in the formulation of national standards
			7. Number of participation in the formulation of industry standards
			8. Standardization disclosed by the enterprise
	4	Standardized output level	9. Proportion of output value of products meeting international standards
Authentication & accreditation capability	5	Technical level of authentication & accreditation	10. Number of laboratory certificates
			11. Number of skills certificates
			12. Number of management system certificates
Detection & testing capability	6	Technical level of detection & testing	13. Number of test reports
			14. Number of inspectors
Quality management capability	7	Comprehensive quality level	15. Number of quality-related awards (national, provincial, municipal and industrial)
			16. Number of patents obtained
			17. Ratio of annual R&D investment by the enterprise
			18. Number of training for quality improvement activities in the enterprise
			19. Number of annual improvement measures for quality and integrity
			20. Employee participation rate in promoting advanced quality management method activities in the enterprise

First-level indicator	No.	Second-level indicator	Basic indicator
	8	Management capability at the key quality control point	21. Scope of quality commitment 22. Effectiveness of quality commitment 23. Number of tests and projects in manufacturing process 24. Pass rate of material in the detection 25. Disposal cycle of substandard materials 26. Number of periodic verification for production equipment 27. Qualification rate of ex-factory product 28. Completion rate of delivery schedule 29. Qualification rate of ex-factory procedure 30. Qualification Rate of sample detection for ex-factory product

5. Research conclusions and Prospects

Based on the research and analysis of relevant literatures about smart-meter evaluation and NQI-capability evaluation at home and abroad, combined with the actual situation of smart meter enterprises in our country, profited from the Delphi method, and taking the representativeness of indicators as the starting point, this paper constructs a NQI capability indicator system for smart meter enterprise composed of 5 first-level indicators including capabilities on measurement, standardization, authentication & accreditation, detection & testing and quality management, 8 second-level indicators and 30 basic indicators. This indicator system has certain guiding significance for evaluating the basic capabilities of smart meter manufacturers on quality technology. It can assist smart meter enterprises to evaluate their basic capabilities on quality technology, and find out the shortcomings of their own quality development and the direction for improvement. Besides, it can be used as a technical indicator and evaluation scheme by the State Grid aiming at quality level of smart meter enterprises, so that the State Grid is able to supervise and guide the construction and development of smart meter enterprises.

This indicator system only provides the construction method in theory and the preliminary system based on this method, which does not involve the calculation and evaluation methods of specific indicators. Therefore, it is still necessary to conduct in-depth research on smart meter enterprises, continuously optimize and improve the indicator system of NQI capability, and further study the evaluation method under the indicator system, build the evaluation model of indicator system, carry out NQI capability evaluation of smart meter enterprises, so as to promote the quality improvement of smart meter enterprises.

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