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Study on Influencing Factors of Technical-economy Effect of VSC-HVDC System Based on Improved ISM Method

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Abstract. With the higher controllability and power supply reliability, VSC-HVDC transmission technology can support the grid connection of offshore wind power and other distributed energy resources, which conforms to the trend of energy revolution. For investors, the technical-economy effect of VSC-HVDC transmission project is the most attractive issue, and furtherly, the influencing factors are necessary when analyzing the technical-economy effect level of a certain project. To help investors identify the main influencing factors, arrange the internal relationship of influencing factors, and make investment decisions, this paper firstly builds an influencing factor set of technical-economy effect of VSC-HVDC transmission system using brainstorming method, and then proposes an improved ISM method to divide the hierarchical structure of influencing factors. The result shows that influencing factors can be divided into 9 categories and four levels, of which design requirements, equipment requirements and project features are superficial factors, while natural environment and policy environment are fundamental factors. The case study proves that improved ISM method is applicable and practicable for influencing factor analysis.

1. Introduction

Currently, most countries regard renewable energy as a key solution to energy and environmental problems. However, renewable energy has a general characteristic of intermittence and randomness, thus affecting the power quality, which highlights the importance of transmission technology [1]. VSC-HVDC (voltage source converter based high-voltage direct current) is a reliable guarantee to make full use of renewable energy because of its unique advantages: flexible operation, high transmission efficiency, high power quality, less occupied area, fast recovery, and enhanced capacity for distributed renewable energy [2]. VSC-HVDC is now widely used in the following fields: offshore wind power integration, distributed energy resources integration, power supply to passive network, and urban power grid renovation [3]. Generally speaking, the technical-economy effect needs to be considered before investing VSC-HVDC transmission projects, and furtherly, the influencing factor analysis is the basis of technical-economy effect calculation, Therefore, this paper firstly summarizes factors affecting the technical-economy effect of VSC-HVDC transmission system, and then uses the improved ISM method (interpretative structure mode) to identify the internal structure and hierarchical relationship of influencing factors.

There are many methods can be used to classify, sort, and analyze influencing factors from different point of view, such as AHP (analytic hierarchy process), factor analysis, ISM, multiple linear regression model, sensitivity analysis and correlation analysis. AHP is a subjective analysis method, while factor analysis method is based on objective data, and both of them divide influencing factors into different categories [4]. ISM method resolves complex factors into a set of elements with logic relation, and arranges the hierarchical relationship by the aid of practical experience and knowledge [5]. The result of multiple linear regression, sensitivity analysis and correlation analysis method is the mathematical relationship between influencing factor set and analysis objective, which reflecting the influence degree of each factor. Due to the lack of comparable VSC-HVDC projects and the ubiquity of qualitative factors, it is difficult to achieve quantitative analysis, thus the ISM method is selected in this paper for its comprehensiveness.

ISM method is widely used in the process of investment decision, physical distribution management, teaching management, risk management, quality control and so on [5-7]. ISM can be combined with DEMATEL method (decision-making and trial evaluation laboratory) to improve the reliability, the key factor can be obtained using DEMATEL method, and the multilevel hierarchical structure of the complex factor set can be built based on ISM method [8]. On the other hand, it is difficult to judge the accurate causality between factors just by definition, but it is possible to convert the simple 0-1 function into a fuzzy binary relation, so we can express the existence of influencing relationship between factors and determine the influencing degree [9]. Different experts have their own subjective judgments on the issue of whether there is any influencing relationship between factors. Based on the thought of fuzzy analysis, this paper uses questionnaire survey to synthesize the opinion of experts and draw the fuzzy relation between factors, and calculates the binary relation according to membership function. The case analysis result shows that the improved ISM method has good practicability and feasibility for analyzing the influencing factors of technical-economy effect of VSC-HVDC system.

2. Influencing factors of technical-economy effect of VSC-HVDC system

Technical level and price level are direct factors affecting the technical-economy effect of VSC-HVDC projects. In addition, the design, construction, operation and maintenance process of projects are inevitably restricted by the external factors consisting of economic environment, natural environment, social environment and policy environment. Moreover, unique design requirements, equipment requirements and project features of a certain VSC-HVDC project are also important influencing factors [10,11].

2.1. Economic environment

Almost all the technical-economy effect of power grid construction projects will be affected by regional economic development level, inflation rate, interest rate, exchange rate and so on. The regional economic development level determines local power load and transmission capacity; the inflation rate, interest rate and exchange rate affect the cost of projects.

2.2. Natural environment

The nature environment factors include resource condition, climate condition, topographic condition, geological condition, hydrologic condition and so on. The resource condition determines the capacity and distribution of power supply, and affects the power fluctuation of grid; the climate condition influences local electricity demand to a certain degree; topographic condition, geological condition, and hydrologic condition are the key issues to be considered during the design of transmission line and converter station, and they also put forward certain requirements for the equipment performance.

2.3. Social environment

The development of VSC-HVDC is greatly influenced by the social environment. If VSC-HVDC transmission line for offshore wind farm involves fishing areas or shipping routes, it will be needed to consider the attitude of fishermen, maritime companies and other related personnel. Government can also participate in coordination activity to help projects accepted by popular. The design, construction and operation of VSC-HVDC transmission system need to take the stability system and acceptable intermittent power capacity into account. The frequency, outlet voltage, phase sequence and voltage phase of generators must be in accord with that of power system.The technical-economy effect of VSC-HVDC transmission system is affected by the quality, performance and parameters of material and equipment. All the system equipment and material, construction machinery and tools, and spare parts need to be obtained in time and meet technical requirements. The construction and operation of VSC-HVDC transmission of offshore wind farms still exist a certain transportation difficulty. Equipment and parts can only be supplied by air and sea transport, resulting in higher cost.

2.4. Policy environment
The development and construction of power system must obey the energy policy and environmental protection policy, whose target is to improve China's resource environment and energy structure, and reduce pollution. VSC-HVDC can be used for distributed renewable energy integration, which is consistent with the requirements of renewable energy development policy. On the other hand, to ensure the orderly construction and stable power supply of power grid, the construction of transmission system must also accord with the overall power grid planning.

2.5. Price level
Price level is the economic factor that directly affects the cost of VSC-HVDC transmission system, including equipment price, material price, labor price, construction machinery price and so on. The main profit source of VSC-HVDC transmission project is the transmission and distribution income, that is, the transmission and distribution price also affect the economic benefit.

2.6. Technical level
Personnel involved in VSC-HVDC transmission system mainly include designer, construction crew and manager. Their technical level directly affects the engineering quality of VSC-HVDC transmission system. Personnel quality of operation and maintenance staffs also affects the reliability and operation cost of power grid.

2.7. Design requirements
VSC-HVDC transmission system should be designed to meet some technical-economy indicators. At present, the localization of VSC-HVDC technology is relatively low, some demonstration projects have higher requirements for technological innovation, so the technology cost is slightly higher. VSC-HVDC transmission system for distributed renewable energy resources integration has strict requirements for the intelligent level. For VSC-HVDC transmission system with modular structure, the standardization degree and extensibility should be taken into consideration, so as to facilitate the future improvement. In addition, the insulation and lightning protection requirements should also be taken into account.

2.8. Equipment requirements
At present, VSC-HVDC is mostly applied to the offshore wind power integration. The special and rugged marine environment determines that the moisture proofing, salt spray proofing, fungus proofing, water proofing, anti-corrosion, typhoon and crazy wave resistance and mechanical strength of equipment needs to reach a higher level. Equipment with longer life period is also required as a result of restrictions of traffic and construction condition on replacing damaged equipment and ageing facilities.

2.9. Project features

Projects are mainly divided into new projects, rebuilt projects and expansion projects, different projects have different requirements for design, construction and purchase. The voltage and transmission capacity of VSC-HVDC transmission system determine the required specification and parameter of material and equipment; construction season directly affects the schedule and plan; transmission distance directly determines the length of transmission line.
The above factors are summarized as shown in Table 1 and Table 2.

Table 1. Influencing factors of technical-economy effect of VSC-HVDC system (a).

Influencing factors		Influencing factor content
Economic environment	S_1	Regional economic development level Inflation rate Interest rate Exchange rate
Natural environment	S_2	Resource condition Climate condition Topographic condition Geological condition Hydrologic condition
Social environment	S_3	Popular acceptance Condition of grid connection Transportation condition Material supply condition
Policy environment	S_4	Environmental protection requirements Power network planning Energy development planning
Price level	S_5	Equipment price Material price Labor price Construction machinery price Transmission and distribution price
Technical level	S_6	Personnel quality of designers Personnel quality of construction units Personnel quality of supervisors Personnel quality of operation and maintenance staffs
Design requirements	S_7	Technological innovation requirements Intelligent level Standardization degree Extensibility

		Insulation requirements
		Lightning protection requirements
Equipment requirements	S_8	Moisture proofing, salt spray proofing, fungus proofing, water proofing, anti-corrosion, and typhoon and crazy wave resistance
		Mechanical strength
		Life period

Table 2. Influencing factors of technical-economy effect of VSC-HVDC system (b).

Influencing factors		Influencing factor content
Project features	S_9	Project classification
		Voltage level
		Transmission capacity
		Transmission distance
		Construction season

3. ISM methodology

In 1973, Professor J. N. Warfield developed an ISM method in order to analyze the structure of complex social and economic system. The basic idea of this method is that the system is made up of elements, and there are a large number of interactions between these elements. Therefore, to establish the structural model, we need to comprehend the relationship between elements and divide the hierarchical structure. Because of the existence of qualitative influencing factors, and considering the different determination of experts on relationship between factors, the concept of fuzzy matrix is introduced to improve the usability and accuracy of ISM method applied in this paper.

Implementation steps of the improved ISM method are as follows:

Step 1: Identify the influencing factors of technical-economy effect of VSC-HVDC system, classify these factors and label them as S_i. In this step, there is no need to analyze the internal relationship for the time being.

Step 2: Organize experts to judge the relationship between pairs of S_i and S_j. The score can be 0 or 1: 1 indicates that row factor affects column factor, 0 indicates that row factor has no influence over column factor.

Step 3: Arrange the result of expert survey and establish a fuzzy adjacency relation matrix $A=(a_{ij})_{n\times n}$.

$$a_{ij} = \frac{m}{M} \tag{1}$$

a_{ij} indicates the influence of S_i on S_j: m means the number of experts believing the influence of S_i on S_j; M means the number of experts; n means the number of influencing factors.

Step 4: Determine the threshold λ and calculate the final adjacency relation matrix $B=(b_{ij})_{n\times n}$.

$$b_{ij} = \begin{cases} 1, a_{ij} \geq \lambda \\ 0, a_{ij} < \lambda \end{cases} \tag{2}$$

Step 5: Calculate the reachability matrix $C=(c_{ij})_{n\times n}$ by MATLAB.

Adjacency relation matrix belongs to boolean matrix, the reachability matrix satisfies the following condition.

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$$(B+I)^1 \neq (B+I)^2 \neq \cdots (B+I)^{r-1} \neq (B+I)^r = (B+I)^{r+1} = C \quad (3)$$

I is a unit matrix. Reachability matrix indicates the channel from one factor to another.

Step 6: Divide the reachability matrix by MATLAB, and draw the multilevel hierarchical directed graph.

The structure division is to obtain a clear understanding of the internal hierarchical relation among factors. Factors belonging to the first layer represent ultimate goal, while underlying factors are the reason for upper factors. Before the division of reachability matrix, the reachability set $R(S_i)$ and antecedent set $Q(S_i)$ are needed to be analyzed. Reachability set $R(S_i)$ represents the column factor with row elements in reachability matrix of factor S_i being 1, while antecedent set $Q(S_i)$ represents the row factor with column elements in reachability matrix of factor S_i being 1. Hierarchical structure division is the gradual extraction of factors according to $R(S_i) \cap Q(S_i) = R(S_i)$. The earliest extracted factors belong to the first layer, and the latest ones are basic factors.

Technology roadmap the process is shown in Figure 1.

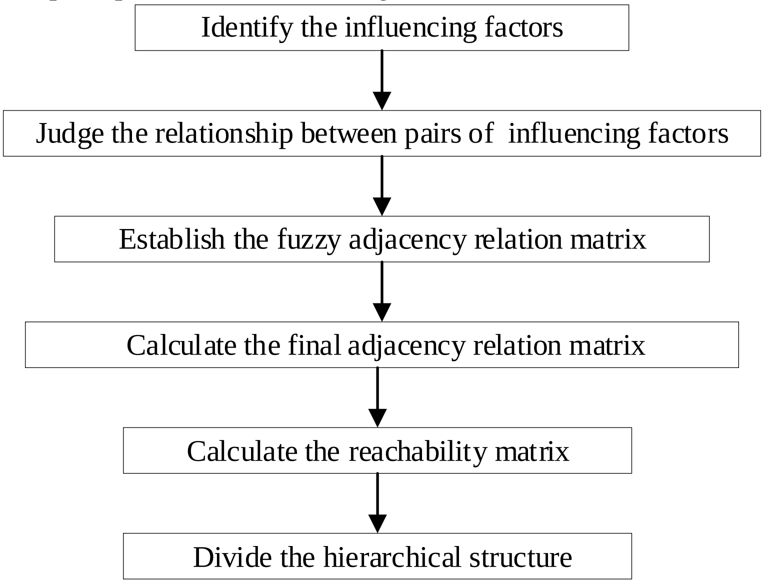

Figure 1. Technology roadmap.

4. Case study

VSC-HVDC plays a prominent role in optimizing the energy structure and improving the environment condition. To provide investors, government and other related institutions with decision support, this paper summarizes the influencing factors of technical-economy effect of VSC-HVDC system, and analyzes the hierarchical structure based on improved ISM method.

Step 1: Establish the influencing factor set.

This paper divides the influencing factors of technical-economy effect of VSC-HVDC system into 9 categories, each category has its own corresponding emphasis. The influencing factor set is shown in Table 1 and Table 2.

Step 2: Questionnaire survey.

To improve the reliability of analysis result, this paper sends 30 questionnaires to 30 experts, and all of them are valid. Because of the limited space, the details of these questionnaires will not be reflected.

Step 3: Summarize the result of questionnaire survey according to equation (1).

$$A=\begin{bmatrix} 0.00 & 0.23 & 0.73 & 0.67 & 0.83 & 0.77 & 0.47 & 0.47 & 0.57 \\ 0.77 & 0.00 & 0.53 & 0.53 & 0.33 & 0.40 & 0.70 & 0.67 & 0.70 \\ 0.73 & 0.30 & 0.00 & 0.67 & 0.60 & 0.70 & 0.57 & 0.57 & 0.50 \\ 0.73 & 0.33 & 0.67 & 0.00 & 0.63 & 0.83 & 0.63 & 0.57 & 0.63 \\ 0.67 & 0.30 & 0.53 & 0.47 & 0.00 & 0.43 & 0.60 & 0.70 & 0.53 \\ 0.67 & 0.50 & 0.60 & 0.60 & 0.57 & 0.00 & 0.80 & 0.83 & 0.80 \\ 0.13 & 0.40 & 0.27 & 0.07 & 0.30 & 0.50 & 0.00 & 0.80 & 0.73 \\ 0.07 & 0.47 & 0.27 & 0.23 & 0.37 & 0.53 & 0.73 & 0.00 & 0.77 \\ 0.17 & 0.40 & 0.33 & 0.23 & 0.43 & 0.43 & 0.77 & 0.77 & 0.00 \end{bmatrix}$$

Step 4: Let the threshold λ be 0.7, the final adjacency relation matrix is:

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

Step 5: The reachability matrix is：

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

Step 6: Reachability sets and antecedent sets are shown in Table 3.

Table 3. Reachability sets and antecedent sets.

S_i	$R(S_i)$	$Q(S_i)$	$R(S_i) \cap Q(S_i)$
S_1	1,3,5,6,7,8,9	1,2,3,4	1,3
S_2	1,2,3,5,6,7,8,9	2	2
S_3	1,3,5,6,7,8,9	1,2,3,4	1,3
S_4	1,3,4,5,6,7,8,9	4	4

S_5	5,7,8,9	1,2,3,4,5	5
S_6	6,7,8,9	1,2,3,4,6	6
S_7	7,8,9	1,2,3,4,5,6,7,8,9	7,8,9
S_8	7,8,9	1,2,3,4,5,6,7,8,9	7,8,9
S_9	7,8,9	1,2,3,4,5,6,7,8,9	7,8,9

According to the rule $R(S_i) \cap Q(S_i) = R(S_i)$, the final level division result is described in Table 4 and Figure 2.

As can be seen from Table 4 and Figure 2, the 9 categories of influencing factors can be divided into 4 levels. Natural environment and policy environment are fundamental factors, which will not only affect the technical-economy effect of VSC-HVDC system, but also affect the economic environment and social environment within the influencing factor set. Price level, technical level, economic environment, and social environment belong to the intermediate level, and the price level and technology level can be affected by the latter two. Design requirements, equipment requirements and project features are superficial factors, which can be affected by all the other factors in the influencing factor set.

Table 4. Hierarchical structure of influencing factors.

Level	Influencing factors
I	S_7, S_8, S_9
II	S_5, S_6
III	S_1, S_3
Ⅳ	S_2, S_4

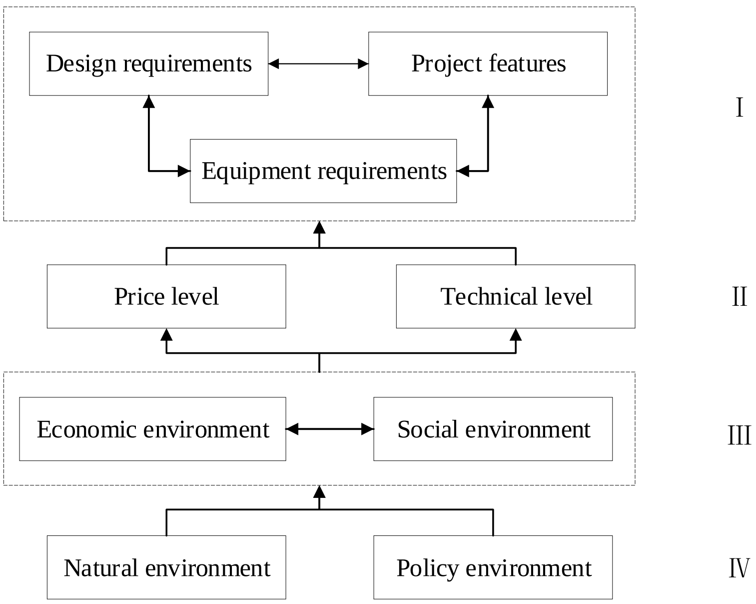

Figure 2. Multilevel hierarchical directed graph.

Based on the above study, we can summarize the technical-economy analysis procedure of VSC-HVDC system as follows:

Firstly, consider the consistency between VSC-HVDC project, natural condition and policy direction; secondly, discuss whether the economic and social environment can provide a smooth channel for VSC-HVDC project; thirdly, consider whether the technical condition can provide sufficient support, and whether the price level is within acceptable range; finally, formulate reasonable design scheme.

5. Conclusion

To provide decision support for investors, government and relevant institutions, this paper establishes a influencing factor system for technical-economy effect of VSC-HVDC system, and divides the hierarchical structure within the system based on improved fuzzy ISM method. The main conclusions are as follows:

(1) There are 39 influencing factors of technical-economy effect of VSC-HVDC system, which can be divided into 9 categories, including economic environment, natural environment, social environment, policy environment, price level, technical level, design requirements, equipment requirements and project features.

(2) Influencing factors of technical-economy effect of VSC-HVDC system can be divided into 4 levels. Natural environment and policy environment are fundamental factors; economic environment and social environment belong to the second level; price level and technical level belong to the third level; design requirements, equipment requirements and project features are superficial factors.

This paper gives a general summary for influencing factors of technical-economy effect of VSC-HVDC system. With the development of VSC-HVDC, the influencing factor system in this paper can be further complemented and perfected, the hierarchical structure division can be more thorough and comprehensive, and the research area can be further broadened.

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