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Research Article

Comprehensive Framework of Major Power Project Management Based on System Thinking

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Major power projects are normally critical nodes of the national power producing and transmission networks. However, the management of major power projects faces a variety of difficulties such as large scale, technical complexity, high quality standard, and frequent coordination. To improve the scientificity and effectiveness of the construction management of major power projects, a comprehensive framework of major power projects is established, which can be further decomposed into 8 subsystems and 28 indicators through system thinking. Then, by combining the G1 method with the cloud model, a new way of management performance evaluation of power projects is provided. Finally, taking the Kunliulong DC demonstration project as a case, the total performance evaluation result using the cloud model is between “excellent” and “great,” and more inclined to “excellent,” the performance of Schedule Control is close to the “outstanding” level, while the performance of Project Breakdown Structure is reaching the “good” level. The result shows that the established management evaluation system of major power engineering is relatively comprehensive, which can provide a reference for the realization of multiobjective and full-cycle overall management. Meanwhile, the exposed weak links in management, such as structural decomposition and environmental protection, should be highly valued and strictly controlled.

1. Introduction

The power grid is the critical infrastructure for energy supply, strengthening the power project management is of great importance to improve the quality of power grid construction and guarantee a reliable supply of electricity [1]. Power facilities contain generating plants, transformer substations, transmission towers, and lines, which are built across all provinces, cities, counties, and villages [2]. They are closely related to daily life and support social and economic development [3]. In recent years, many countries have generally increased power investment and put forward smart grid strategies in line with their actual situation [4]. In the background of the smart grid, the expansion of the power investment scale and the introduction of smart technologies have not only improved the operation status of the grid but also challenged the traditional management methods of power projects.

Major power projects are extremely important since they act as critical nodes of the national power producing and transmission networks. For example, the transmission project from Wudongde in Yunnan province to Guangdong/Guangxi province (abbreviated as Kunliulong Transmission Project) is the largest extreme high voltage direct current (DC) transmission project in the past decade and a critical part of the West to East transmission network as well as the high-efficiency power system of China [5]. And, another transmission project from Yunnan/Guizhou province to Guangdong province (abbreviated as Yun-Guizhou Connection Project) is the first ±500 kV three-terminal direct current transmission project of the world, and the primary power passageway from western China to Guangdong-Hong

Kong-Macao Greater Bay Area. However, these major power projects face a variety of difficulties along with their significance, such as large scale, high investment, long period, multiobjective, complex coordination, and frequently changing environment. It is an urgent research topic that how to build a systematic and efficient management framework for these major power projects, and then to build a safe, reliable, green, efficient, and intelligent power network. The composition of the systematic framework of power project management from the theoretical research aspect is discussed, including four dimensions and eight subsystems. Subsequently, a comprehensive evaluation system of major power projects is proposed, and the G1 method is used to determine the weights of 28 factors. Finally, the project management of the Kunliulong Project is empirically analyzed by using the cloud model and G1 method. At the same time, the weak aspect of this project is also revealed, which can provide a valuable reference for major power project management.

2. Literature Review

2.1. Overview of Power Project Management. The power project, including power transmission engineering, wind power engineering, etc., plays an important role in the development of the economy and our daily life [6]. It has some typical features, such as huge investment, tight schedule, high quality standards, advanced technologies, and complex environment. With the fast development of power project, its management is faced with great challenges and urgently need to establish a systematic and efficient management framework. Many studies have been performed on the management of power projects from different aspects. According to the type of research, they can be divided into the following categories:

(1) Objective management. Li et al. [7] carried out a comprehensive analysis of the carbon emissions during the entire life cycle of a wind power project according to the LCA theory, aiming at providing some references and recommendations for decision makers. A fuzzy canonical model was proposed for the cost overrun risk assessment of power plant projects [8].

(2) Process management. Zhao and Chang [9] established the main procedure model for the management of Chinese wind power projects, which can be divided into four segmental processes: project approval process, land application process, design process, and licensing and construction process.

(3) Coordinate management. Jami and Walsh [10] proposed a participatory model to construct a robust collaborative framework for a more effective decision-making process in the wind power project.

Generally, the previous research provided a good foundation for analyzing the power project management. Their research was just from a certain perspective, such as cost, safety, environment protection, coordination, etc., ignoring other factors would be hardly to get a comprehensive framework to promote power project management. In view of this aspect, She et al. [11] made some useful discussions and put forward a design method of project management system in nuclear power engineering, including construction project process management subsystem, organizational subsystem, responsibility center subsystem, cost management subsystem, and enterprise database subsystem. However, this research is only in the conception stage and lacks quantitative calculations and case support, which is an improvement of this study.

2.2. Overview of Performance Evaluation Methods. Power projects are dynamic and complex in nature, with the combined effects of human and a myriad of other factors, which greatly increases the difficulty of power project management. It is urgent to establish a set of performance evaluation systems, which can help optimize the construction process, control costs reasonably, and improve the allocation efficiency of electric power. Many scholars have made valuable explorations on the performance evaluation of power engineering projects. Purohit and Purohit [12] presented the technical and economic performance evaluation of grid-interactive solar photovoltaic (PV) projects implemented under the first phase of India's national solar mission. Akinyele [13] conducted an environmental analysis of a solar photovoltaic power generation (SPPG) plant model, proposed for small off-grid communities. The results showed that the effect of solar irradiation, lifetimes, performance ratios, and the battery lifespan have an influence on the SPPG plant's environmental performance. Sangi [14] evaluated the performance of solar chimney power plants in parts of Iran theoretically, developing a mathematical model based on energy balance to estimate the quantity of the produced electric energy. However, the above-given studies were more concerned with the evaluation of electric energy production of power engineering projects and rarely involved the management performance evaluation of the project construction process.

Various qualitative evaluation methods and models have been proposed for this purpose. A quantitative evaluation model was established using the Delphi method, Analytic Hierarchy Process (AHP), and fuzzy logic to compare the low-carbon and energy saving development levels of communities [15]; while Ngacho and Das [16] made an attempt to develop a multidimensional performance evaluation framework of construction projects incorporating all essential elements and collected the viewpoints of 175 respondents regarding to their perception on 35 performance related variables. On the other hand, Tohumcu and Karasakal [17] developed an approach based on analytic network process (ANP) and data envelopment analysis (DEA) to evaluate the performance of Research and Development projects. Some commonly used weight determination methods were involved in the above-given studies, such as AHP, Delphi, and DEA methods. Compared with these weight determination methods, the order relationship analysis method (G1 method) has the following significant advantages: (1) the calculation principle is clear and easy to generalize; (2) it is not necessary to construct a judgment matrix and conduct the consistency test; (3) when the number of schemes changes, the weight coefficient of schemes still has strong order preservation; (4) applications do not require a strong mathematical foundation [18].

The cloud model belongs to the category of uncertain artificial intelligence and is a branch of fuzzy mathematics. The traditional fuzzy comprehensive evaluation methods use membership functions to quantify fuzziness. The membership functions have been questioned because the use of exact function curves instead of fuzzy concepts has hindered the development of fuzzy theory. In contrast, the cloud model is developed based on the normal distribution and fuzzy mathematics and is an uncertainty model used to achieve the conversion between qualitative and quantitative, which is proposed by Li et al. [19]. Its main view is to use the cloud model to replace the fuzzy membership function for fuzzy comprehensive evaluation. The cloud model can model both randomness and fuzziness with fixed parameters and has been widely applied to solve many scientific problems, including multicriteria group decision-making [20], safety performance evaluation of prefabricated building projects [21], and comprehensive evaluation of smart distribution grid [22]. Therefore, on the above-given basis, this study introduces cloud model theory into the management performance evaluation of power projects and sets up a comprehensive and systematic performance evaluation system. By combining the G1 method with the cloud model, a new way of management performance evaluation of power project is provided.

3. Methodology

To improve the management level of major power projects, this study achieves the research objectives through three phases. In the first phase, the systematic framework of major power project management is built based on system thinking [23]. The contributing indicators of the comprehensive evaluation index system of major power projects are systematically identified through a literature review, expert interviews, relevant laws, and regulations. These indicators are the research basis for the next phase. In the second phase, the weights of indicators are determined reflecting the relative importance of different indicators by using the G1 method [24]. Then, the cloud Model method is adopted to evaluate the general performance of power project management by a special seven-member expert team. In the final phase, to verify the practicability of the established systematic framework and comprehensive evaluation index system, a major power project is selected to conduct a case study [25]. The experiences about objective control, organization, and coordination are summarized; at the same time, the weak aspects of this project are also revealed to provide a valuable reference for similar power project management.

Thus, the qualitative research in the first phase helps to establish the systematic framework of major power project management. The quantitative research in the second phase is used to determine the weights of indicators and evaluate the performance of power project management. The combination of qualitative and quantitative analysis contributes to obtaining different but complementary results to form systematic thinking and understanding [26]. The research process and methods are shown in Figure 1.

4. Systematic Framework

4.1. Characteristics of Major Power Project Management. Traditional project management framework concentrates on four stages (decision, design, construction, and maintenance), five objectives (quality, safety, schedule, cost, and environment protection), and five fundamental elements (man, machine, material, method, and environment) [27]. However, the major power project has a variety of complexities about the construction quantities, technologies, and environment and faces greater challenges.

(1) Large quantity and very tight schedule. For example, Kunliulong Transmission Project has a general investment amount of USD 3.8123 billion and a long transmission path of 1,452 km. It contains eight soft straight transmission stations and their roofs are steel grid structure, the total area of which are 52 thousand $m^{2,}$ and ranks as the biggest among power transmission stations all over the world. Especially, the North-Kunming convertor station has a huge earth-fill quantity of 2.20 million m^3, which also ranks as the biggest among convertor stations all over China. The transmission path located in high mountains more than 50%, overlaps 2,691 times, while the total time limit is only one year and eight months which is hard to meet.

(2) Advanced technologies and difficult development. Kunliulong Transmission Project has a voltage level of ±800 kV and a transmission volume of 8000 MW. Yunnan-Guizhou Connection Project has a voltage level of ±500 kV and a transmission volume of 3000 MW. Both projects have advanced technologies, such as extreme high voltage, multiterminal, large volume, mixed transmission structure, and so on. Accordingly, lean construction/installation methods and corresponding intelligent equipment need to be developed.

(3) High quality and stability standard. If a large power transmission project encounters with a both-pole lock emergency, a serious unbalanced power rate between the sending and receiving terminals may reach 8000 MW at most. Therefore, the stability control system must meet the requirement of 8000 MW volume in the sending terminal and 2300 MW volume in the receiving terminal. It means a very high standard for the quality and stability of construction, equipment installation and system debug.

(4) Complex environment and difficult coordination work. The long-distance power transmission project crosses some areas which are abundant of mineral

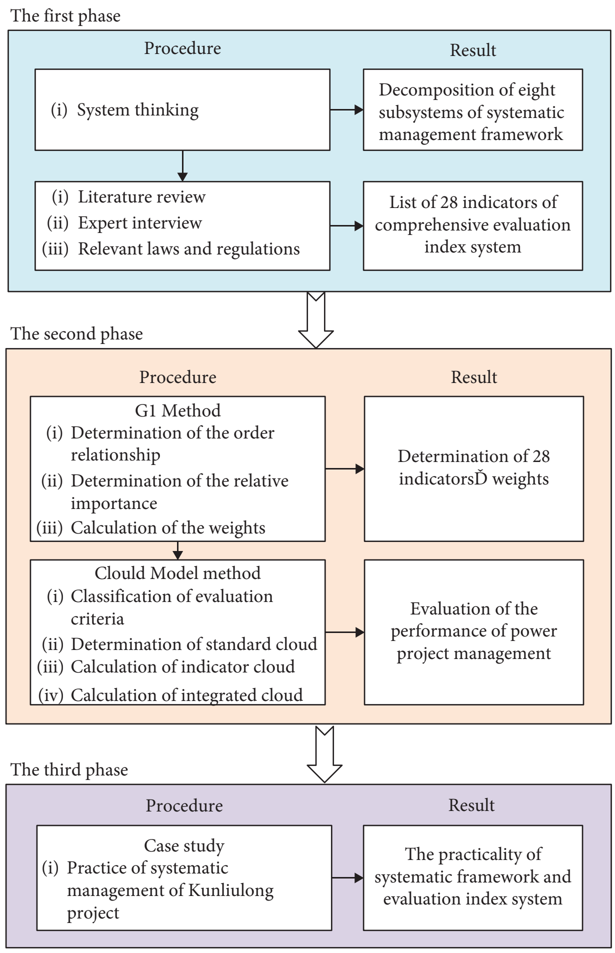


Figure 1: The research process and methods.

resources and has a well-developed economy. Land acquisition, existed building removal, and compensation are always difficult to handle. More, this project encountered with the COVID-19 disaster, which brought great disturbances and severe pressure for schedule control, worker allocation, material supply, transportation, and other aspects of the project management.

4.2. Systematic Framework of Major Power Project Management. The complexities about the quantity, organization, technology, and environment decide that more scientific and comprehensive principles and methods need to be introduced into major power project management. System thinking is a structural and dynamic thinking method that focuses on system structure, system behavior, and multiple connections among system elements forming a purposeful whole [28]. System thinking can be useful in describing the various components and factors, analyzing their correlations, and establishing the framework of integrated management. Specifically, the management of major power projects can be considered as a system and divided into four dimensions and eight subsystems. The four dimensions are construction entity, objective management, organization, and technical support, while the eight subsystems are project breakdown structure, quality management, safety management, schedule management, cost management, environment protection, organization/coordination, and technical innovation. Each subsystem contains institutions, methods, and elements of project management, as shown in Figure 2.

5. Systematic Evaluation Model

5.1. Establishment of Evaluation Index System. During the design, construction, and maintenance stages of major power projects, a tracking evaluation and feedback mechanism needs to be established, so as to accomplish the virtuous cycle and continuous improvement of project management. According to the framework of four dimensions and eight subsystems, and based on the objective requirements of the China Southern Power Grid Company, a comprehensive evaluation index system for the systematic management of major power projects is proposed, as shown in Table 1. It should be noted that the indicators in the comprehensive evaluation index system are independent of each other, which can be adjusted appropriately according to different projects.

(1) Project breakdown structure contains two aspects. EBS (engineering breakdown structure) means a power engineering project can be decomposed into a foundation, main structure, transmission lines, towers, electric equipment, and other parts according to functions and specialties. While WBS (work breakdown structure) means a power engineering project can be decomposed into site survey, design, bidding, procurement, construction, delivery, and other stages according to management tasks [29].

(2) The basic five objectives of a power engineering project involve quality, safety, schedule, cost, and environment protection, and they should be accomplished through several paths: establishing a management system, implementing a management institution, improving management methods, and enhancing management performance. A circle of PDCA (plan, do, check, and action) should be built for each objective. Furthermore, five objectives need to be achieved in a balanced status and none can be neglected so that a final result of multiobjective integrated optimization can be realized [30].

(3) Organization and coordination contain four aspects. Firstly, OBS (organization breakdown structure) means a reasonable organization structure should be set for each power engineering project. Secondly, major participants need to fully perform their management duties about quality, safety, schedule, and others. Thirdly, the coordination mechanism means major participants communicate and cooperate well obeying the partnering principle [31]. Fourthly, political mechanism means strong leadership and culture can play important roles for

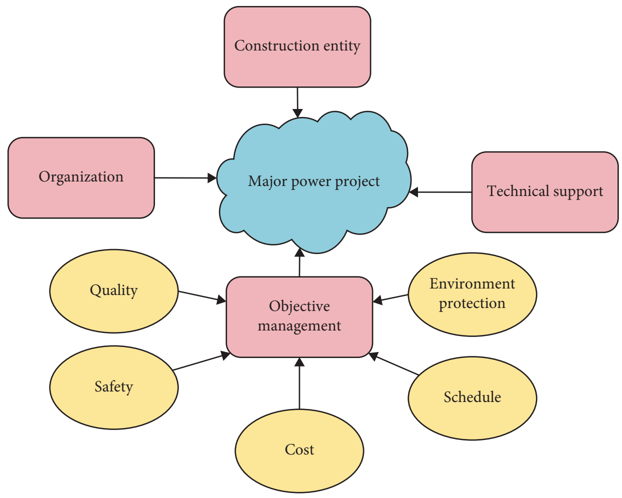


FIGURE 2: Systematic framework of major power project management.

project management, especially when facing the severe pressure of fighting against the COVID-19 disease.

(4) Advance technologies and innovation are essential for the design and construction of power projects. The four types of new technologies (new methods, mew equipment, new materials, and new procedures) can greatly improve work efficiency and ensure quality, safety, etc. The intelligent technologies such as information portal, video monitoring, and worker database can greatly promote the on-site construction management. Besides that, advanced information technologies such as cloud computing [32], big data [33], and Internet of things [34] are also used in power projects.

5.2. Determination of Indicator Weights Based on G1 Method. After completing the evaluation index system, the weight of each index needs to be determined. There are a large number of indicators, and the relationships among them are complex and difficult to describe. In this case, the subjective weighting method is more appropriate. The most commonly used subjective weighting method is the AHP method, but it is likely to face the problem of unsatisfying the consistency requirements of the judgment matrix. To solve this problem, Guo [35] proposed the G1 method, which avoided its shortcomings by adapting the AHP method. The relative importance of each index was calculated through the comparison between two indexes, and the calculation results of the G1 method were in good consistence. The specific steps are as follows.

Step 1. Determination of the order relationship of the eight subsystems and various indicators. The indicators are represented as $X=\{x_1, x_2, \ldots, x_n\}$, where n means the number of indicators. The most important index in X is determined by the expert group and is marked as x_1'. Next, the most important factor among the rest ones is selected and marked as x_2'. The above-given steps are repeated until only one indicator left, which is marked as x_n'. The importance order of all indicators has been obtained so far, which is denoted as $X' = \{x_1', x_2', \ldots, x_n'\}$.

Step 2. Determination of the relative importance between x_{k-1}' and x_k'. The relative importance of adjacent indicators is obtained through expert discussion in accordance with the criteria of Table 2. It can be represented according to the following equation:

$$\mathrm{r}_k = \frac{w_{k-1}}{w_k}, k = 2, 3, \ldots, n, \tag{1}$$

where w_{k-1} and w_k represent the weights of indicators x_{k-1}' and x_k', respectively.

To ensure the accuracy of the evaluation work and reduce the subjective impact of the G1 method, the importance ranking and scoring of various indicators in this evaluation are completed by external experts. These experts who have been engaged in power project management for a long time are all from China Southern Power Grid Energy Development Research Institute, and their specific information is shown in Table 3.

Step 3. Calculation of the weights of the eight subsystems and various indicators. After all values of r_k $(k = 2, 3, \ldots, n)$ are provided by the expert group, the weight of indicator k is calculated by using the following equation:

$$\omega_k = \left(1 + \sum_{k=2}^{n} \prod_{i=k}^{n} r_i\right)^{-1} \quad (k = 2, 3, \ldots, n). \tag{2}$$

Based on the calculation result of the weight of indicator k, the weights of the other indicators can be obtained by using the following equation:

$$\omega_{k-1} = r_k \omega_k \ (k = 2, 3, \ldots, n). \tag{3}$$

Step 4. Calculation of the comprehensive weights of the indicators in each subsystem. The comprehensive weights can be calculated by using the following equation, as shown in Table 1:

$$W' = W_a^T \times W_b, \tag{4}$$

where W_a and W_b represent the subsystem weight vector and the corresponding indicator weight vector, respectively.

6. Case Study

6.1. Establishment of Evaluation Index System. Kunliulong Transmission Project is the first ±800 kV UHV multiterminal hybrid power transmission "highway" all over the world during its construction period. It crosses four provinces (Yunnan, Guizhou, Guangxi, and Guangdong), 15 cities or states, and 38 counties. When the project enters its production stage, it is expected to have the capability of transmitting 33 million kWh of electricity annually. Moreover, the electricity transmitted is renewable energy,

Table 1: Comprehensive evaluation indicators and weights of major power project management.

Dimension	Layer	Weight of layer	Indicator	Weight of indicator	Integrated weight
Construction entity	Project breakdown structure (*A*)	0.0728	EBS (a_1)	0.5000	0.0364
			WBS (a_2)	0.5000	0.0364
Objective management	Quality management (*B*)	0.1510	Quality management system (b_1)	0.3956	0.0597
			Physical quality (b_2)	0.2747	0.0415
			Quality behavior (b_3)	0.3297	0.0498
	Safety management (*C*)	0.1510	Safety management system (c_1)	0.2683	0.0405
			Risk control (c_2)	0.1863	0.0281
			Hazard elimination (c_3)	0.2235	0.0338
			Accidents, injuries and deaths (c_4)	0.3219	0.0486
	Schedule management (*D*)	0.1258	Schedule management system (d_1)	0.2479	0.0312
			Milestone control (d_2)	0.2479	0.0312
			Acceleration measurements (d_3)	0.2066	0.0260
			Construction delay (d_4)	0.2975	0.0374
	Cost management (*E*)	0.1049	Cost management system (e_1)	0.2586	0.0271
			Payment control (e_2)	0.2155	0.0226
			Cost saving measurements (e_3)	0.2155	0.0226
			Cost overrun (e_4)	0.3103	0.0325
	Environment protection (*F*)	0.0874	Environment protection system (f_1)	0.3956	0.0346
			On-site environment protection (f_2)	0.3297	0.0288
			Green construction (f_3)	0.2747	0.0240
Organization	Organization and coordination (*G*)	0.1812	OBS (g_1)	0.2835	0.0514
			Responsibility mechanism (g_2)	0.2362	0.0428
			Coordination mechanism (g_3)	0.1969	0.0357
			Political mechanism (g_4)	0.2835	0.0514
Technical support	Technical support (*H*)		New technology utilization (h_1)	0.2546	0.0320
			Intelligent construction site (h_2)	0.2122	0.0267
			Information technology (h_3)	0.1768	0.0222
			Innovation and promotion (h_4)	0.3564	0.0449

Table 2: The values of r_k.

Value of r_k	Description
1.0	x'_{k-1} is as important as x'_k
1.2	x'_{k-1} is slightly more important than x'_k
1.4	x'_{k-1} is more important than x'_k
1.6	x'_{k-1} is much more important than x'_k
1.8	x'_{k-1} is extremely more important than x'_k

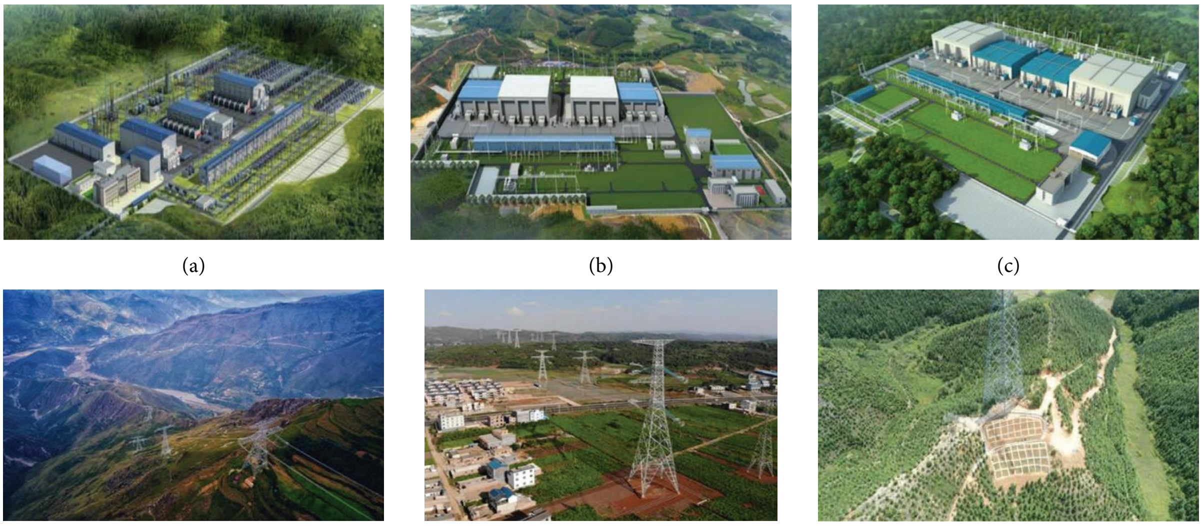
Table 3: Basic information of the experts.

Item	Working years (n)		Education		Job title	
Sub-item 1	$n \geq 20$	1	Graduate	2	Senior	1
Sub-item 2	$15 \leq n < 20$	1	Undergraduate	3	Deputy senior	2
Sub-item 3	$10 \leq n < 15$	2	College	1	Intermediate	3
Sub-item 4	$5 \leq n < 10$	3	Other	1	Other	1

which is equivalent to reducing 9.5 million tons of coal consumption and 25 million tons of carbon dioxide annually. This project may effectively promote energy conservation, emission reduction, and air pollution prevention, and it is a strong driving force for South China to develop a green economy. Some different sceneries of this project are shown in Figure 3

(1) Project breakdown structure. Besides EBS and WBS, Kunliulong Transmission Project adopted a milestone control technique. A total of 30 milestones were set, such as procurement of main electricity equipment, land acquisition, North Kunming station construction, North Liuzhou station construction, Longmen station construction, etc. These milestones provided a basis for lean control of quality, schedule, and other objectives.

(2) Objective control. Kunliulong Transmission Project has accumulated abundant of experience in the field of quality, safety, schedule, cost management, and environment protection. These experiences cover normal aspects of project management such as institution, process optimization, and risk control and gain outstanding performance. For example, the pass percentage of random inspection for critical construction procedures reached 99.63%, the construction cost saving reached 2.16% of the total construction budget, and the whole project was



(a) (b) (c) (d) (e) (f)

Figure 3: The Kunliulong DC project construction site. (a) Scene of north-Kunming convertor station. (b) Scene of Liuzhou convertor station. (c) Scene of Longmen convertor station. (d) Landform along DC line. (e) Design of route in crowded area. (f) Hidden danger management of tower foundation slope.

completed a half year earlier. The major experiences and performance of objective control are shown in Figure 4.

(3) Organization and coordination. A special project organization structure about project department plus subdepartment was set by the owner in the Kunliulong Transmission Project, which covered the management duties of coordination, technical, cost estimation, culture, and other affairs, as shown in Figure 5. Besides, strong leadership promoted the progress of projects. Almost 30 temporary leader teams and 107 special service teams were set to resolve certain technical or management problems and insistently pushed the project ahead, especially when facing difficult situations such as rainstorm, remote area, and COVID-19 disease.

(4) Technical support. Advanced information technologies were fully adopted in the Kunliulong Transmission Project, such as GIS (geological information system), BIM (building information technology), and IOT (Internet of things). An integrated intelligent platform was built, which has various functions: dynamically restoring design parameters, schedule plans, drawings, photos, and other documents; remotely connecting the on-site face recognition, video monitoring, environment testing, and other equipment and executing real-time, visualized, and mobile construction site management. After that, great innovations were accomplished, including resolving more than 140 technical problems, compiling 51 technical standards and obtained 103 important patents. All major equipment were produced in China, and a total of 19 ranked first all over the world, such as the longest distance (1,452 km), the highest transmission volume (8000 MW), and the biggest single-station volume (5000 MW).

6.2. Performance Evaluation of Kunliulong Transmission Project Based on Cloud Model. In March 2021, a seven-member expert group was set up by China Southern Power Grid Energy Development and Research Institute and inspected the details of Kunliulong project management. The main inspection indicators covered eight aspects, namely, project breakdown structure, quality management, safety management, schedule management, cost management, environment protection, organization/coordination, and technical support. The inspection methods included observing the management system, checking the construction records and documents, interviewing project participants and departments, inspecting construction sites, inquiring about the project teams, and on-site measuring. And, the calculation method is Cloud Model.

6.2.1. Evaluation Method. The cloud model is an uncertainty conversion model, which can achieve the conversion between qualitative and quantitative. Cloud digital characteristics and cloud generators are two central theories of the model.

(1) Cloud Digital Characteristics. A cloud is composed of many cloud droplets, and a cloud droplet is a specific realization of the qualitative value in number. The abscissa value represents the quantitative value corresponding to a qualitative concept, and the ordinate value expresses the membership degree of the quantitative value on behalf of the qualitative concepts, as shown in Figure 6. Expectation (E_x) is the most representative and typical sample of the qualitative concept, reflected by the center value of the corresponded qualitative concept. Entropy (E_n) represents the measure to the fuzzy degree of the qualitative concept, the size of which directly determines the margin of qualitative value. While Hyper entropy (H_e) expresses the uncertainty measurement of entropy, the size of which indirectly reflects the cloud's thickness.

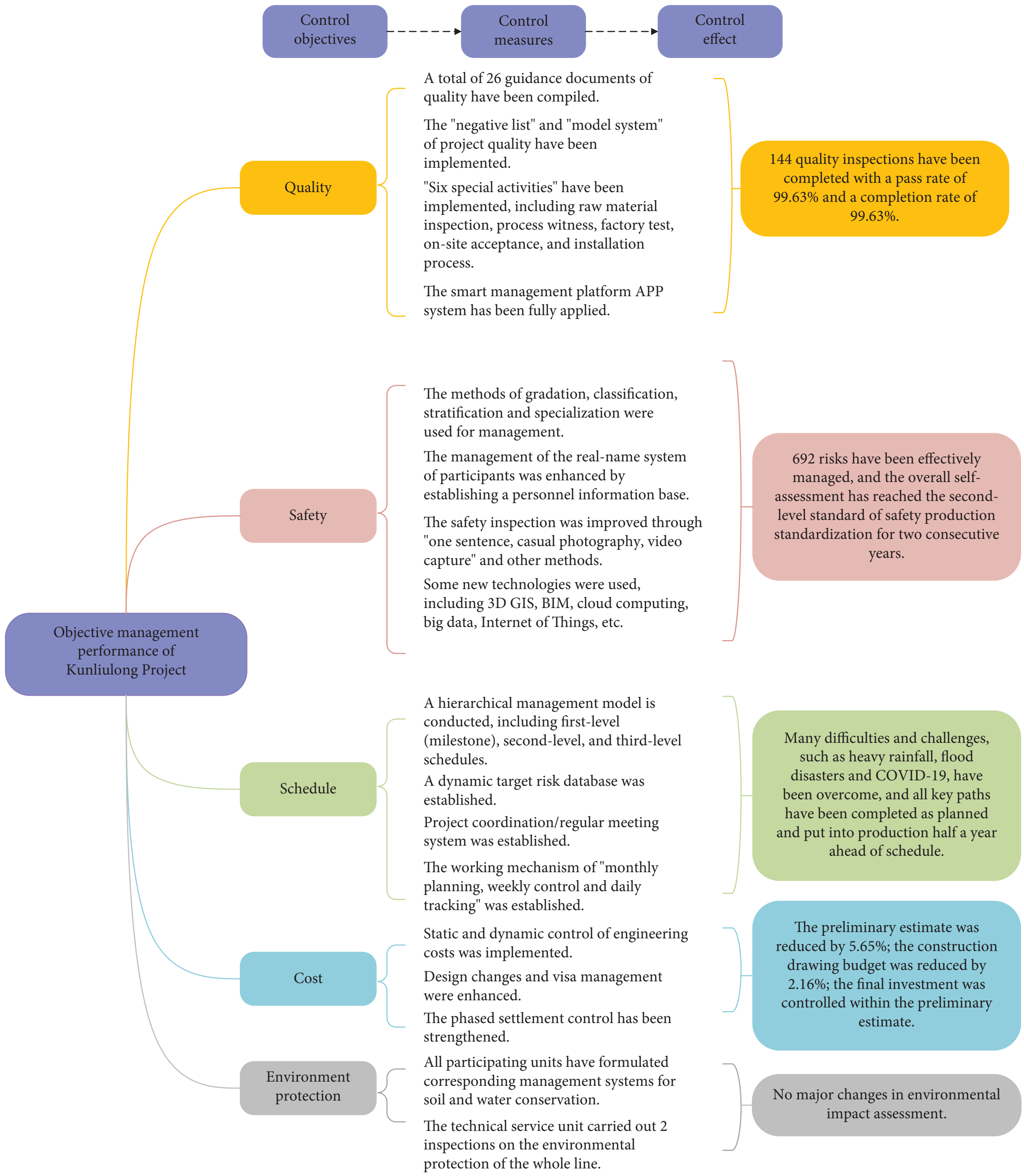


Figure 4: Objective management performance of Kunliulong transmission project.

(2) Cloud Generators. The forward cloud generator and reverse cloud generator are the two main types of cloud generators, as shown in Figure 7. The forward cloud generator generates cloud droplets that meet the requirements from the digital eigenvalues of the cloud, so as to realize the conversion from qualitative concepts to quantitative values. On the contrary, after the specific sample cloud droplet value of the reverse cloud generator is processed, a qualitative concept represented by the sample eigenvalues is obtained.

6.2.2. Evaluation Process. First of all, it is necessary to determine the characteristic values of the standard cloud and integrated cloud. And, then the result and grade of the evaluation are determined by comparing standard cloud and integrated cloud, and the specific steps are as follows:

(1) Classification of evaluation criteria. The system management performance evaluation of major power projects is incentive-oriented. Therefore, the score range of each index is set as [60, 100], and

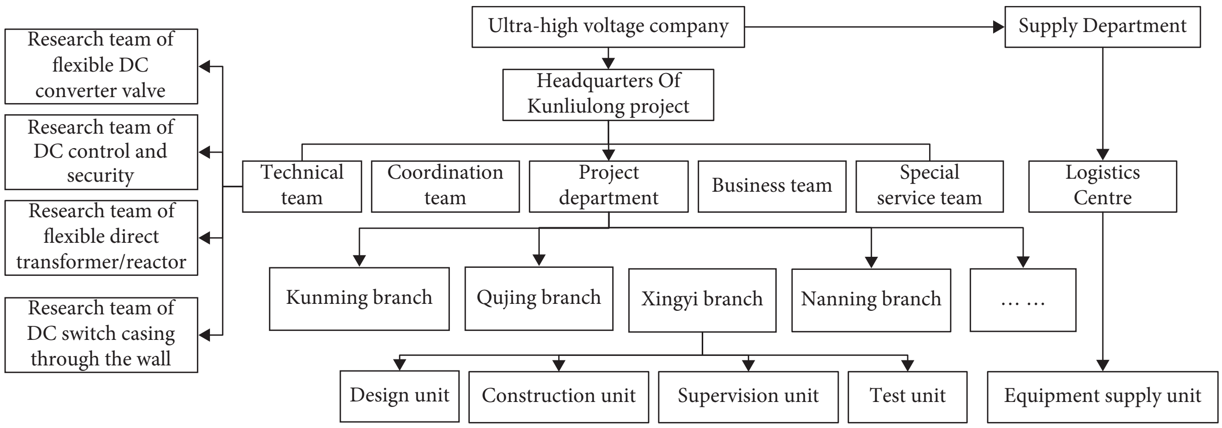


FIGURE 5: Organizational structure of project department plus subdepartment in Kunliulong transmission project.

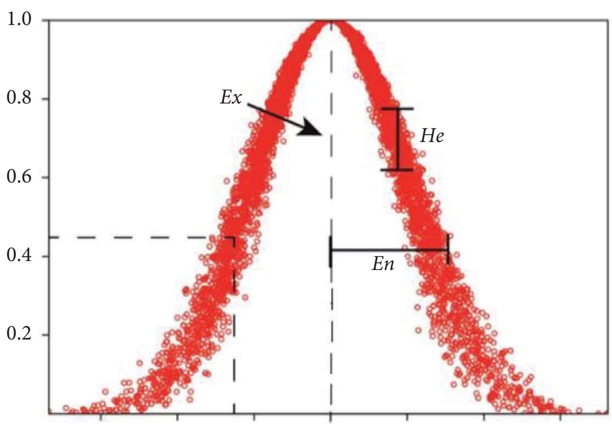


FIGURE 6: Eigenvalue meanings in cloud model.

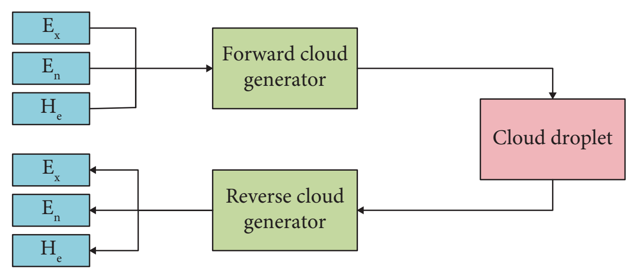


FIGURE 7: Cloud generators in cloud models.

further divided into 5 different grades. The classification of evaluation criteria for each grade are shown in Table 4.

(2) Determination of standard cloud. The rating levels are set as "outstanding," "excellent," "great," "good" and "Qualified," and each rating interval is denoted as $[A_{\min}, A_{\max}]$, where $A_{\min}$ and $A_{\max}$ are the minimum and maximum values corresponding to a certain evaluation level. The standard cloud eigenvalues of the five levels are calculated by using the following equation, as shown in Table 4:

$$\begin{cases} E_x = \dfrac{1}{2} \times (A_{\min} + A_{\max}), \\ E_n = \dfrac{1}{6} \times (A_{\max} - A_{\min}), \\ H_e = b. \end{cases} \quad (5)$$

B is a constant, it can be adjusted specifically according to project characteristics.

(3) Calculation of indicator cloud. The 28 indicators were scored and evaluated by 7 experts according to the daily management of the Kunliulong Project. In order to explain the expert's scoring process in detail, taking the indicator of risk control (c_2) as an example, experts generally consider whether project participants implement hierarchical management and control of risks according to the consequences of safety risks and the possibility of safety risks; whether relevant risk control measures are formulated according to the results of hazard identification and risk assessment; whether each responsible unit has completed rectification and review as required. The scoring results of the experts are denoted as $Z_{pq} = (p) = 1, 2, \ldots, 7$, representing the seven experts, and $q = 1, 2, \ldots, 28$, representing the 28 indicators). The cloud eigenvalues of indicators can be calculated by using equations (6) to (9), so as to realize the transformation from quantitative to the qualitative expression of the scoring results, as shown in Table 5.

TABLE 4: The performance evaluation grade and standard cloud eigenvalues of major power projects.

Rating interval	Performance level	Standard cloud eigenvalues
[95, 100]	Outstanding	(97.5000, 0.8333, 0.50)
[90, 95)	Excellent	(92.5000, 0.8333, 0.50)
[80, 90)	Great	(85.0000, 1.6667, 0.50)
[70, 80)	Good	(75.0000, 1.6667, 0.50)
[60, 70)	Qualified	(65.0000, 1.6667, 0.50)

Table 5: The indicator scoring results and cloud eigenvalues of the Kunliulong project.

Indicator	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Cloud eigenvalues of indicators		
								E_x	E_n	H_e
a_1	75	73	77	79	75	75	74	75.4286	1.8416	0.7489
a_2	82	82	84	85	82	80	81	82.2857	1.5858	0.6244
b_1	97	96	98	97	98	97	95	96.8571	0.9720	0.4451
b_2	88	89	88	87	88	88	85	87.5714	1.1254	0.5937
b_3	85	83	82	86	85	85	85	84.4286	1.3812	0.2113
c_1	93	93	91	92	90	93	92	92.0000	1.0743	0.4234
c_2	88	87	86	88	89	88	87	87.5714	0.9720	0.0876
c_3	89	89	88	87	86	90	88	88.1429	1.2789	0.4171
c_4	92	93	94	93	92	90	92	92.2857	1.1254	0.5521
d_1	90	89	90	90	89	88	87	89.0000	1.0743	0.4234
d_2	96	95	94	96	94	95	95	95.0000	0.7162	0.3921
d_3	95	93	93	95	97	95	94	94.5714	1.3300	0.4282
d_4	98	99	97	98	97	99	98	98.0000	0.7162	0.3921
e_1	88	86	88	89	89	89	90	88.4286	1.1766	0.4845
e_2	85	83	85	85	87	87	85	85.2857	1.2277	0.6304
e_3	85	84	87	84	85	83	84	84.5714	1.1766	0.4845
e_4	85	83	81	83	84	85	86	83.8571	1.6370	0.3603
f_1	85	83	83	85	87	85	86	84.8571	1.3300	0.6114
f_2	80	80	78	80	82	82	80	80.2857	1.2277	0.6304
f_3	83	82	81	83	82	86	84	83.0000	1.4324	0.7842
g_1	92	90	92	91	93	91	92	91.5714	0.9720	0.0876
g_2	86	85	85	83	83	86	85	84.7143	1.2277	0.2532
g_3	88	87	88	89	83	86	85	86.5714	2.0462	0.3141
g_4	98	96	95	96	95	98	96	96.2857	1.2277	0.2532
h_1	82	81	82	84	80	83	79	81.5714	1.6881	0.3203
h_2	80	79	81	83	81	80	82	80.8571	1.2789	0.4171
h_3	88	86	87	88	89	89	88	87.8571	0.9720	0.4451
h_4	98	96	98	97	96	97	97	97.0000	0.7162	0.3921

$$E_{Xn} = \frac{1}{m}\sum_{p=1}^{m} z_{pq}, \tag{6}$$

$$E_{Nn}\sqrt{\frac{\pi}{2}}\ \frac{1}{m}\sum_{p=1}^{m} \left|z_{pq} - E_{Xn}\right|, \tag{7}$$

$$H_{En}\sqrt{\left|S_n^2 - E_{Nn}^2\right|}, \tag{8}$$

$$S_n^2 \frac{1}{m-1}\sum_{p=1}^{m}\left(z_{pq} - E_{Xn}\right)^2. \tag{9}$$

(4) Calculation of integrated cloud. According to the indicator weights and eigenvalues of the indicator clouds, the eigenvalues of the integrated cloud ($C_U = (E_X, E_N, H_E)$) can be obtained by using equation (7). Then, the integrated cloud map can be generated by using the one-dimensional reverse normal cloud generator model.

$$\begin{cases} Ex = \sum_{n=1}^{28}\left(E_{Xn} \times \omega_n\right), \\ E_N = \sqrt{\sum_{n=1}^{28}\left(E_{Nn}^2 \times \omega_n\right)}, \\ H_E = \sum_{n=1}^{28}\left(H_{En} \times \omega_n\right), \end{cases} \tag{10}$$

6.2.3. Evaluation Result. The integrated cloud eigenvalues of the Kunliulong project were calculated as $C_U = (88.5340, 1.2606, 0.4202)$ by using the indicator weights and eigenvalues of the indicator clouds. When the number of cloud droplets is $N = 3000$, the integrated cloud map is shown in Figure 8. From the simulation results, the performance evaluation integrated cloud map of the Kunliulong project is between “excellent” and “great” and more inclined to

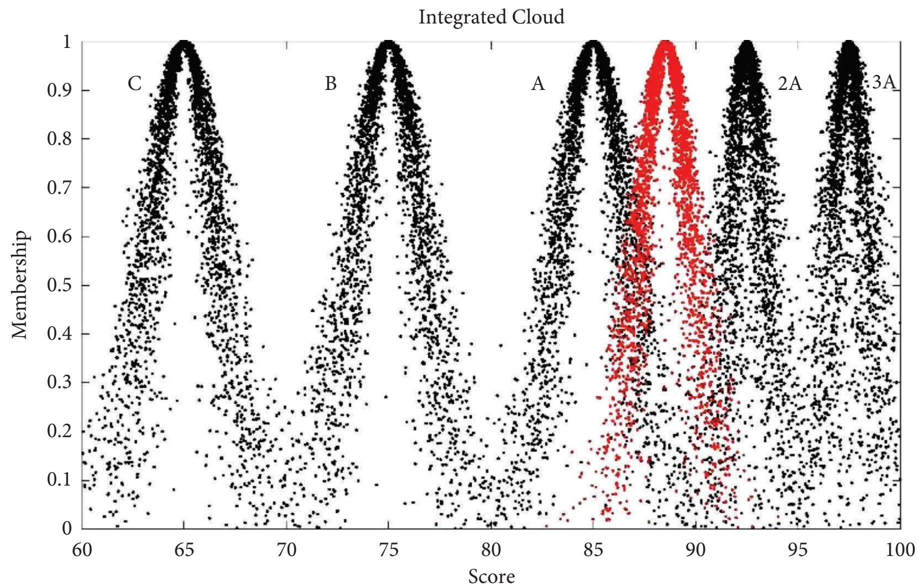


Figure 8: The performance evaluation integrated cloud map of Kunliulong project.

"excellent." It shows that the overall management level is relatively high, and there is a large room for improvement.

In order to understand the performance of the Kunliulong project more intuitively, the evaluation results of the eight subsystems are displayed using a radar chart, as shown in Figure 9. Obviously, there are differences in the management level of the Kunliulong project among different subsystems. Among them, the comprehensive score of the Schedule management subsystem is 94.32, which is close to the "outstanding" level. Followed by the three subsystems of Quality management, Safety management, and Organization and coordination, the comprehensive score of each item is greater than 90, reaching the "excellent" level. The comprehensive score of the three subsystems of Cost management, Environmental protection management, and Technical support is between 80 and 90, which is at the "great" level. The Project breakdown structure subsystem has the lowest score, with a comprehensive score of 78.86, identified as the "good" level.

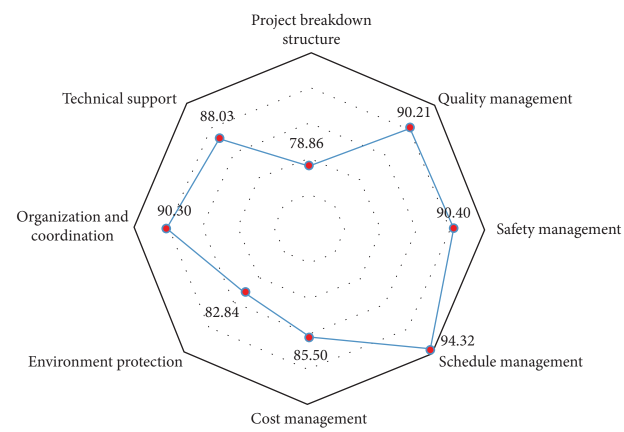


Figure 9: System management performance evaluation results of Kunliulong project.

For the Project breakdown structure subsystem, due to the lack of clear understanding of EBS and WBS by project managers, the subitems and work obtained by the decomposition are not enough to guide the actual construction. Power engineering construction is a systematic process involving many contents. In order to improve the evaluation performance of the project structure decomposition subsystem, project managers can analyse the functional types and professional elements of the power engineering system through EBS, so as to facilitate the later project planning, design, and construction. Taking the power transmission project as an example, substation civil engineering, substation electrical engineering, overhead line structural engineering, overhead line electrical engineering, and cable line engineering by using EBS. In addition, power engineering can be divided into four stages: planning and approval, design and preparation, construction, and summary and evaluation from the perspective of time sequence. After the stage division, it is also necessary to use the WBS work breakdown structure to refine the work content and scope of the power project.

Overall, the results of cloud model evaluation and expert inspection are in good consistency. It is confirmed that the established management evaluation system of major power projects is relatively comprehensive, which can provide a reference for the management of other similar projects. At the same time, the weak links in management, such as project breakdown structure and environmental protection management, should be given more attention and strict control.

7. Conclusions

In order to improve the management level of major power projects, this study established a system of management performance evaluation, conducted the verification of specific cases, and obtained the following conclusions:

(1) Major power projects act as critical nodes of the national power producing and transmission network, but their management faces various difficulties such as huge quantities, technical complexities, high quality standards, and hard coordination. Therefore, it is necessary to adopt system thinking and establish a comprehensive framework of power project management, so as to meet the requirement of controlling multiobjective, whole lifecycle, various participants, and different types of construction elements.

(2) Based on the principles of decomposition, simplification, and integration, the management of major power projects is considered as a system and divided to four dimensions and eight subsystems, including project breakdown structure, quality management, safety management, schedule management, cost management, environment protection, organization/coordination, and technical support. For each subsystem, through the optimization of institutions, process, methods, and skills, the management of power projects may be raised to a leaner standard.

(3) In order to establish a tracking evaluation and feedback mechanism, a comprehensive evaluation system for major power projects is proposed. The index system involves 28 factors, and by using the G1 method, the weights of factors are determined reflecting the relative importance of different factors. The evaluation system can promote the virtuous cycle and continuous improvement of power project management.

(4) Kunliulong Transmission Project, as the first ±800 kV UHV multiterminal hybrid power transmission "highway" all over the world during its construction period, is adopted as a case study. The general performance of Kunliulong project management is evaluated by a special seven-member expert team using the cloud Model method. The experiences about project breakdown, objective control, organization, and coordination are summarized and refined, at the same time the weak aspect of this project is also revealed, which can provide a valuable reference for the improvement of major power project management.

The system framework of major power project management is constructed and the contributing indicators of the comprehensive evaluation index system of major power projects is determined in the paper. However, with the deepening of engineering practice, more indicators need to be incorporated into the evaluation system. In addition, combining the G1 method with the cloud model provides a new way of management performance evaluation of power project. However, the G1 method relies on the subjective opinions of experts to a certain extent, which may reduce the credibility of the evaluation results. The weight of each indicator can be obtained through better methods in future research. These deficiencies may be refined and improved in further research.

Data Availability

The data used to support the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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