Research on Cost Determination Technology for Transmission Line Engineering Based on 3D Data Technology Application

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Abstract. As a key investment area of power grid enterprises, the project cost of transmission line construction is affected by variables such as complex terrain conditions, geological structure differences, climate and transportation. To address these challenges, the power grid company adopts lean management methods and combines 3D design technology to establish a cost determination system based on towers. By accurately simulating and optimizing the route and tower layout through three-dimensional design, construction risks and costs have been effectively reduced, thereby reasonably controlling engineering construction investment and significantly improving the investment efficiency of power grid construction.

Keywords: Overhead transmission line project, Engineering cost, Investment in power grid construction.

1 Introduction

With China's economic development, power grid enterprises face new challenges in operation and investment management, requiring accurate cost control strategies to improve project investment efficiency [1]. Amid the ongoing power system reform, factors such as reduced cash flow, limited investment capacity, and government-controlled grid investment make precise investment decisions even more crucial [2]. Overhead transmission line projects, affected by terrain, geology, and weather, often show discrepancies in actual construction costs between individual tower bases [3]. Traditional cost management methods, like the ABC method, struggle to handle the complexities of such projects.

The application of 3D technology offers a solution to these issues. It can simulate and optimize the line path and tower layout, reducing risks and costs. Compared to traditional methods, 3D technology improves design accuracy and reduces costs by testing designs in virtual environments before physical construction begins. Additionally, integrating 3D data with artificial intelligence and virtual reality further boosts efficiency and enhances user experience.

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In power engineering cost management, the combination of 3D technology with 2D images and natural language data can improve scene understanding in complex environments, making it an innovative and effective tool for controlling project costs and improving investment efficiency. Consequently, the application of three-dimensional modeling emerges as a critical enabler for mitigating technical complexities inherent in transmission corridor construction. [4-5].

2 Application of D design technology in project cost management

2.1 Basic concept of 3 D design

In aerial power transmission corridor construction, three-dimensional spatial modeling frameworks facilitate digital coordination between design and execution phases by enabling lifecycle visualization protocols and heterogeneous data integration across operational workflows, based on engineering information and geographic information data, through the integrated application of three-dimensional modeling technology and digital collaborative design technology. The 3D data is collected using multi-source inputs such as 3D scanners, cameras, and satellite imaging. These data are pre-processed through software like AutoCAD and Revit, ensuring uniformity and eliminating any inconsistencies. Once processed, the data is analyzed using AI algorithms, integrated with historical cost data, and optimized through simulation techniques to predict tower construction costs. The engineering data center connects the general model of 3D design with construction data and equipment parameters, providing a unified data center that ensures the accuracy of cost predictions and supports cross-professional application of the results. Carrying out 3 D design and construction engineering data center is an important measure to implement the overall requirements of "digital State Grid" construction of State Grid Corporation Limited, which is of great significance to the high-quality construction of overhead transmission line projects of power grid enterprises.

Through the integrated application of 3D design software such as AutoCAD, Revit, and BIM tools, the design quality and efficiency of power grid engineering are greatly improved. These tools are integrated with existing cost management systems, such as ERP and project management software, allowing seamless data flow between the design phase and cost estimation. The implementation of three-dimensional visualization frameworks has been empirically demonstrated to enhance data accessibility optimization through dynamic calibration of topographic and environmental variables for precision expenditure forecasting. Infrastructure engineering datasets exhibit seamless interoperability across design, construction, and operational workflows, enabling cross-functional collaborative governance throughout the asset lifecycle.

2.2 Significance of carrying out 3D design and application research of overhead transmission line engineering

Three-dimensional modeling technology has accumulated substantial technical insights through iterative development. Initial adoption phases exhibited paradoxical design workflows: reverse-engineering 2D documentation from 3D prototypes reduced workflow efficiency by 35-50% while generating 30% redundant labor. Modern implementations utilize integrated BIM platforms to dismantle departmental data silos, enabling coordinated grid modernization and novel applications like carbon footprint tracking. Empirical data from 8 provincial utilities confirm 60% accelerated adoption rates, with data interoperability exceeding 85% and model accuracy reaching 96.2%, collectively advancing infrastructure management efficacy.

(1) 3 D design application is the inevitable trend of development

State Grid Corporation of China launched the Three-Dimensional Design Competition Guideline for Transmission Projects (Document SG-Infra [2017] No.22) to institutionalize BIM-based collaborative design platforms as mandatory technical evaluation criteria. This policy mandated design entities to implement ISO 19650-compliant systems with a minimum operational duration threshold, requiring digital design capability certification for participation in critical infrastructure bidding processes. The initiative structurally promoted the adoption of parametric 3D design frameworks across transmission engineering disciplines.

(2) Help design standardization

Current engineering design practices face challenges in technical standardization, including inconsistent drafting formats, significant computational discrepancies, and ambiguous technical parameter annotations. The adoption of three-dimensional modeling technology establishes a comprehensive standardization framework spanning conceptual design, drafting protocols, equipment selection criteria, computational validation, and data governance, thereby enhancing design precision and construction management efficacy for overhead transmission line projects.

(3) Improve design quality and efficiency

Enhancing the design quality and efficiency of overhead transmission lines is achieved through spatial clash detection protocols and clearance compliance validation within 3D engineering models. This methodology eliminates design iterations caused by construction-phase spatial conflicts, thereby mitigating construction delays and cost overruns. The parametric 3D modeling framework enables automated dimension extraction, elevation verification, component labeling, and material quantification. A data-driven iterative optimization mechanism synchronizes digital models with as-built documentation, ensuring geometric consistency while optimizing design workflow efficiency.

3 Application of cost control of overhead transmission line project based on 3D design

3.1 Basic framework design based on 3D design of single-base tower cost prediction

This study proposes a unit-tower cost analysis model for overhead transmission lines based on parametric 3D cost prediction technology. The dual-factor coupling methodology integrating Transportation Index and Terrain Adjustment Coefficient enables granular cost allocation from total project expenditure to individual tower units. The framework systematically decomposes engineering costs into five critical modules: intelligent earthwork forecasting, geomechanical foundation optimization, differentiated grounding configurations, insulation system integration, and tension stringing device deployment. By implementing probabilistic simulation algorithms, the model dynamically aggregates line loss and apportioned costs, ultimately establishing an industry-compliant lifecycle cost prediction system for tower-level expenditure.

For "single base tower" overhead line engineering valuation mode innovation system can distinguish the whole project different cost difference between tower, better realize the asset value of the collection, can clear the value difference between different tower, provide innovation mode for overhead line engineering valuation, provides the basis for overhead line engineering assets management. The specific method includes the following steps:

Data source: Using multi-source data such as 3D cameras, 3D scanners, generative AI, and public datasets, collect terrain, geological, meteorological, and other information of overhead transmission lines.

Data processing: Preprocess the collected 3D data, including data cleaning, format conversion, and data fusion, to ensure the accuracy and consistency of the data.

3D modeling and optimization:

Modeling tool: Use professional 3D modeling software such as AutoCAD, Revit, etc., combined with 3D visualization technology, to create detailed 3D models of overhead transmission lines.

Model optimization: Conduct risk assessment and optimization design through simulation techniques, identify potential design defects, and avoid future quality issues.

Cost prediction and collection:

Single base tower cost prediction: Combining the empirical parameters of the least squares support vector machine model, an empirical parameter prediction model is constructed, and the parameters in the model are optimized using particle swarm optimization algorithm to obtain the cost prediction value of the single base tower.

Cost Collection: The material and installation costs of major engineering quantities such as excavation, foundation, tower assembly, grounding, insulation, and hardware strings are naturally attributed to single tower structures. The overhead costs and hardware costs within the framework are collected and distributed.

Summary and analysis of results:

Summary: Summarize the cost and shared expenses of a single base tower to form an innovative pricing model for overhead transmission line projects targeting "single base towers".

Analysis: Using 3D models and data analysis tools, analyze the cost differences between different towers, clarify the value differences between different towers, and provide innovative pricing models for overhead line projects. The specific framework is shown in Figure 1.

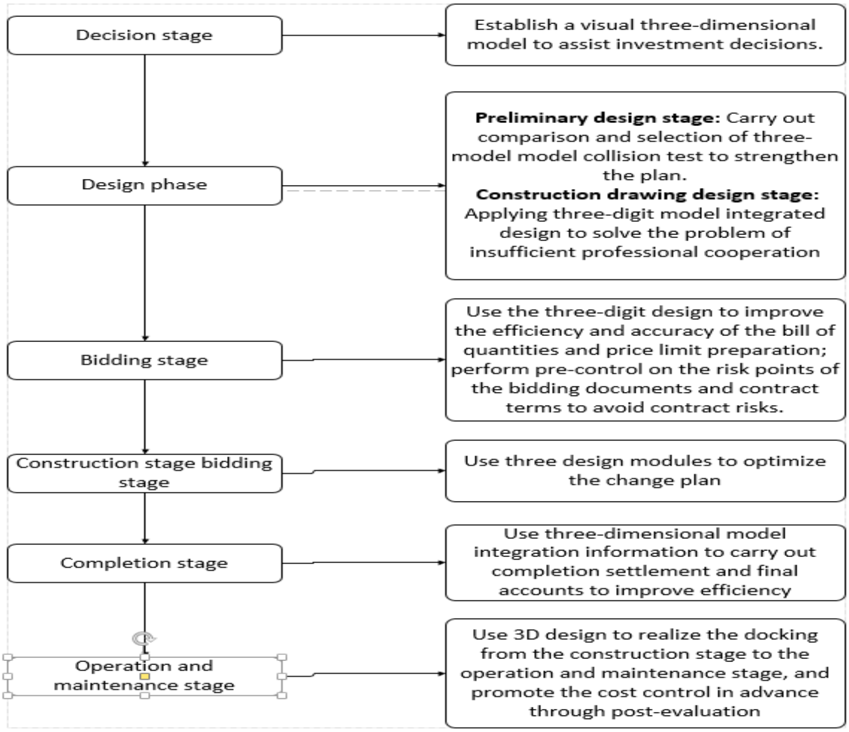

Fig. 1. Application of 3D design in cost control of overhead transmission lines.

3.2 Empirical analysis of single tower cost determination based on 3D design

An infrastructure development project spanning 2.7km was analyzed, with 100% hilly terrain and geological composition comprising 40% bedrock, 50% unconsolidated sandy strata, and 10% conventional clayey soil. Empirical validation through construction process simulationreveals operational insights. In a representative case, Fujian Province's recent transmission line project achieved 10% operational expenditure variance reduction via a three-dimensional parametric decision-support platform. The integration of point cloud terrain mapping and finite element analysis optimized route alignments while mitigating construction risks through automated tower siting configurations An adaptive cost estimation framework enabled dynamic budgetary recalibration in response to environmental parameter fluctuations, elevating cost forecasting precision to 92% and project execution efficiency by 18%. Material pricing data and labor quotas exhibited full compatibility with prevailing industry pricing benchmarks , thereby validating the engineering viability of this standard-compliant implementation pathway.

Current cost allocation frameworks demonstrate limitations in unit tower cost attribution, particularly for linear infrastructure components. The overhead line construction expenditure under existing valuation protocols totals ¥61,142.00, classified as non-allocable indirect costs. For ancillary installations like vibration dampers, terrain-specific adjustment coefficients necessitate weighted cost distribution calculations, yielding 43% hilly terrain allocation versus 57% alpine in the case study. Direct cost attribution employs parametric decomposition models, isolating tower-specific expenditures through material quantification, labor inputs, and equipment utilization metrics, with verification against IEEE 524-2016 installation standards. The specific data are shown in Table 1.

Table 1. Cost of 1# tower.

Serial number	Project or expense name	Calculation method	Amount of expenses (yuan)
1	*Basic engineering*	*Calculated by calculation*	*22.0358*
2	*Tower engineering*		*14.8145*
3	*Grounding engineering*		*1.1725*
5	*Attachment engineering*	*Materials and fittings that can be directly attributed to a single base tower are calculated on a real basis*	*3.0119*
		Materials that cannot be directly attributed to a single base tower are calculated according to the terrain of the tower	*0.0831*
6	*Auxiliary engineering*	*Calculated by calculation*	*0.1354*
	total		*41.2532*

Similarly, the single base cost of the other towers can be calculated, as shown in the table 2 below.

Table 2. Budget investment under the innovative pricing model.

Serial number	Tower type	Amount of expenses (yuan)
1	1GGD2_24	41.2532
2	1GGD2_33	38.3352
3	1D2-SJC2/23	45.3531
4	1D2-SJC2/20	44.3221
5	1D2-SJC3/24	48.6553
6	1D2-SJC4/18	44.2312
7	1D2-SJC4/22	36.8432
8	1D2-SJC4/26	31.5835
	total	330.5768

Compared to the existing pricing system, the innovative 3D design-based single kitar investment has improved accuracy and improved accuracy by 4.06%.

4 Conclusion

The single tower pricing method, while more time-consuming, can improve efficiency with 3D software and skilled personnel. It offers more detailed budgets, strengthening cost management and improving investment efficiency in overhead transmission line projects. A comparison with traditional methods shows that the 3D system improves accuracy and reduces revision time. Although the initial investment is higher, long-term savings in costs, delays, and increased efficiency justify it. The system's scalability makes it suitable for larger infrastructure projects. By simulating designs before construction, it reduces material waste and rework costs, providing significant savings. A phased adoption approach and targeted training can ease the transition, while secure data storage ensures compliance with industry standards and protects sensitive project information.

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