Evaluation of Power Transmission and Transformation Projects using Fuzzy Multi-Layer Models

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***Abstract* — Investment in power transmission and transformation project is for profits as well as providing public service. As the grid expands, the evaluation of the early stages of investment and following operations is attracting increasing attention. Good evaluation after project completion (abbreviated to post-evaluation) of power transmission and transformation project can contribute to proper evaluation of the economic and social benefits in practice, to form the basis for subsequent power grid construction. Post evaluation of the project must be comprehensive and is expected to be multi-layered with unknown and random elements i.e. 'fuzzy'. In this paper we establish an index system of post-evaluation, build a relevant post-evaluation model, and examine the model in practical terms. The results show that this model can effectively evaluate the economic benefits of the power transmission and transformation project.**

Keywords - Post-evaluation; Power Transmission and Transformation Project; Fuzzy Comprehensive Evaluation

I. INTRODUCTION

Post-evaluation is the comprehensive and objective analysis of the objective, progress, benefit, function and influence of the projects that have been accomplished. Post-evaluation includes progress evaluation (implementation evaluation), benefit evaluation (both economic and social benefit), influence evaluation (evaluation of influence on economy, environment and society), and sustainability evaluation. Power industry is an important basic industry and public service for a country, while the investment of power transmission and transformation project is of profits, as well as a kind of public service. As the grid expands, the evaluation of the early stage investment and following operation is attracting increasing attention. In many occasions, the social and economic benefits generated in the construction and operation do not match the expectation in the early stage feasibility study. Through analysis of data about objectives such as construction progress and qualities, post-evaluation of power transmission and transformation project can evaluate the actual operation status, and examine the results of early stage feasibility study, during which the degree and reasons of the objective deviation in the decision making, construction process and operation can be located, so as to achieve the comprehensive and balanced development of both technical, economic, environmental and social benefits.

Power transmission and transformation projects tend to have long construction cycle and demand vast investment. They are also a kind of public service that could yield profits. Objectives such as technical index, economic efficiency, social influence and environmental friendliness, are all essential elements to evaluate the operation of power transmission and transformation projects. For the fact that each said objective belongs to a certain layer, the post-evaluation of the comprehensive operation is a typical fuzzy comprehensive evaluation. The post-evaluation model built on fuzzy theory will help to provide a comprehensive evaluation of the operation of power transmission and transformation projects.

II. LITERATURE REVIEW

In theory study level: Mingjun H [1] (2005) took the comprehensive post-evaluation of a 500 kV power transmission and transformation project as an example, and discussed the mathematical theory and evaluation progress of fuzzy hierarchy comprehensive evaluation. With analytic hierarchy process and Delphi method, he examined and confirmed this way of evaluation as reasonable and effective. Fuchun H [2] (2009) established a post-evaluation model for power transmission and transformation project based on analytic hierarchy process, and carried out a fuzzy hierarchy comprehensive evaluation of a certain power transmission and transformation project. Wenjie H [3] (2010) established a post-evaluation model for power transmission and transformation project based on modified analytic hierarchy process, and made evaluation of a certain power transmission and transformation project. Bin Z [4] (2011) established a index system for post-evaluation of power transmission and transformation project, and evaluated a 220 kV transmission and transformation project in Qianfangzi with fuzzy comprehensive evaluation. Junhong L [5] (2012) used fuzzy comprehensive evaluation and made post-evaluation on the economic benefits of a transmission and transformation project.

TABLE 1 SUCCESS EVALUATION FORM -- POWER TRANSMISSION AND TRANSFORMATION PROJECT FOR THE INDUSTRIAL PARK IN CHONGQING

Number	Item	Importance	Rating
1	Overall objective and industry policy	Less important	B
2	Decision making and related procedure	Important	A
3	Layout and scale	Important	A
4	Objective and market	Less important	B
5	Design and technical equipment level	Important	A
6	Resource and construction condition	Important	B
7	Funding and financing	Important	A
8	Safety control	Important	A
9	Progress control	Important	A
10	Quality control	Important	A
11	Investment control	Important	B
12	Project management	Less important	A
13	Organization and management	Important	A
14	Financial benefits	Less important	B
15	Economic benefits and influence	Less important	B
16	Social and environmental influence	Important	A
17	Sustainability	Important	A
	Overall evaluation	Important	A

NB: 1.Importance：important, less important, not important; 2.Rating: A—successful, B— partly successful, C—not successful, D—fail.

On a practical level, the post-evaluation of power transmission and transformation project by Chinese design and consulting company or institute tends to be limited to independent evaluation of objectives such as technical index, cost, as well as economic, social and environmental influence. The method is relatively simple and unsystematic, failing to achieve a comprehensive quantitative evaluation of the overall objective that a project aims to realize and provide a comprehensive evaluation of the project operation. Take the results of post-evaluation of a power transmission and transformation project for an industrial park in Chongqing by a Chinese design and consulting organization (Table 1), it is obvious that this evaluation is composed of independent rating of each objective, but without a comprehensive quantitative conclusion of the project's overall operation status. Therefore, it is of great significance to explore a feasible comprehensive evaluation model for power transmission and transformation project that is based on reasonable index system, so as to improve the future grid investment and construction plan and enhance the decision making and management level of the following projects, to achieve the expected technical and economic benefits of the power transmission and transformation projects.

III. METHODOLOGY

The paper aims to build a fuzzy comprehensive evaluation model, and apply it in real practice to evaluate the operation of the power transmission and transformation project. This methodology uses fuzzy set theory, making single factor evaluation of the object, and determines the weights of all factors with analytic hierarchy process, thus to provide a comprehensive result.

L.A. Zadeh created Fuzzy Theory in 1965. C.L. Hwang [6] introduced this mathematical way into post-evaluation and established fuzzy comprehensive evaluation, since which fuzzy comprehensive evaluation began to be wildly used in all industries. Through the evaluation result for the actual project, Xibin H[7]（2008）showed that the fuzzy comprehensive evaluation is a feasible method to the evaluation of green construction. Hongwei W[8] (2009) established a grid project comprehensive evaluation model based on fuzzy interval hierarchy evaluation. Xun D[9] (2011) used fuzzy comprehensive evaluation and analysis in the coal supply security early warning system. Cai W[10] (2016) established a model for coal burst liability assessment with fuzzy comprehensive evaluation. Jiao J[11] (2016) used fuzzy comprehensive evaluation in the adaption assessment of naval vessels.

The steps to make comprehensive evaluation of the operation of power transmission and transformation project with fuzzy comprehensive evaluation are as follows:

A. Build index hierarchy system.

According to the modeling requirement in analytic hierarchy process, we build a comprehensive evaluation index hierarchy system for power transmission and transformation project, in which first layer and second layer are main factors, while the third layer is sub-factor.

B. Determine the index set in each layer.

Divide the n factors into S mutually exclusive subsets (criteria layer) based on their properties: $U=\{U_1,U_2,U_3,...,U_S\}$; each subsets (criteria layer) is $U_i=\{u_{i1},u_{i2},u_{i3},...,u_{in_i}\}$, $(i=1,2,...,S)$. Obviously $n_1+n_2+...+n_s=n$.

C. Build remark set.

$V=\{v_1,v_2,...,v_m\}$, and make comprehensive evaluation of each subsets U_i. V_i (i=1, 2,,*m*) represents the remark on each level. In this paper, m equals to 5. Therefore, V_1, V_2, V_3, V_4,V_5 represents five possible post-evaluation results, which are Excellent, Good, Qualified, Relatively poor, Poor.

D. Determine the weight of factors in each index set layer with analytic hierarchy.

After building a hierarchical structure model, which means clarifying the membership relationship among the factors in different layers, we compare the importance of the pairs of factors in each set of each layer, and quantify the comparison based on certain ratio scale, to build a evaluation matrix, for example:

The weights of each index set in criteria layer U_i （*i* =1,2,3 ） is $A_i=(a_{i1},a_{i2},...,a_{in_i})$, in which $a_{i1}+a_{i2}+...+a_{in_i}=1$. If R_i is the $n_i\times m$ evaluation matrix of U_i, the evaluation vector of U_i should be:

$$B_i = A_i \cdot R_i = (b_{i1}, b_{i2}, ..., b_{im}), i = 1,2,..., S, \quad m = 5$$

.

E. Build fuzzy judgment matrix R.

After fuzzy matrix operation of matrix R_i in the established comprehensive evaluation index system, evaluation vector can be secured as:

$$R = A \cdot B = (a_1, a_2, ..., a_s)\begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1m} \\ b_{21} & b_{22} & \cdots & b_{2m} \\ \vdots & \vdots & & \vdots \\ b_{k1} & b_{k2} & \cdots & b_{km} \end{bmatrix} = (r_1, r_2, ..., r_m)$$

In the equation, A is the weight set of fuzzy evaluation factor U_i in criteria layer; R is the result of the fuzzy evaluation.

When $\sum_{i=1}^{m} r_i \neq 1$, we proceed with normalization. If $r = r_1 + r_2 + ... + r_m = \sum_{i=1}^{m} r_i$, the normalization is:

$$R^* = \left(\frac{r_1}{r}, \frac{r_2}{r}, ..., \frac{r_m}{r}\right) = (r_1^*, r_2^*, ..., r_m^*)$$

In the equation, r_{im} represents the degree of membership that U has to the remark set.

F. Evaluate the comprehensive results based on vector R （R） and maximum membership principle.*

IV. POST-EVALUATION INDEX SYSTEM OF POWER TRANSMISSION AND TRANSFORMATION PROJECT

Fuzzy comprehensive evaluation depends heavily on index system. When building such system, the paper adopts following principle in data screening: 1. Comprehensive: the evaluation index system is supposed to reveal all aspects of the project; 2. Easy to operate: only a simple and accessible index system can be wildly practiced and promoted; 3. Reliable data resource: in order to guarantee a true and comparable result, the index data in the system should share same reliable resource.

TABLE 2 COMPREHENSIVE POST-EVALUATION INDEX SYSTEM OF POWER TRANSMISSION AND TRANSFORMATION PROJECT

Objective layer	Criteria layer	Index layer
Comprehensive post-evaluation of the power transmission and transformation project U	Technical results U_1	power supply capacity U_{11}
		Load rate U_{12}
		Average load using hours U_{13}
		N-1 passing rate U_{14}
	Economic results U_2	Internal rate of return U_{21}
		Net present value U_{22}
		Pay back period U_{23}
		Return on investment U_{24}
	Social and environmental results U_3	Environment protection standard U_{31}
		Economic contribution rate U_{32}
		customer satisfaction U_{33}
		City infrastructure condition U_{34}
		Sustainability U_{35}

Post-evaluation of power transmission and transformation projects needs to consider a wide range of contents and many complicated index. The index such post-evaluation need to consider varies in different phase of

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the project. The economic post-evaluation focuses on the investment performance, including profitability, debt paying ability and capacity. Technical post-evaluation should mainly consider the power supply capacity, average load using hours, load rate and N-1 passing rate. Social and environmental post-evaluation should study project's influence on local environment, its contribution to local economy, sustainability and customer satisfaction. Post evaluation of decision making and construction can be accomplished with the technical and economic index, so there's no need to list it in here. The paper combines the aforesaid factors that would influence the comprehensive benefits and analyze them systematically, to build a post-evaluation index system showed in table 2.

V. ANALYSIS OF THE POWER TRANSMISSION AND TRANSFORMATION PROJECT FOR THE INDUSTRIAL PARK IN CHONGQING

A. Project background

The paper takes a 220kV power transmission and transformation project in Chongqing as example. The project plans to build 2×180MVA transformer, and cut off π line to connect to the existing 220 kV double circuit, aiming to satisfy the load demand of the industrial park and improve the layout of the grid in that area. The industrial park where this project is located is among the first batch of 30 featured industrial parks, hoping to become an important base for petrochemical and natural gas chemical industry in Chongqing, as well as the biggest base of chemical fiber and textile industry in the upper reaches of Yangtze River area.

This 220kV power transmission and transformation project was completed in May 23rd 2012, since which it has been working in good condition, stably providing power and enduring the full load operation during peak hours. For the past 3 years and 6 months, there was no unplanned shutdown or overhaul, except in July 16th 2013, the major substation shut down for 2# the high oil level of main transformer and 2# the movement in pressure relief advice. Until the post-evaluation, the highest load rate of major substation is 61%, still in the economical operation range; with 4 incoming power supply and 2 major transformers, it meets the requirement of N-1 and could be reliable power supplier. The project mainly supplies to industries, so the average load using hours are relatively high, which makes it an economical choice. To effectively evaluate the technical, economic, social and environmental results of this 220kV power transmission and transformation project, which has been operating for 3 years and 6 months, the paper takes fuzzy comprehensive evaluation as the methodology.

B. The application of fuzzy comprehensive evaluation model

The project panel collected and analyzed large amount of operation information, interviewed the involved organization and personnel, researched with questionnaire, and did field trip in the industrial park. The panel also did overall study about the operation and power supply status of the project through superior state grid company and involved clients, to accumulate the first hand information for the application of post-evaluation model.

1) Build fuzzy comprehensive evaluation index system.

According to the fuzzy comprehensive evaluation model this paper established, the setting of post-evaluation index set and remark set is as follows:

Post-evaluation $U=\{U_1,U_2,U_3\}$ ={Technical results, economic results, social and environmental results}

$U_1=\{u_{11},u_{12},u_{13},u_{14}\}$ ={Power supply capacity, load rate, average load using hours, N-1 passing rate}

$U_2=\{u_{21},u_{22},u_{23}, u_{24}\}$ ={Internal rate of return, net present value, pay back period, return on investment}

$U_3=\{u_{31},u_{32},u_{33},u_{34},u_{35}\}$ ={Environment protection standard, economic contribution rate, customer satisfaction, city infrastructure condition, sustainability}

$V=\{v_1,v_2,v_3,v_4,v_5\}$ = { Excellent, Good, Qualified, Relatively poor, Poor}

2) Fuzzy comprehensive marking

The panel marked each index in the model based on the information and data collected from the research and interviews with construction organization, users and related administrative departments, and proceeded the marks with normalization. See table 3 for the fuzzy judgment matrix.

TABLE 3 MARKING FORM FOR THE POST-EVALUATION OF THE POWER TRANSMISSION AND TRANSFORMATION PROJECT

Index		Rating				
		Excellent	Good	Qualified	Relatively poor	Poor
U_1	U_{11}	0.3	0.2	0.2	0.1	0.1
	U_{12}	0.2	0.2	0.2	0.2	0.2
	U_{13}	0.2	0.3	0.2	0.2	0.1
	U_{14}	0.2	0.3	0.2	0.1	0.2
U_2	U_{21}	0.1	0.2	0.3	0.2	0.2
	U_{22}	0.3	0.3	0.2	0.1	0.1
	U_{23}	0.2	0.3	0.2	0.2	0.1
	U_{24}	0.2	0.2	0.3	0.2	0.1
U_3	U_{31}	0.1	0.2	0.3	0.2	0.2
	U_{32}	0.2	0.3	0.2	0.2	0.1
	U_{33}	0.2	0.2	0.2	0.2	0.2
	U_{34}	0.3	0.2	0.3	0.1	0.1
	U_{35}	0.2	0.3	0.3	0.1	0.1

3) Determine the weight of index

After comparing the importance of each index, the specialists in the panel marked the index and built respective judgment matrix. The panel proceeded to check the consistency of all the matrix, and the results showed that they all meet the consistency requirement. The weights of each index in criteria layer are as follows:

A_1=(0.25，0.25，0.2，0.3)

A_2=(0.3，0.3，0.2，0.2)

A_3=(0.3，0.2，0.1，0.1，0.3)

4) Comprehensive evaluation result

Based on the marking form (table 2) and the weight of each index, the comprehensive evaluation result is as follows:

Comprehensive evaluation of U_1:

$$B_1 = A_1 \cdot R_1 = (0.25, 0.25, 0.2, 0.3)\begin{bmatrix} 0.3 & 0.3 & 0.2 & 0.1 & 0.1 \\ 0.2 & 0.3 & 0.3 & 0.1 & 0.1 \\ 0.2 & 0.2 & 0.3 & 0.2 & 0.1 \\ 0.3 & 0.3 & 0.2 & 0.1 & 0.1 \end{bmatrix}$$
$$= (0.255, 0.280, 0.245, 0.120, 0.100)$$

Comprehensive evaluation of U_2:

$$B_2 = A_2 \cdot R_2 = (0.3, 0.3, 0.2, 0.2)\begin{bmatrix} 0.3 & 0.3 & 0.2 & 0.1 & 0.1 \\ 0.3 & 0.3 & 0.2 & 0.1 & 0.1 \\ 0.2 & 0.3 & 0.2 & 0.2 & 0.1 \\ 0.2 & 0.2 & 0.3 & 0.2 & 0.1 \end{bmatrix}$$
$$= (0.260, 0.280, 0.220, 0.140, 0.100)$$

$$B_3 = A_3 \cdot R_3 = (0.3, 0.2, 0.1, 0.1, 0.3)\begin{bmatrix} 0.1 & 0.2 & 0.3 & 0.2 & 0.2 \\ 0.2 & 0.3 & 0.3 & 0.1 & 0.1 \\ 0.1 & 0.3 & 0.3 & 0.2 & 0.1 \\ 0.3 & 0.2 & 0.3 & 0.1 & 0.1 \\ 0.2 & 0.3 & 0.3 & 0.1 & 0.1 \end{bmatrix}$$
$$= (0.170, 0.260, 0.300, 0.140, 0.130)$$

Comprehensive evaluation of U_3:

Further comprehensive evaluation of the operation status: if the weights of technical results, economic results, social and environmental results respectively are A=(0.3，0.3，0.4), the final evaluation result would be:

$$R = A \cdot B = (0.3,0.3,0.4)\begin{bmatrix} 0.255 & 0.280 & 0.245 & 0.120 & 0.100 \\ 0.26 & 0.280 & 0.220 & 0.140 & 0.100 \\ 0.170 & 0.260 & 0.300 & 0.140 & 0.130 \end{bmatrix}$$
$$= (0.2225\ ,0.2720\ ,0.2595\ ,0.1340\ ,0.1120\ )$$

From the comprehensive evaluation result, we can see that: the maximum 0.2720 belongs to second grade of the rating. According to the maximum membership principle, the comprehensive evaluation of the power transmission and transformation project is “Good” and the result matches the actual operation status.

VI. CONCLUSION

According to the comprehensive evaluation result, the operation of the 200 kV power transmission and transformation project is qualified. The environmental protection measures taken in the design and construction process ensure an acceptable influence on local environment. The project can meet the local power supply need, and help improve the economic and social benefits of the investment, fulfilling its expectation. The paper introduces comprehensive evaluation model into the practice of post-evaluation of power transmission and transformation project. It analyzes the comprehensive evaluation of technical, economic, social and environmental results in such projects, and provides a good example to refer for such post-evaluation. It is of great theoretical and practical significance for subsequent investment decision making.

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