Research on the Evaluation Technology of Cost Control Effect in the Construction Stage of Power Grid Engineering Based AHP-GRA Method

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Abstract. Effective regulation of investment expenditures is pivotal for maintaining operational efficiency in power grid systems. Nevertheless, numerous regional grid enterprises demonstrate deficiencies in contemporary organizational management frameworks, coupled with underdeveloped methodologies for systematically assessing the efficacy of project cost control measures. Therefore, this paper applies the life cycle theory to construction project management. It proposes an index framework and evaluation method for power grid project cost control based on the AHP - GRA method. Through the analysis of actual construction project cases, the effectiveness of this method has been verified.

Keywords: AHP-GRA method, power grid project, construction cost, evaluation technology

1 Introduction

The power industry serves as a vital part of national infrastructure, and it is intricately linked to the economy and society of any modern country. Such infrastructure not only provides essential services for daily life but also drives innovation in various sectors, contributing to the development of a modern economy. In recent years, it has become evident that the rapid development of the power sector is fundamental to promoting the progress of other economic sectors and achieving growth in various industries. Particularly, during the second half of the 13th Five - Year Plan, the power sector reached a crucial development stage [1]. Despite this, as new power networks are being constructed, it is essential to improve management practices by drawing on the experiences of past projects. Thus, a performance assessment method for power distribution network projects has become a valuable tool for continuous improvement [2].

The unprecedented expansion of China's power grid has brought about a series of acute problems. In many regions, the existing power grids need to be reconfigured and upgraded to meet the requirements of modern power consumption, which requires

S. M. Ghadiri et al. (eds.), *Proceedings of the 2025 4th International Conference on Engineering Management and Information Science (EMIS 2025)*, Advances in Computer Science Research 121,
https://doi.org/10.2991/978-94-6463-736-6_6

more efficient resource utilization and management. On the other hand, the growth rate of managers is much slower than that of grid assets. This has led to a high demand for personnel management. Due to limited personnel management capabilities, the management precision is low, and the management quality is poor. Moreover, many regional power grid companies lack a robust project post - evaluation system. As a result, it is difficult for them to assess the effectiveness of their investments and the benefits they obtain, making it challenging to optimize their investment plans effectively [3]. Therefore, it is of great significance to study how to evaluate distribution network projects using the life cycle theory. This approach can help address current issues, improve management, and enhance the return on future investments.

2 Constructing a Post-Evaluation Index System Based on the Whole Life Cycle Theory

In power grid engineering, the Whole Life Cycle Theory refers to managing the entire lifespan of a power grid system, from its design and construction to its decommissioning. It emphasizes considering all stages of the system's life to ensure optimal performance, cost - effectiveness, and sustainability. This concept is particularly important in an industry that requires long - term planning, large - scale investments, and continuous maintenance [4].

Anchored in the Whole Life Cycle Theory and the operational specifications governing distribution network infrastructure, this study develops a post - evaluation system for these projects. The system is formulated with the advice of top - level project management experts. The evaluation framework consists of four main groups of indicators, each corresponding to a different stage of the project's life cycle. These groups include: decision - making stage indicators, preparation stage indicators, construction stage indicators, and operation and maintenance stage indicators. The complete evaluation system is presented in Table 1.

Table 1. Evaluation index system for the whole life cycle of distribution network projects.

First tier indicator	Secondary indicators	Three-tier indicators
Pre-decision and post-evaluation indicators	Feasibility Study Formulation Competency	Feasibility Study Formulation Quality
		Load Forecasting Accuracy
	Engineering Decision-Making Proficiency	Project Objective Attainment Level
	Plan Implementation Stratification	Completion degree of project production plan
		Project scale production degree
Evaluation indicators after implementation preparation	Standardization of project bidding and tendering	Project bidding work status
		Project investment work status
	Project preliminary design tier	Preliminary design estimate quality
		Preliminary Design Rigor
		Design Modification Dynamics
	Adequacy of preparation for project	Construction organization

	implementation	design quality Preparation status of materials for start of construction
Evaluation indicators after construction implementation	Progress control tier	Project completion degree on schedule
	Quality control tier	Project first acceptance pass degree Completion acceptance quality
	Safety control tier	Personnel Safety Governance Framework Mechanical Safety Compliance Protocols
	Investment control	Project investment change degree
	Contract management tier	Contract execution status Contract changes
Evaluation index after production operation	Project operation capability	Main transformer load degree
	Reasonable tier of power grid structure	Automation coverage Line contact degree
	Power grid safety and reliability	Line insulation degree Average outage events per user Grid comprehensive voltage qualification degree
	Social benefit	Impact on economic development Impact on industrial progress
	Economic benefit	Investment internal degree of return Payback period
	Energy saving and environmental protection	Proportion of energy-saving equipment Line loss degree

3 Overview of the Post-Evaluation and Evaluation Model Ideas and Evaluation Theory

3.1 Weight Determination Method Model and Idea

The AHP is a widely used method that quantifies human opinions. It is a useful decision - making tool when dealing with multiple influencing factors. AHP can convert qualitative opinions into quantitative data. It is also a well - known method for determining weights based on subjective judgments, providing a clear and organized way to represent these judgments [5]. The main steps of AHP are as follows:

(1) Based on the theory of importance scaling, a pairwise comparison matrix, denoted as A, is constructed for the evaluation index system.

$$A=\left(a_{ij}\right)_{n\times n}\left(i,j=1,2,\cdots,n\right) \tag{1}$$

(2) Then, the judgment matrix is normalized. The calculation formula is as follows:

$$\overline{a}_{ij} = a_{ij} / \sum_{k=1}^{n} a_{kj} \left(i, j = 1, 2, \cdots, n\right) \tag{2}$$

(3) Calculate the index weight:

$$w_i = \overline{w}_i / \sum_{i=1}^{n} \overline{w}_i \left(i = 1, 2, \cdots, n\right) \tag{3}$$

(4) Finally, Results of consistency testing was performed. If the consistency ratio meets the required standard, the results are considered acceptable. However, if the consistency check fails, adjustments need to be made to improve the accuracy and reliability of the results.

3.2 Development of a Post-Evaluation Model for Distribution Network Projects Using Fuzzy Theory

The fuzzy comprehensive evaluation method is based on fuzzy set theory. It integrates multiple factors into a quantitative evaluation framework. This method can transform qualitative judgments into numerical values, enabling the evaluation of complex situations with multiple interacting elements. The steps to establish a fuzzy comprehensive evaluation model are as follows:

(1) Establish the Assessment Factor Set

The assessment factor set U represents the hierarchical structure of evaluation indices. The main (first - tier) indicators in this set are:

$$U = \{U_1, U_2, U_3, U_4, U_5\} \tag{4}$$

The second-level index matrix is as follows:

$$U_i = \{U_{i1}, U_{i2}, ..., U_{ij}\} \tag{5}$$

In the formula, U_{ij} is the i -th index of the j-th criterion layer.

(2) Conduct the evaluation combined with the determination

The comment set is usually formed by collecting the evaluations of a group of experts. These evaluations focus on various factors that may occur during a distribution network project. The feedback is then organized into a complete set, which serves as the basis for further analysis and decision - making.

$$V = \{V_1, V_2, V_3, V_4, V_5\} = \{\text{Excellent}, \text{Good}, \text{Middle}, \text{Qualified}, \text{Poor}\} \tag{6}$$

(3) Calculate the weight results

$$W = \{W_1, W_2, W_3, W_4, W_5\} \tag{7}$$

(4) Create an assessment affiliation matrix. For example, for a certain project, the total cost was 67,786,300 yuan. After the project was completed and put into operation, the 110kV grid structure of Company D was improved. This solved the problems of insufficient power supply and peak - time overload in the area and promoted the local economic and business development. The main components of the 110kV power transmission and transformation project are as follows:

$$R = \begin{bmatrix} R_1 \\ R_2 \\ \cdots \\ R_3 \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{21} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{8}$$

Among them, R_1 is the evaluation outcome for the i-th factor, r_{ij} signifies the membership degree quantifying the association between the i-th evaluation factor and the j-th evaluation tier, reflecting how each factor corresponds to different assessment tiers. Here, corresponds to the aggregate count of evaluation factors, and n indicates the total stratification levels within the evaluation scale.

(5) Fuzzy evaluation and settlement results

The initial phase involves executing a primary fuzzy comprehensive evaluation. This process validates the weight coefficients derived from the Analytic Hierarchy Process (AHP) through fuzzy operational principles. Subsequently, an assessment membership matrix R is constructed, followed by integrated computational procedures and normalization operations. These steps yield the membership degree vector S_i, which quantifies the correlation intensity between individual evaluation factors and the predefined assessment category set V.

$$S_i = W_i * R_i = (W_{i1}, W_{i2}, \ldots, W_{ij}) \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{21} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{9}$$

The second phase involves executing a secondary fuzzy comprehensive evaluation, building upon outcomes derived from the primary assessment. By applying the "fuzzy vector normalization rule," the aggregate assessment vector A is computationally derived, culminating in the final evaluation outcome. This hierarchical approach ensures systematic integration of multi-tiered evaluation criteria, enhancing analytical robustness and fidelity in complex decision-making frameworks.

$$A = W * S \tag{10}$$

To enable comparative analysis of evaluation outcomes, the results are quantitatively standardized through score conversion. Let V represent the predefined assessment tier scores, and F denote the synthesized composite score derived from normalized aggregation. This transformation facilitates cross-comparative interpretation by mapping multidimensional assessment vectors onto a unified metric scale, thereby enhancing analytical objectivity in performance benchmarking.

$$F = A * V \tag{11}$$

4 Example Calculation and Conclusion Analysis

To determine the membership grades of evaluation metrics for high-voltage power transmission and transformation projects post-implementation, a systematic analytical framework is established. This methodology focuses on quantifying the correlation between post-completion performance indicators and predefined assessment criteria, leveraging fuzzy logic principles to derive hierarchical affiliation values. The approach ensures rigorous alignment of empirical project outcomes with theoretical evaluation benchmarks, facilitating objective post-project performance characterization within energy infrastructure management contexts, the first step is to define the fuzzy assessment comment set. Once the set is defined, the membership degree of each index can be calculated. Based on existing research on distribution network projects and consultations with experts, this paper defines the assessment levels for the full - lifecycle post - assessment of distribution network projects. The assessment levels are shown in Table 2:

Table 2. Comment rating table.

Evaluation results	value
Especially good	90-100
fine	80-90
sort	70-80
Difference	60-70
inferior	0-60

A panel of ten domain experts was convened to evaluate the preliminary planning and post-decisional evaluation phases of a metropolitan distribution network infrastructure project. Employing a fuzzy logic matrix, a hierarchical analytical process was executed, progressing from foundational to composite evaluation metrics. Outcomes were synthesized through iterative expert consensus, adhering to probabilistic assessment principles. Subsequent computational procedures yielded a fuzzy membership degree ensemble, characterizing the project's assessment indices within a structured evaluative framework. This methodology ensures systematic alignment of granular operational metrics with overarching strategic objectives, enabling robust post-implementation performance validation.

$$Q = (0.1453\ ,0.2370\ ,0.2150\ ,0.4517\ ) * \begin{bmatrix} 0.7401 & 0.2277 & 0.0421 & 0 & 0 \\ 0.8785 & 0.1037 & 0.0527 & 0 & 0 \\ 0.8233 & 0.1022 & 0.0232 & 0 & 0 \\ 0.7632 & 0.1245 & 0.1232 & 0 & 0 \end{bmatrix} = (0.76730\ ,0.1322\ ,0.0558\ ,0,0)$$

Based on the results of the multi-level fuzzy comprehensive assessment, the membership degree of the assessment indices to the comment categories for the full lifecycle of the distribution network project is labeled as AAA. This shows that the overall assessment of the project is excellent.

5 Conclusion

This article presents a post - evaluation framework for distribution network projects using lifecycle management. It examines the entire project process, from planning to maintenance. This approach helps local grid companies better manage and optimize each stage of a project. The feasibility of this framework was tested through a 2020 project of a local grid company, demonstrating its effectiveness in real - world project management. With the rapid development of China's power industry, improving the efficiency and quality of local grid construction is a significant challenge. This research promotes the transition to comprehensive project management, which can enhance competitiveness and industry development. In summary, this article provides a useful framework that improves construction quality, enhances investment efficiency, and offers guidance for similar projects, supporting the scientific management of local grid companies.

Acknowledgement

This research is supported by the "Research on the Evaluation System and Method of Cost Control Effectiveness in Power Grid Engineering Based on Data Mining Technology" project (Project No. 2024A-134), funded by the State Grid Shandong Electric Power Company Economic and Technological Research Institute.

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