Analysis Of the Influence Mechanism of Power Market Reform Affecting the Power Transmission and Transformation Construction Projects Under the DB Mode

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Abstract. Under the background of the new round of power market reform, the power transmission and transformation construction projects are faced with many new influencing factors. Therefore, the article firstly uses the Delphi method to sort out the influencing factors faced by the power transmission and transformation construction projects built under the Design and Build(DB) mode, and categorize various influencing factors into four dimensions; then analyses the interaction mechanism between the influencing factors by constructing an interpretative structural model of the influencing factors of the power transmission and transformation project construction, and builds a hierarchical structure diagram of the influencing factors. Based on this hierarchical structure diagram, the origin factors and process factors of the influencing factors can be clearly seen, as well as the risk transfer chains of five major influencing factors, including diversified electricity sales entities and opening up of newly-added power distribution network. Finally, based on the five risk transfer chains, specific suggestions have been proposed for the construction of power transmission and transformation projects after the new round of power market reform.

Keywords: Power transmission and transformation construction; power market reform; DB mode; interpretative structural modeling method; risk transfer chain.

1. Introduction

The new round of power market reform aims to break the integrated power transmission and transformation industry structure and build a highly efficient and competitive power market system, which will exert profound impact on the supply side, transmission and transformation side and sales side of electricity. The DB mode (Design-Build Mode) is a modern project management mode commonly used in international engineering projects in recent years. Described as "a kind of architectural service in which the design and construction work is carried out by a single agency", DB mode integrates design and construction in depth. Therefore, using the DB mode is conducive to the continuous optimization of the overall project construction planning, effectively mitigating the contradiction of mutual constraints and disconnection between design and construction. In addition, the DB mode can also contribute to the reasonable connection of design and construction work at all stages, and effectively realizing the construction plan as well as the cost and quality control objectives of the construction project, which portrays the main development direction of future power transmission and transformation construction projects.

Under the new situation, the power transmission and transformation construction work suffer from intensified uncertainties, and the interaction relationship between various links would be more

complex. The power transmission and transformation construction work under the new situation should take the influence of new factors such as the grid connection of distributed power supply, opening up of newly added power distribution network and the entry of diversified power sales entities into account. Therefore, analyzing the influence mechanism of the influencing factors under the new situation will help improve the adaptability of the power transmission and transformation construction projects under DB mode.

At present, there is few literatures that systematically studies the impact of power market reform on the power transmission and transformation construction projects. Most scholars conduct their research on a local quantitative basis. In general, the power transmission and transformation construction work under the background of the new round of electricity market-oriented reform will face the challenge of more diversified contents, higher flexibility, more diverse subjects and stricter auditing. Therefore, these four types of macro factors will bring profound changes to the planning objectives, implementation plans and resource selection of the projects [1-2]. As for the power transmission and transformation construction projects, the main objectives of the projects before the power market reform are to meet the demand for newly added power load, improve grid reliability, eliminate equipment safety hazards and ensure the construction of power transmission lines [3-4]. However, the market competition after the power market reform would be intensified, with new power sales and investment entities entering into the market. So, the power grid enterprises, in addition to meeting the demand for existing planning projects, need to take into account the needs of power transmission corridor reservation, strategic deployment and other issues necessary for adapting to the competitive market environment [5-7]. Therefore, after the power market reform, the power transmission and transformation construction projects need to focus on how to seize the market share, instead of simply meeting the demand for grid capacity and solving local imbalance in electricity consumption [8-10]. And in the face of the security problems brought by the large-scale and random connection of distributed power generations and new energy resources, power transmission and transformation construction work need to optimize its planning algorithm and enhance the flexibility and adaptability of its planning model [11-12].

Based on the literature review, there is few systematic research on the mechanism of the impact of the new round of power market reform on the power transmission and transformation construction work. On the basis of a systematic analysis of various influencing factors faced by the power transmission and transformation construction work in the context of the new round of electricity market-oriented reform, this paper produces the following results. First, a hierarchical structure diagram of the interaction of influencing factors of power transmission and transformation construction projects has been constructed. Second, the risk transfer chain of major influencing factors by using the interpretative structural modeling method has been plotted. Hence, the origin factors and process factors among the influencing factors have been identified to provide reference for improving the adaptability of the power transmission and transformation construction work under the new round of power market-oriented reform.

2. Interpretive Structural Modeling

Interpretive Structural Modelling (ISM) is a model that uses practical experience as well as computer software to divide a complex set of interacting factors into a number of subsystems and then divide the system into a multi-layer transfer model according to some certain rules, which can reveal the influence mechanism and transfer paths of the influencing factors in a clear manner [13]. ISM Modelling consists of the following steps.

Create a set of influencing factors. Collate the constituent influencing factors of the system and define the set of system consisting of all the identified factors, noted as [14-16]:

$$N = \left\{ r_i \middle| \left(i = 1, 2, \cdots, n \right) \right\} \tag{1}$$

Establish a directional relationship. To judge whether a direct binary relationship exists between any two factors in a factor set, the direct binary relationship between any two factors r_i and $r_j$can be expressed as:

$$a_{ij} = \begin{cases} 0(Factor\ i\ has\ no\ influence\ on\ factor\ j) \\ 1(\ Factor\ i\ has\ influence\ on\ \ factor\ j) \end{cases} \tag{2}$$

Construct the adjacency matrix. The sum of all direct binary relations can form the adjacency matrix $A = (a_{ij})_{n \times n}$.

Calculate the reachable matrix. The reachable matrix M is calculated based on the matrix transformation rules given by (3), where the multiplication of the matrix can satisfy the Boolean algebra rules and I stands for the unit matrix.

$$(A+I) \neq (A+I)^2 \neq \cdots \neq (A+I)^m = (A+I)^{m+1} = M \tag{3}$$

Hierarchical division. The set influenced by the factor r_i is defined as the reachable set of the factor r_i, and it can be expressed as $P(r_i)$. The set of factors influencing the factor r_i is defined as the predecessor set of the factor r_i, and it can be expressed by $Q(r_i)$. If $P(r_i) \cap Q(r_i) = P(r_i)$, then r_i is the highest level factor, and the factors satisfying this condition are classified into the same hierarchy L_1 . By doing so, the different hierarchies L_2 , ... L_3 can be attained.

Generate a hierarchical structure diagram. Once the hierarchical division is complete, the hierarchy of the system can be represented in the form of a directed graph.

Generate a risk transfer chain. Obtain risk transfer chains based on the hierarchical structure.

3. Identification of influencing factors

Compared to the situation before the new round of power market reform, the power industry has undergone major changes in several aspects of power generation, transmission and transformation, and power sales. As a result of these changes, the transmission and transformation construction project would face increasing uncertain influencing factors. Based on the Delphi method, this chapter mainly identify the influencing factors of power transmission and transformation construction projects from three aspects: power generation side, power transmission and transformation side and power sales side, and 18 main factors affecting the construction plan of power transmission and transformation construction projects have been attained. The specific factor types and divisions of influencing factors are shown in Table 1.

Tab. 1 Classification of the main factors affecting the power transmission and transformation construction work.

Factor category	Influencing factors
Power generation side (1) to (5)	(1) New energy power resources connection
	(2) Distributed power generations connection
	(3) Coordination with power planning
	(4) Electricity price on grid
	(5) New energy power price subsidy fluctuations
Power transmission and transformation side (6) to (10)	(6) Fluctuations in power transmission and transformation prices
	(7) Comprehensive line loss rate
	(8) Grid reliability
	(9) Coordination between main network planning and distribution network planning
	(10) Scale of opening-up of newly added power distribution network
Power sales side (11) to (15)	(11) Accuracy of power load forecasing
	(12) Fluctuations in electricity consumption for various types of loads
	(13) Fluctuations in sales prices for various types of electricity
	(14) Scale of direct purchase of electricity by large consumers
	(15) Market entry of diversified electricity sales entities
Others (16) ~ (18)	(16) Planned station sites and line corridor changes
	(17) Planning capacity changes
	(18) Electricity System Reform Policy

According to the 18 influencing factors mentioned above that would affect the power transmission and transformation construction work in the new round of power market reform, the Delphi method has been used to establish the directional relationship between the influencing factors, which can be the basis for establishing the adjacency matrix in the next step. Based on the research results, the directional relationship among the factors is shown in Table 2.

Tab. 2 Directional relationship between factors influencing the power transmission and transformation construction projects under the power market reform.

Factors	Direct influencing factors	Factors	Direct influencing factors
1	3,8	**10**	7,8,9,16
2	3,7,8,11	**11**	16
3	16,17	**12**	11,16,17
4	1,2,12,13,14	**13**	12,14,15
5	1,4	**14**	7,9,10
6	14,15	**15**	8,10
7	16	**16**	-
8	16,17	**17**	-
9	16,17	**18**	4,5,6,10,13,14,15

Taking Factor 1 as an example, the findings of the table indicate that new energy resources connection would have a direct impact on two influencing factors: coordination with power planning and grid reliability.

4. Hierarchies of influencing factors and risk transfer chains

Based on the directional relationships of the main influencing factors constructed in Table 2, the direct correlations between the above 18 variables are expressed by the adjacency matrix A_{ij} shown below, where a value of 1 in the matrix A_{ij} indicates that the risk factor corresponding to row i has a direct influence on the risk factor in column j, whereas a value of 0 indicates that the corresponding influencing factor has no direct influence.

$$A_{ij} = \begin{bmatrix}
0&0&1&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0\\
0&0&1&0&0&0&1&1&0&0&1&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&1&0\\
1&1&0&0&0&0&0&0&0&0&0&1&1&1&0&0&0&0\\
1&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&1&1&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&1&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&1&0\\
0&0&0&0&0&0&1&1&1&0&0&0&0&0&0&1&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0\\
0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&1&1&0\\
0&0&0&0&0&0&0&0&0&0&0&1&0&1&1&0&0&0\\
0&0&0&0&0&0&1&0&1&1&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&1&0&1&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&1&1&1&0&0&0&1&0&0&1&1&1&0&0&0
\end{bmatrix}$$

According to equation (3), using MATLAB software, the Boolean algebra of the adjacency matrix has been carried out. The reachable matrix M of this system can be calculated, and the calculation results are shown in the following equation.

$$M = \begin{bmatrix}
1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
1&1&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
1&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
1&1&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0\\
1&1&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0\\
1&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0\\
1&1&1&0&1&0&0&1&0&0&0&0&0&0&0&0&0&0\\
1&1&0&1&1&0&1&0&1&0&0&0&0&0&0&0&0&0\\
1&1&0&1&1&1&0&0&0&1&0&0&0&0&0&0&0&0\\
1&1&0&0&0&0&1&0&0&0&1&0&0&0&0&0&0&0\\
1&1&0&1&0&1&0&0&0&0&0&1&0&0&0&0&0&0\\
0&0&0&0&1&0&0&0&0&1&0&0&1&0&0&0&0&0\\
1&1&0&0&0&0&0&1&1&0&1&1&0&1&0&0&0&0\\
1&1&0&0&0&0&0&1&0&0&0&0&0&1&1&0&0&0\\
1&1&0&0&0&0&0&0&0&0&0&1&1&0&0&1&0&0\\
1&1&0&0&0&0&0&0&0&0&1&1&1&0&0&0&1&0\\
1&1&1&1&1&1&1&1&1&1&0&1&1&1&0&1&1&1
\end{bmatrix}$$

Using the principle of hierarchical division in the interpretive structural model, the risk factors affecting the construction of power transmission and transformation projects in the model can be divided into five hierarchies, expressed by L1, L2, L3, L4, L5. The five hierarchies of influencing factors are: L1= {16,17}; L2= {4,5,6,13}; L3= {1,2,12,14,15}; L4= {3,7,8,9,10 ,11}; L5={18}. The hierarchical structure diagram of the main risk factors affecting the construction of power transmission and transformation projects has been drawn according to the reachable matrix and the hierarchical structure of the influencing factors, which is shown in Fig.1.

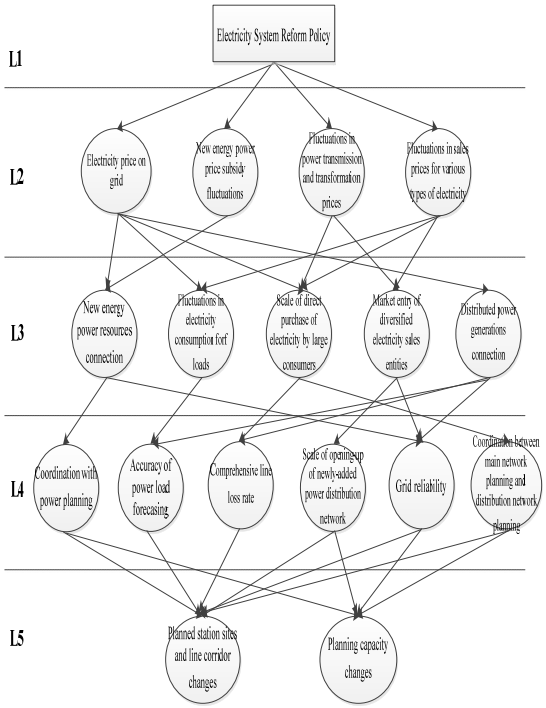


Fig.1. hierarchical structure diagram of factors affecting the construction of power transmission and transformation projects.

In the five hierarchies of influencing factors, different levels of influencing factors have different impacts on the construction of power transmission and transformation projects. Specifically, the lower the hierarchy, the greater the influence is. These 5 hierarchies of influencing factors form different risk transfer chains from the bottom up. According to the different positions in the risk transfer chain, the 18 influencing factors can be divided into origin factors, process factors and final factors. Among these three types of factors, the process factors refer to the intermediate links for the influence transfer from the origin factors to the final factors. In other words, the origin factors can either indirectly influence the final factors through the upper-level process factors or directly influence the final factors. Origin factors are the root causes of final factors. Each of these origin factors forms a different risk transfer chain, which would ultimately have an impact on the power transmission and transformation construction projects, as shown in Fig.2.-Fig.6.

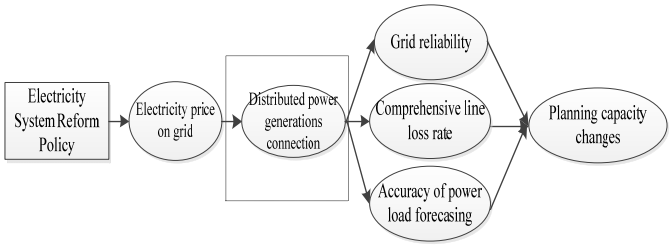


Fig.2. Risk transfer chain of the distributed power generations connection

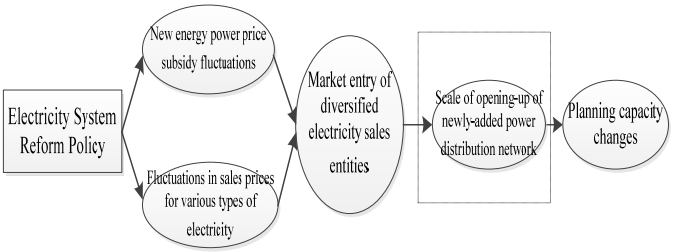


Fig.3. Risk transfer chain of the opening-up of newly-added power distribution network

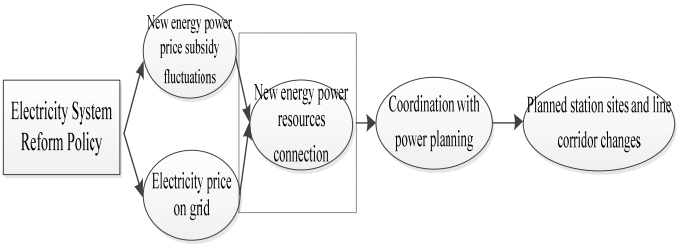


Fig.4. Risk transfer chain of new energy resources connection

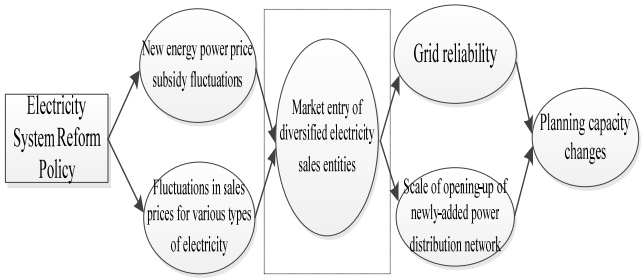


Fig.5. Risk transfer chain of the market entry of diversified electricity sales entities

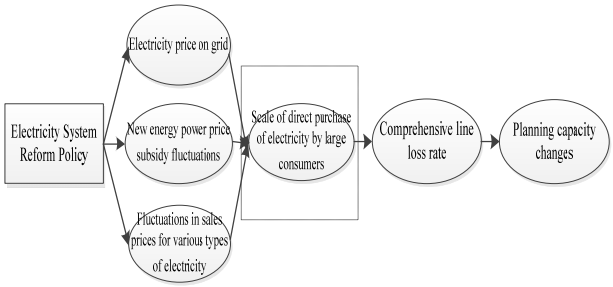


Fig.6. Risk transfer chain of the scale of direct purchase of electricity by large consumers

Based on the interpretive structural model, the risk transfer chain of the main influencing factors of the power market reform on the construction of power transmission and transformation projects has been drawn, mainly including risk transfer chains of the distributed power generations connection, the opening-up of newly-added power distribution network, new energy resources connection, the market entry of diversified electricity sales entities and the scale of direct purchase of electricity by large consumers. From the influence mechanism of the risk transfer chains, it can be perceived that the new influencing factors brought by the above-mentioned power market reform policies are defined as the process factors. Therefore, the power market reform affects the construction of power transmission and transformation projects mainly through the stepwise influence transfer of various electricity price policies and then affect the planning of power transmission and transformation construction project.

5. Conclusions and suggestions

Using the interpretive structural model, this paper systematically analyses the main influencing factors that will be faced by the construction work of power transmission and transformation projects under the new circumstances in the future. Among them, the policies of the electricity market reform would serve as the origin influencing factor, directly affecting various process factors such as distributed power generations connection, new energy power resources connection, direct power purchase by large consumers, opening-up of newly-added distribution power network and diversified power sales entities through various power pricing policies, which further affect the final planning for power transmission and transformation construction projects. At the same time, the new influencing factors brought about by the reform of the electricity market and the influencing factors of traditional power transmission and transformation construction projects are intertwined, forming a complex system of influencing relationships. This paper reveals the factors that need to be considered

in the future market-oriented environment for the construction of power transmission and transformation projects, so as to provide reference for the future construction work of power transmission and transformation projects. To be specific, the following recommendations are put forward for the future construction work of power transmission and transformation projects:

A. In the context of the new round of power market reform, more attention should be paid to the pre-planning and decision-making work of power transmission and transformation projects. Based on the above research, it can be seen that distributed power generations connection, new energy power resources connection, the scale of direct power purchase by large consumers and the market entry of the power entities at the sales side would ultimately affect the construction plan of power transmission and transformation projects under DB mode. Therefore, when making preliminary project decisions, it is important to make a coordination between the feasibility study stage with the preliminary design phase scheme, so as to avoid radical changes fundamental in nature when the DB general contractor carries out the detailed scheme design during the preliminary design stage.

B. The need for early deployment should be considered when formulating planning schemes. In the future, the distribution network will be opened up, allowing diversified investment entities to participate in the construction and operation and maintenance of the distribution network. In the face of intensified market competition, DB general contractors are required to participate in advance when making pre-construction decisions for power transmission and transformation projects, so as to seize key corridors and points and strategically capture the market for low-voltage power distribution networks.

C. The new influencing factors brought about by the electricity market reform should be incorporated into the electricity load forecasting. Electricity load forecasting is a fundamental task in the construction work of power transmission and transformation projects. In the future, electricity load will be influenced by more market-oriented factors. Therefore, when making load forecasts, new influencing factors such as the scale of distributed power generations connection and the scale of direct power purchase by large consumers should be taken into consideration, so as to make the load forecasts more close to reality and improve the adaptability of power transmission and transformation project construction plans.

D. Efforts should be made to develop and apply new technologies that can increase the scale of grid connection of new energy resources and distributed power generation. In the future, the connection of distributed power generation and new energy resources will bring serious challenges to the reliability and comprehensive line loss of the power grid. The application of highly flexible and adaptable power transmission and transformation technologies will provide greater scope and space for power transmission and transformation construction work under different planning schemes. Therefore, the capacity for power transmission and transformation construction projects can be increased to resist risks in the new environment.

However, this paper has only studied the influencing mechanism of the factors affecting the construction of power transmission and transformation projects in the context of the new round of power market reform and has not yet studied how each process factor quantitatively affects the construction programme of the projects, which has showed the path for future in-depth analysis and research.

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