Renewable Energy Generation Commonality Risk Analysis Model Based on the Full Life-cycle

Shunkun YU[1], Guokun BAO[1, 2]

[1] *School of Economics and Management*, North China Electric Power University, Beijing 102206,China
[2] *School of Economics and Management*, Inner Mongolia University of Science and Technology, Baotou 014010, China

Abstract **- Taking the commonality risk system of renewable energy generation as the object, and introducing the full life cycle management theory, the paper analysis the risk factors of China's renewable energy generation by using interpretative structural modeling. It also construct a layered structure diagram for risk factors of renewable energy generation. By means of this diagram, the relationship and the level relations between risk factors of renewable energy generation can be visually seen. Then, the paper determines the source, process and terminal risk factors of China's renewable energy generation, and finally proposes a corresponding risk control approach.**

Keywords - Full life cycle; Renewable energy generation;Risk analysis

I. INTRODUCTION

The development of renewable energy in 12th five-year plan was announced in December of 2011 in China, this plan required that annual interest amount of renewable energy should reach 4.78 tons of standard coal, accounting for 9.5% in energy consumption at least[1]. This requirement provides an important opportunity for renewable energy generation in the next five years. Institutional investors pay more attention to renewable energy power generation projects for their characters of energy-saving and emission reduction, which promotes risk management of those projects to some extent.

However, the generation risk management of renewable energy is different from the traditional energy. It should not only cope with inherent risks in traditional energy generation (such as safety operation and maintenance optimization), but also face unprecedented risks (such as uncertain supply and demand, peaking equipment risk) [10], at the same time, some traditional risks are given new meaning[11]. At present, the risk management of renewable energy generation is only considereda single factor in China, such as the grid risk[2-5], electricity price risk[6-8], construction project risk[9]in wind power, solar energy and biomass power. The risk factors of renewable energy power generation are lack of systematic management[12,13], which leads measures cannot reach desired goal when conducting risk management, some measures are even contradictory with others frequently.

Based on the above analysis, in order to overcome the shortcomings on generation risk of renewable energy, this paper analyzed the risk factors based on the theory of whole life cycle, and further analyzed the relationship among those factors using interpretative structure modeling. So the system management for renewable energy power generation risk can be achieved.

II. LIFE CYCLE MANAGEMENT THEORY

Life Cycle Management (LCM) theory is originated from Life Cycle Cost (LCC) that presented by A. Gordon's in 1964. From the point of risk management, the project risk distributes in each phase of the project and the risk has different risk characteristics in different phase. So introducing LCM to divide the potential risk can help identify the possibility of the different risk and make targeted control in the corresponding phase.

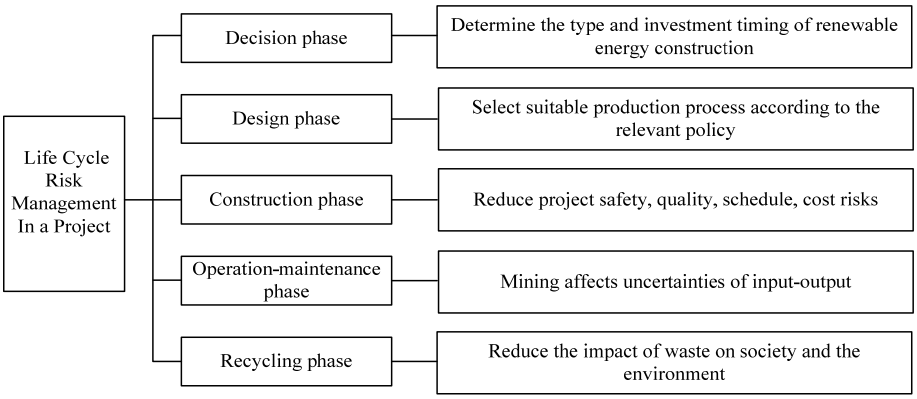

Figure 1 Process of life cycle risk management

In terms of the renewable energy generation project, the LCM should be based on comprehensive benefit, and then identify, analyze, estimate and control the potential risk. Risk identification could find the all risk factors in whole life cycle, risk analysis could take risk factors out, risk evaluation could estimate the risk loss and risk control could provide suitable control measures like risk deflection, risk avoidance, risk management and risk retention. Introducing LCM makes risk managements more timely, concentrated and accurate in the implementation process. So the difficulty of the risk management is reduced and the efficiency is improved.

COMMON RISK INDEX SYSTEM IN WHOLE LIFE CYCLE

The construction of common risk index system aims to reflect the risk factors of renewable energy generation projects in the whole life cycle, and to make accurate evaluation on the projects. So the construction of renewable energy power generation project could be promoted more scientifically. In this paper, the risk factors are divided by the life cycle, the main risks are determined in different period. The system covers five phases with a total of 27 risk factors in renewable energy generation investment, as shown in figure 2.

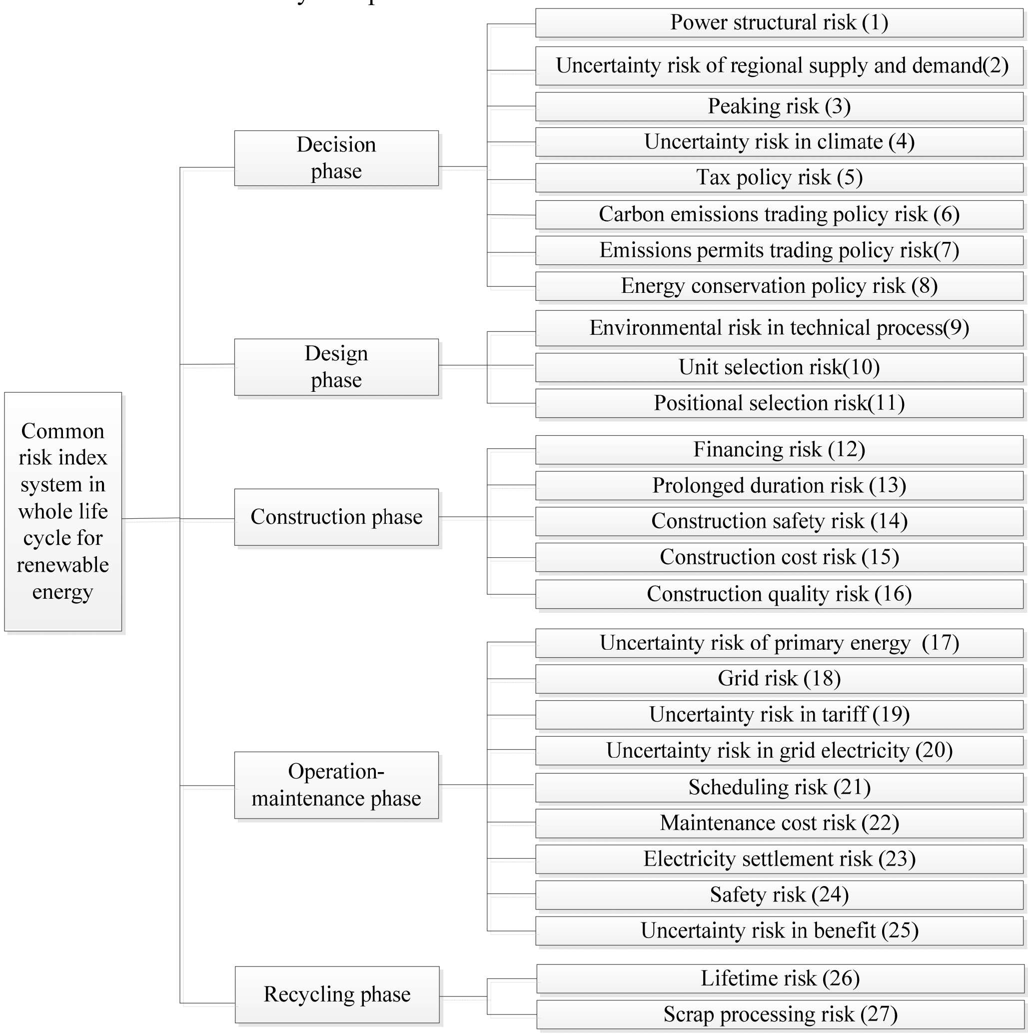

Figure 2 Universal risk index system of renewable energy

III. 4. COMMONALITY RISK ANALYSIS BASED ON ISM

A. *Interpretative structural modeling*

1) Overviewof ISM

In 1973, the interpretive structural model was proposed by Professor Phil J. Hua in America, and was applied to analyze complicated social-economic system. This model divided the complex system into a number of sub-systems by analyzing relationships among factors. It reflects a causal relationship between subsystems or internal elements by directed edges, so a system with obvious radial relationship and clear hierarchy is formed.

2) Elements inISM

Directed graph. Directed graph is a collection of nodes and directed edge. It reflects the relationship among the various elements. The relationship is shown in Figure 3.

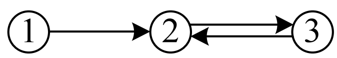

Figure.3 Directed graph of ISM.

In Figure 3, nodes 1, 2, 3 show elements in the system. The connection between node 1 and 2 means node 1 has a direct impact on 2. The connection between node 2 and 3 means the mutual influence.

Adjacency matrix. If there are n elements in the system, then there are $n \times n$ relationships between any two elements. The adjacency matrix $A = (a_{ij})_{n\times n}$ represents connection status among elements in the connection diagram, matrix elements a_{ij} represents the effect of i on j . a_{ij} is equal to 1when element i affects j, a_{ij} is equal to 0 when element i do not affect j.

Reach ability matrix. There may not be a direct impact among elements, but there may be indirect relationship through the transmission. The reach ability matrix can express that if there is causal delivery path from one element to another, it reflects reach ability degree of each element in directed graph. The adjacency matrix A satisfies this formula:

$$(I + A)^m = I + A + A^2 + \cdots + A^m$$

If matrix M meets the following formula when m is big enough.

$$(A+I) \neq (A+I)^2 \neq \ldots\ldots \neq (A+I)^m = (A+I)^{m+1}, (m < n-1)$$

So we can get this adjacency matrix. $M = (A+I)^{k+1}$.

3)Build-steps of ISM

The build-steps of ISM are as follows.

Define analytical goal. The construction goal of ISM should be understood at first, and then related factors could be found in the model.

Identify risk factors. Potential risk factors are discovered by research needs, so the elements of the system are formed.

Establish awareness model. This step needs to determine the directed relationships among elements, and then establish awareness model with the adjacency matrix, so the reach ability matrix can be solved.

Generate structural model. This step needs to divide ranks base on the reach ability matrix, and the system structure is expressed by multilevel hierarchical directed graph.

Interpret structural model. This step needs to do further analysis for the results of directed graph and to research incentive of elements transfer.

B. Commonality risk structuralmode

1) Awareness model

Causal relationships among elements are determined by commonality risk indicator system of renewable energy generation project, relationships are shown in table 1.

TABLE.1 IMPACT RELATIONSHIP OF RISK INDICATORS

Indicators	Impact indicators	Indicators	Impact indicators
(1)	(6)(7)(8)(10)(18)(21)	(15)	(12)(13)(16)(25)
(2)	(3)(21)	(16)	(13)(14)(15)(22)(24)(25)(26)(27)
(3)	(10)(21)	(17)	(20)(21)(25)
(4)	(2)(11)(17)(20)(21)(22)(24)	(18)	(20)(25)
(5)	(12)	(19)	(23)(25)
(6)	(9)(10)(11)(25)	(20)	(25)
(7)	(9)(10)(11)(25)	(21)	(20)(24)(25)
(8)	(9)(10)(11)(18)(20)(21)(25)	(22)	(25)
(9)	(12)(13)(15)(21)(22)(26)	(23)	(25)
(10)	(12)(13)(15)(21)(22)(26)(27)	(24)	(25)
(11)	(14)(17)(18)(19)(21)(22)(24)	(25)	--
(12)	(13)(15)(16)(25)	(26)	(25)
(13)	(12)(14)(15)(16)(18)(25)	(27)	(25)
(14)	(13)(15)(25)		

We can get the adjacency matrix A from relationships in table 1. The next step needs to obtain the reach ability matrix of risk factors according to equations of (3-2), (3-3). The essence of the reach ability matrix is to obtain the stable form of adjacency matrix, unit matrix and multi-stage squaring matrix according to the laws of Boolean algebra.

The computing of reach ability matrix is to make four times of adjacency matrix squaring based on Boolean algebra algorithm.

2) Structural mode

(1) Regional division. In order to analyze the transfer relationship of each element in the system, regional division is needed after obtaining the reach ability matrix, the system is divided into several subsystems. For the element i , the set of elements which influenced by i is defined as $R_{(i)}$ (reachable set). In addition, the set of impact elements such as i is defined as $T_{(i)}$ (antecedent set). If element i is the most advanced element in the M, then we can get the following formula.

TABLE.2 FRAMEWORK MATRIX OF RENEWABLE ENERGY GENERATION'S RISK FACTORS

	25	20	22	23	24	26	27	18	19	21	16	17	5	9	10	11	3	6	7	8	1	2	4
25	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	1	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
16	1	1	1	0	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
17	1	1	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
5	1	1	1	0	1	1	1	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
9	1	1	1	0	1	1	1	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0
10	1	1	1	0	1	1	1	1	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0
11	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0
3	1	1	1	0	1	1	1	1	0	1	1	0	0	0	1	0	1	0	0	0	0	0	0
6	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	0	0	0	0	0
7	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	1	0	0	0	0
8	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0	1	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	0	0
2	1	1	1	0	1	1	1	1	0	1	1	0	0	0	1	0	1	0	0	0	0	1	0
4	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	0	0	0	1	1

$$R_{(i)}=R_{(i)}\cap T_{(i)}$$

According to the above formula, the element with highest level in structure can be determined and then the appropriate row and column should be struck out. The next step is to find new element with highest level and repeat the above step. Then advanced elements set can be found and partition of reach ability matrix is realized. For the example of M, the reachable set and antecedent set of element (25) meet the following formula.

$$R_{(25)}=R_{(25)}\cap T_{(25)}$$

Therefore, element (25) has the highest level in whole system. The ranks corresponding to element (25) are deleted to form a new matrix. The next step is to find new element with highest level and repeat the above step. The matrix M can be divided into 8 layers.

(2) The framework matrix. Risk elements (12) - (16) in construction stage are strongly connected elements. There are interactive relationships among elements, and the strongly connected elements are completely connected in stage, so elements that they influence or influence them are identical. Through the establishment of framework matrix, a hierarchical graph can be obtained more convenient, and the complex connections will be decreased. Therefore, risk elements (12) - (15) are removed in framework matrix, as shown in Table 2.

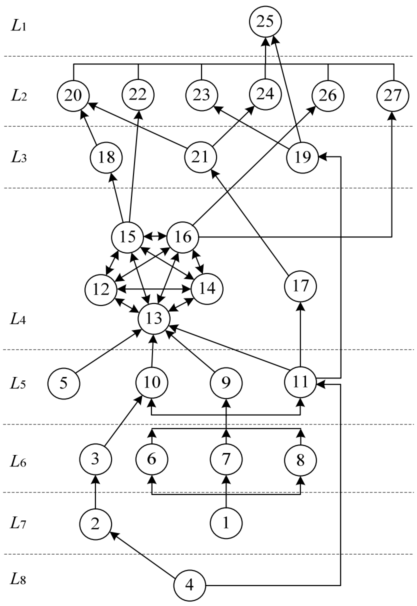

Figure4 Digraph of the renewable energy project investment risk factors

(3) The hierarchical graph. The hierarchical graph of investment risk factors for renewable energy project can be drawn combined with table 2, so the transfer relationships of risk factors can be expressed more intuitive, as shown in figure 4.

4.2.3 Result analysis

According to figure 4, the investment risk factors of renewable energy project can be divided into eight levels using interpretive structural model, this will facilitate the enterprise to distinguish and manage the complicated risk factors. Through the hierarchical graph, enterprises can quickly find the impact of a risk factor or the lead factor, so enterprises can understand risk factors more deeply and then enhance the risk management efficiency. Because the risk factors of renewable energy projects are strongly correlated factors in construction stage, enterprises can focus on management of one risk factor according to their characteristics. Using the strong relationships of risks can help improve the efficiency of risk control and management.

From the hierarchical graph, we can see the property of different risk factors is different, such as terminal risks, process risks, sources of risks. For example, the uncertainty risk in benefit (25) in the first layer is a terminal risk, and the occurrence of various risks will affect it through risk transfer, these effects will ultimately reflect in the benefit.

The process risks are from the second to the seventh layer. They will be affected indirectly by source or other risks, and then affects the terminal risks directly or through other risks. Among them, risks in the second layer [including uncertainty risk in grid electricity (20), maintenance cost risk (22), electricity settlement risk (23), safety risk (24), lifetime risk (26), scrap processing risk (27)] and in the third layer [including uncertainty risk in tariff (19)] affect the benefits of renewable energy generation project directly. Enterprises should control the critical process risks combined with their own situation. The uncertainty risk in climate (4) in the eighth layer belongs to source of risk. It affects other risk through uncertainty risk of regional supply and demand(2),positional selection risk(11) and uncertainty risk in tariff (19), and finally affects the terminal risks indirectly. Because the enterprises cannot control the uncertainty risk in climate, so they should do preventive work in advance. The power structural risk (1) and tax policy risk (5) affect other risks only, and there are not risks to influence them. When controlling renewable energy generation, the enterprises should be as detailed as possible to do research work. They should also reduce the effects of uncertainty and avoid losses due to improper control.

IV. CONCLUSIONS

This paper has analyzed the risk factors in different stages of renewable energy generation in China using the life cycle theory, and has been simplified the risk factors using ISM, the main conclusions are as follows.

In the management of renewable energy generation risk, relationships among risk factors should be considered. The implementation of risk measures from overall perspective can obtain better management effectiveness.

The risk factors of renewable energy generation can be analyzed more comprehensively by using ISM, and systemic risk structure model can be formed more clearly and completely, so a complete framework for the risk management will be provided.

Through the introduction of the life cycle theory into ISM, relationships among elements can be analyzed better, and a new developing direction of ISM is opened up.

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