ARCHIVES OF ELECTRICAL ENGINEERING VOL. 70(1), pp. 103–113 (2021)

DOI 10.24425/aee.2021.136055

Design and application of comprehensive evaluation index system of smart grid based on coordinated planning of major network and power distribution network

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(Received: 15.05.2020, revised: 14.09.2020)

Abstract: The comprehensive evaluation of the smart grid is of great significance to the development of the power grid. This study mainly analyzed the coordinated planning of major networks and power distribution networks of the grid. Firstly, the coordinated planning of major networks and power distribution networks was introduced, then a comprehensive evaluation index system was established based on six domains, i.e., economy, safety, reliability, coordination, environmental protection, and automation. The evaluation of the indexes was realized through the expert scoring method. Finally, taking the power grid planning of Boao Town, Qionghai City, Hainan Province, China, as an example, the current scheme and planning scheme were evaluated. The results showed that the planning scheme had better performance in aspects such as economy and reliability, and its score was 15.39% higher than the current scheme, which verifies the effectiveness of the planning scheme and its feasible application in practical projects.

Key words: coordinated planning, index system, major network, power distribution network, smart power grid

1. Introduction

With the development of economy, people's requirements for power are also increasing. The power grid can connect the power supply end and power consumption end, which is an indispensable part of people's life [1, 2]. Once the power fails, it will cause some social and economic consequences [3]. In order to realize the safe and reliable development of the power grid, it is necessary to plan the power grid and then evaluate the planning method scientifically, so as to realize the evaluation and optimization of the power grid [4]. In the current power grid planning, there are some problems such as waste of resources, low accuracy of load forecasting [5], and untimely problem solving; moreover, the relevant study focuses on separation, i.e., studying the planning of the main network and distribution network separately, and there are few studies on the coordinated planning of the main network and distribution network, let alone the evaluation. Power grid planning evaluation can provide a decision-making support for power grid planning. An *et al*. [6] studied the evaluation of substation, analyzed the attributes of the power transmission distribution factor (PTDF) using the analytic hierarchy process (AHP), and verified the effectiveness of the method through the case study of the South Korea power system. Taking the intelligent distribution network as the subject, Wei *et al*. [7] established the hierarchical evaluation index system, including the basic layer and the management layer, and defined the corresponding index for estimating the intelligent level of the distribution network, providing some references for its improvement and development. Based on the dynamic Bayesian network (DBN), Cai *et al*. [8] evaluated the intermittent fault grid connected photovoltaic system, analyzed the centralized, series and multi-series systems, and discussed which parameters had a great impact on the system to improve the reliability and availability of the system. Xue *et al*. [9] evaluated the grid-connected micro-grid to minimize the life cycle cost, defined the indexes such as redundancy, optimized them in the random scenario, and carried out the simulation on the actual data to verify the performance of the method. In this study, the coordinated planning of major networks and power distribution networks of the smart grid was evaluated, the corresponding index system was designed, and an example was analyzed, with the intention of providing some theoretical guidance for the power grid planning of Boao Town and improve the economy and rationality of the local power grid planning.

2. Coordinated planning of main network and distribution network

The smart grid refers to the grid with advanced technologies such as communication technology, intelligent technology and information technology [10, 11], high power supply quality, [12] and a high utilization rate [13], which is the main development trend of the modern power grid [14]. It has higher requirements on the security and flexibility of the power grid. Therefore, it has very important values to evaluate it correctly: 1) it is conducive to objectively reflect the development level of the power grid; 2) it is conducive to better evaluation of the development benefits of the power grid; 3) it is conducive to scientific guidance of the development direction of the power grid.

At present, in the power grid planning, the main network and distribution network are usually studied separately. To achieve the better operation of the main network and distribution network, it is necessary to realize a good coordinated planning between them, i.e., realize the plural complementarity between the power supply side and demand side to ensure the sufficient power and reasonable distribution of the distribution network. In the evaluation of the coordinated planning of the main network and distribution network, most of the current methods are to evaluate the basic quality of the power through some indicators, or to evaluate the technical level of the power, which is not comprehensive and strongly applicable and has a low guidance for the power grid planning work. On the basis of previous studies, this study selected six domains to evaluate the planning scheme, as follows:

1) economy [15]: extra expenditure shall be avoided during construction to prevent decision-making mistakes,
2) safety: stable load operation should be ensured to avoid sudden failure,
3) reliability [16]: the power supply of the main distribution network shall be stable to avoid the impact on the normal power consumption of users,
4) coordination: each part of the main distribution network shall be kept in a balanced state to prevent the local load from being too high,
5) environmental protection [17]: the power grid structure shall be optimized as much as possible in the planning to reduce pollutant emissions,
6) automation: it should have certain information and automation characteristics citeg18.

On the basis of the above six domains, this study designed a set of comprehensive evaluation index systems, which mainly includes two parts: index design and analysis, as shown in Fig. 1 and 2.

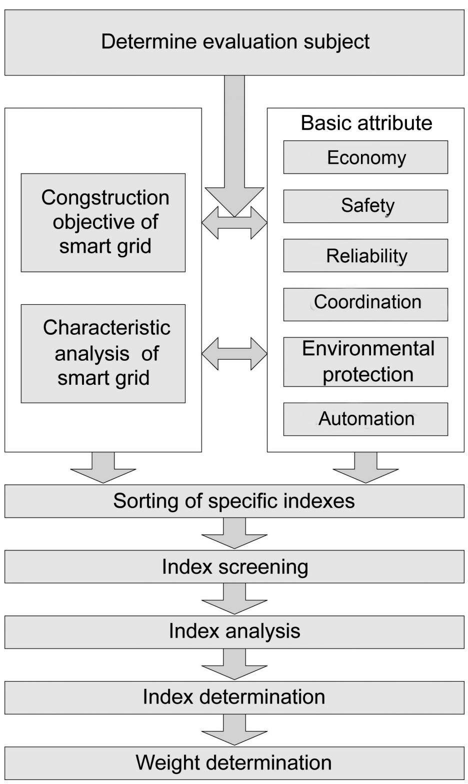

Fig. 1. Design of comprehensive evaluation index

In the index design part, after determining the evaluation subject (power grid), specific evaluation dimensions were selected from aspects of its construction objectives and characteristics; then for these dimensions, the specific evaluation indicators were further determined, and the selected

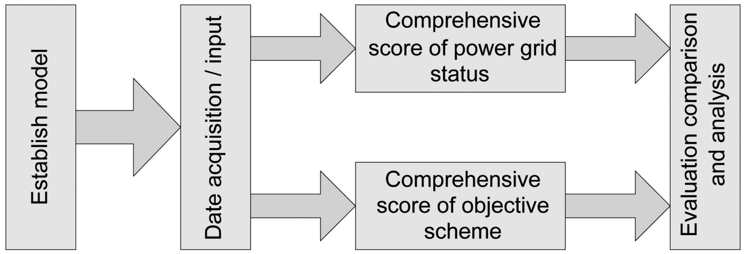

Fig. 2. The comprehensive evaluation index analysis

indicators were screened and analyzed; a comprehensive evaluation model was established, and the weight of the indicators was determined using some method.

In the index analysis part, after establishing the evaluation model, the relevant grid data were input into the model, and the current score was compared with the score obtained after planning, so as to determine the rationality of the planning scheme.

3. Comprehensive evaluation index system

3.1. Construction principle

In the selection of evaluation indexes, comprehensive indexes that can reflect the real situation of the power grid should be selected. Moreover, aspects such as the difficulty of collecting data, the size of the calculation amount, and the complexity of the power grid should be considered. The following principles should be followed:

1) systematic principle: to be able to reflect the overall performance and characteristics of the power grid,
2) consistency principle: keep consistent with the evaluation objectives,
3) principle of independence: to be able to reflect the grid situation from different perspectives, without overlapping,
4) testability principle: to be able to be quantified and have a clear meaning.

3.2. Index system

After the study of power grid economy, security, etc., this study established the index system which is shown in Fig. 3 based on the construction principle in section 3.1.

1. Economy Comprehensive line loss rate (%): it refers to the ratio of electric energy loss to the output electric energy of the first section. The larger the value is, the worse the economy is.

One-time investment (ten thousand yuan): it refers to the sum of equipment cost and construction cost.

2. Safety

The number of single component failure grid accident risks (n): it refers to the number of accidents caused by a component failure.

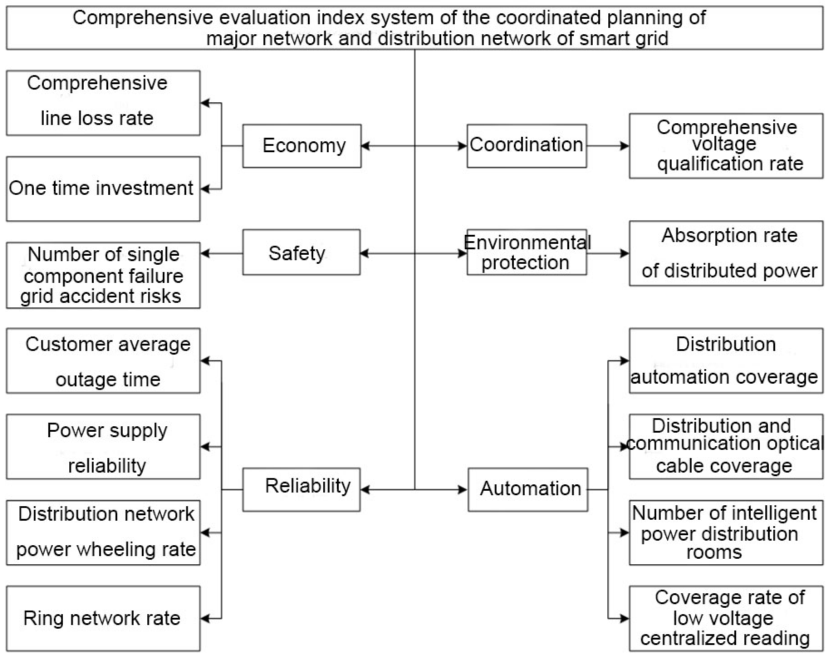

Fig. 3. The comprehensive evaluation index system

3. Reliability

Customer average outage time (min): it refers to the customer outage time caused by failure.

Power supply reliability rate (%): it refers to the ratio of effective power supply time to total time, which can reflect the power supply capacity of the power grid.

Distribution network power wheeling rate (%): it refers to the proportion that the load can be transferred to other lines when one line is out of service.

Ring network rate (%): it refers to the proportion of lines adopting a ring network structure.

4. Coordination

Comprehensive voltage qualification rate (%): it refers to the ratio of actual voltage qualification time to total operation time.

5. Environmental protection

Absorption rate of distributed power supply (%): it refers to the absorption capacity of the grid to the connected distributed power supply.

6. Automation

Distribution automation coverage (%): it refers to the coverage of distribution automation lines.

Distribution communication optical cable coverage (%): it refers to the distribution automation through optical fiber communication.

The number of intelligent power distribution rooms (n) [19]: be capable of real-time monitoring of power grid equipment.

The coverage rate of low-voltage centralized reading (%): it can remotely collect data of electricity meters to help users better master power consumption information.

3.3. Index weight design

The Delphi method [20], i.e., the expert scoring method, has a good application in many fields of evaluation. It firstly sets several indicators for the evaluation subject and then determines the weight and score by the experts from several related fields based on personal experience and knowledge. The specific steps are as follows:

(1) n experts are organized to estimate the weight of R_j ($j = 1, 2, \ldots, m$), and estimation values $w_{k1} w_{k2} \cdots w_{kr}$ ($k = 1, 2, \ldots, n$) are obtained.

(2) The average value of estimation values of the weight given by n experts is calculated:

$$\overline{W}_j = \frac{1}{n} \sum_{k=1}^{n} w_{kj} \quad (j = 1,\ 2, \ldots, m). \tag{1}$$

(3) The difference between the estimation value and average value is calculated:

$$\Delta_{kj} = \left| w_{kj} - \overline{w}_{kj} \right| . \tag{2}$$

(4) If the value of Δ_{kj} is relatively large, then it should be reestimated by the experts until the difference value satisfies the requirement. Finally, the weight of the index is $\overline{w}$.

4. Example

Taking Boao Town, Qionghai City, Hainan Province as an example, the major network and power distribution network planning scheme was comprehensively evaluated by the method proposed in this study. Firstly, weights of indexes were obtained through the expert scoring method. Twenty industry experts were involved in the scoring, and the average score was taken as the final result, as shown in Table 1.

Table 1. Weight of indexes

Index	Weight
Economy	0.18
Security	0.15
Reliability	0.15
Coordination	0.20
Environmental protection	0.15
Intelligence	0.17

The evaluation criterion for each indicator was specified by experts, as shown in Table 2.

Table 2. Scoring criteria

Index	Scoring criteria	
Comprehensive line loss rate (%)	> 6	0 point
	4.5 ≤ X < 6	60 points
	3 ≤ X < 4.5	80 points
	< 3	100 points
One-time investment (10 000 yuan)	> 15 000	0 point
	10 000 ≤ X < 15 000	60 points
	5 000 ≤ X < 10 000	80 points
	≦ 5 000	100 points
Number of single component failure grid accident risks (*n*)	> 0	0 point
	0	100 points
Customer average outage time (min)	> 52	0 point
	20 ≤ X < 52	60 points
	15 ≤ X < 20	70 points
	10 ≤ X < 15	80 points
	5 ≤ X < 10	90 points
	< 5	100 points
Power supply reliability (%)	≤ 99.863	0 point
	99.863 ≤ X < 99.965	60 points
	99.965 ≤ X < 99.990	70 points
	99.990 ≤ X < 99.999	80 points
	≥ 99.999	100 points
Distribution network power wheeling rate (%)	≤ 70	0 point
	70 ≤ X < 80	60 points
	80 ≤ X < 90	70 points
	90 ≤ *X* < 95	80 points
	> 95	100 points
Ring network rate (%)	≤ 90	0 point
	90 ≤ *X* < 95	80 points
	> 95	100 points
Comprehensive voltage qualification rate (%)	98.79 ≤ X < 99.95	60 points
	99.95 ≤ *X* < 99.97	70 points
	99.97 ≤ *X* < 99.99	80 points
	≥ 99.99	100 points

Table 2 – *Continued on next page*

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Index	**Scoring criteria**	
Absorption rate of distributed power (%)	< 100	0 point
	100	100 points
Distribution automation coverage (%)	≤ 80	0 point
	80 ≤ X < 90	60 points
	90 ≤ X < 95	80 points
	95 ≤ X ≤ 100	100 points
Distribution and communication optical cable coverage (%)	≤ 80	0 point
	80 ≤ X < 90	60 points
	90 ≤ X < 95	80 points
	95 ≤ X ≤ 100	100 points
Number of intelligent power distribution rooms (n)	≤ 1	0 point
	1 ≤ X < 3	60 points
	3 ≤ X < 6	70 points
	6 ≤ X < 9	80 points
	> 9	100 points
Coverage rate of low voltage centralized reading (%)	≤ 90	0 point
	90 ≤ X < 100	80 points
	100	100 points

Then, the indicators were scored according to the evaluation criteria given by the experts, and the score of the current grid method was compared with the planning scheme in the D-th year. The final results are shown in Table 3.

It was seen from Table 3 that the final scores of the two schemes were:

– the current scheme: 12.6 + 15.12 + 16 + 15 + 12.75 = 83.35 points,

– the planning scheme: 16.2 + 15 + 14.25 + 20 + 15 + 15.725 = 96.175 points.

It was found that the score of the planning scheme was significantly higher than that of the current scheme, which showed that the planning scheme was reasonable. Specifically, in terms of security and coordination, there was no difference between the two schemes. Then, in terms of economy, after planning, the comprehensive line loss rate of the power grid was lower. In terms of investment in power grid planning, the cost was less after planning; the economy scores of the power grid increased by 28.57% after planning; in terms of reliability, after planning, the customer average outage time reduced from 6 min to 5 min, and other indexes also improved, for example, the reliability score increased by 18.75%. From the perspective of coordination, after planning, the comprehensive voltage qualification rate of the power grid increased from 99.98% to 100%, and the score increased by 25%. From the perspective of automation, the automation and informatization degree of the power grid were effectively improved, more intelligent power distribution rooms were built, and the score improved by 23.33%. Finally, overall, the evaluation score of the planning scheme was 15.39% higher than that of the current scheme, which verified that the power grid planning scheme was scientific and could be applied in practice.

Table 3. Comparison between the current scheme and planning scheme

The first-level index	The second-level index	Current			The D-th year		
		Value	Score	Normalization	Value	Score	Normalization
Economy (0.18)	Comprehensive line loss rate (%)	$3 \leq X < 4.5$	80	**12.6**	< 3	100	**16.2**
	One time investment (ten thousand yuan)	12789	60		7312	80	
Safety (0.15)	Number of single component failure power grid accident risks (*n*)	0	100	**15**	0	100	**15**
Reliability (0.15)	Customer average outage time (min)	6	90	**12**	5	100	**14.25**
	Power supply reliability (%)	99.96	70		99.99	80	
	Distribution network power wheeling rate (%)	94	80		100	100	
	Ring network rate (%)	93	80		100	100	
Coordination (0.2)	Comprehensive voltage qualification rate (%)	99.98	80	**16**	100	100	**20**
Environmental protection (0.15)	Absorption rate of distributed power (%)	100	100	**15**	100	100	**15**
Automation (0.17)	Distribution automation coverage (%)	93	80	**12.75**	100	100	**15.725**
	Distribution and communication optical cable coverage (%)	92	80		100	100	
	Intelligent power distribution room (*n*)	2	60		5	70	
	Coverage rate of low voltage centralized reading (%)	95	80		100	100	

5. Conclusions

This study mainly analyzed the comprehensive evaluation of the coordinated planning of the major network and power distribution network of the smart grid. Six domains were selected, and then the corresponding indicators were designed. The power grid was evaluated through the expert scoring method, and the power grid of Boao Town, Qionghai City, Hainan Province, China, was taken as an example for analysis. The results showed that the evaluation score of the planning scheme was 15.39% higher than that of the current scheme, which showed that the planning scheme had high scientificity and rationality and could be applied in practical engineering.

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