System Dynamics Modelling of Renewable Power Generation Investment Decisions under Risk

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***Abstract* -- As an emerging industry, renewable energy power generation has the advantages of low pollution, renewable, energy conservation and emission reduction. Its development potential is tremendous, suitable for the development of modern social philosophy. As more and more institutions began to invest in renewable energy power generation project, the impact of the uncertain factors in the process on the investment performance is also growing. This paper proposes investment risk evaluation index system and performance evaluation index system of the renewable energy power generation. Then it establishes a renewable energy power generation system dynamics model of investment risk decision, on the basis of the relationship between the elements of the system are analysed. It is deduced that for renewable energy power generation, the elements of the process of investment risk decision-making has positive or negative feedback. It is helpful to take more targeted risk control strategy to make the renewable energy power generation investment system more stable.**

Keywords* -- *Renewable power generation investment; Risk controlling; Investment performance; Risk decisions; System dynamics model

1. INTRODUCTION

Under the background of both protecting the development and promoting the transformation, the development and utilization of renewable energy are becoming more and more important, and the development of renewable energy has become the necessary way to solve the energy conservation and emission reduction of power generation industry in China. As the basic way to coordinate the social economic development, to ensure the energy security and to deal with the climate change, realizing the energy conservation and emission reduction of power generation industry has been generally recognized by the countries all over the world. In the face of increasingly severe resource environment and energy security posture, China's renewable energy power generation industry is developing rapidly. While there are many uncertain factors in the construction of renewable energy power generation project and it is facing more and more risks, and the internal relations between these risk factors are more intricate and the cross-impacts between risk factors and external factors are multiple-layered. Therefore, the research on the investment risk of the renewable energy power generation is helpful to control the investment risk of the renewable energy project, and to maximize the efficiency of the investment.

System Dynamics, SD. A major feature of the SD model is that it can make long-term, dynamic and strategic quantitative analysis, and so far, it has been widely used in the fields of population, economy, environment, energy, education and so on. For the power industry risk research, the literature [1] builds the offshore power engineering project investment risk prevention and control system which is suitable for power supply enterprises from the aspects of enterprise itself and the government. The literature [2] analyzed the risks and precautions in the process of financing and construction of power plant. The literature [3] discussed the reasons and sources of investment risks of power enterprises, as well as the impact of risk and the characteristics of investment in power generation enterprises. The literature [4] established the interpretative structural model (ISM) for the power industry investment marketing factors, and used this model to analyze the investment risk of the power generation industry, and analyzed the primary and secondary and internal relations of the factors. The literature [5] analyzed the characteristics of electric power supply chain and established the power combination model of bi-objective programming. In the field of application of system dynamics, the literature [6] proposed that recognize the risk factors, category attributes, development and evolution path of the project risk of large-scale design enterprises by using system dynamics theory. The literature [7] studied the system dynamic model of power generation investment under the electricity market environment and validated the correctness and effectiveness of system dynamic model with imitation results and sensitivity analysis. The literature [8] introduced the system dynamic model and analyzed the carbon emission of future electric power system in China with it. In literature [9], the power generation investment system is used as the sub structure of the long-term dynamic model of the electricity market. It simulated the dynamic evolution law of the electricity market and the analysis of the power generation investment is relatively simple. Based on the current research status at home and abroad, using system dynamics to research renewable energy generation

investment risk and establishing system dynamics model to analyze the impact of various factors on the risk system have certain reference significance in developing renewable energy risk control strategies and ensuring the investment efficiency.

TABLE 1. INVESTMENT RISK EVALUATION SYSTEM OF RENEWABLE ENERGY POWER GENERATION

	Total categories	**Primary indicator**	**Secondary indicator**	
Renewable Energy Power Generation Investment Risk	External risks	1）natural environment risks	Wind, light and other resource conditions	
			weather and climate conditions	
			Natural geological hazards	
		2）legal policy risks	Legal environmental conditions	
			Industrial policy	
			Electrovalence regulation and adjustment policies	
			Power dispatching and market transactions policies	
		3）economic risks	Macroeconomic environment	
			Regional economy environment	
			Development degree of power grid	
		4）market risks	Growth ability of market	
			Industrial competitions	
			Industry life cycle	
			Difficulty of market admittance	
		5）technology risks	Technical self research and development abilities	
			Technical maturity	
			Technical advancement	
	Internal risks	1）planning, organization and management risks	planning risks	Position of power source
				Power types
				Power capacity
			construction risks	Materials of construction
				Safety in construction
				Construction quality
				Construction period and cost
			Fitness of organization structure	
			Level of management and control system	
		2）operational risks	Decision-making level	
			Accuracy of load prediction	
			Maintenance arrangements	
			Material management	
			Economic dispatch	
			Bidding strategies	
			Information accuracy	
		3）financial risks	Financing capacity	
			Fund structure	
			Profitability	
			Distribution of profits	
		4）human resource risks	Personnel allotment and reserve	
			Salary design	
			Training of workers and staff	
		5）security risks	Security defense capability	
			Emergency capacity	
			Crypto security	

This paper selected the system dynamic theory and method and established the SD model, the main objectives are followed: firstly, the main risk factors of the investment risk decision making system of renewable energy power generation are analyzed; secondly, the relationship between risk, risk control and investment performance as well as the whole information feedback mechanism in the process of investment risk decision-

making of renewable energy power generation is studied, and causality diagram of each subsystem and system dynamics diagram of the whole system are painted; and then factor correlation analysis of system dynamic model is made, so that it can make the investment risk control strategy of renewable energy power generation more targeted.

II. INVESTMENT RISK EVALUATION INDEX SYSTEM AND PERFORMANCE EVALUATION INDEX SYSTEM OF RENEWABLE ENERGY POWER GENERATION

Based on the main characteristics of the investment risk strategies of renewable energy power generation, by means of combing the relevant literatures at home and abroad, renewable energy power generation investment risk can be divided into internal risk factors and external risk factors according to the location of risk in enterprise. Internal risks include natural environment risks, legal policy risks, economic risks, market risks and technology risks. External risks include planning, organization and management risks, operational risks, financial risks, human resource risks and security risks. The risk evaluation index system that produces and affects these risks is shown in Table 1.

The power generation investment performance of renewable energy power enterprises can be evaluated from the aspects of economic benefits, social benefits and environmental benefits of investment projects and abilities of power enterprises themselves so that the evaluation index system of renewable energy power generation investment performance can be shown in Table 2.

TABLE 2. THE INVESTMENT RISK PERFORMANCE EVALUATION INDEX SYSTEM OF THE RENEWABLE ENERGY POWER GENERATION

Evaluation target	Index types		Evaluation index
Investment performance of renewable power generation	Economic benefits of investment		Net assets returns ratio
			Profit ratio of sales
			Ratio of profits to cost
			EVA
			Revenue
	Social benefits of investment		Regional economic Development impact
			Increment rate of labor employment
			The lives of residents impact
			Industrial technology progress impact
			Renewable energy power increment
	Environmental benefits of investment		Fractional energy saving
			Emission reduction rate
			Regional environmental quality impact
			Environmental management ability
	Abilities of power enterprises	Financial conditions	Total assets turnover
			Liquidity ratio
			Asset-liability ratio
		Management abilities	The perfection of management system
			The perfection of supervision system
			Optimization of management team
		Technological innovation abilities	Research and development expenditure
			Research and development personnel proportion
			Development cycle of new power generation technology and equipment
			Numbers of professional skill
			Introduction rate of new power technology
		Power enterprise social capital	Government-enterprise relationship index
			Loyal power consumer ratio
			Index of cooperation with scientific research institutions
		Power enterprise growth opportunities	Total Assets Growth Rate
			Operating profit growth rate
			Functionality
			Market prospect

III. RENEWABLE ENERGY POWER GENERATION SYSTEM DYNAMICS MODEL OF INVESTMENT RISK DECISION

A. System Boundary

From the system point of view, the investment risk management and decision-making of renewable energy power generation is an organic whole with specific functions, which is composed of a variety of factors, the system consists of three subsystems, including investment risk, risk control and investment performance, and the three subsystem also contains a large number of departments, which continually carry out a variety of information, goods and money exchanges in the implementation of their respective functions and the external environment as well as between the departments. All of these decided that the renewable energy generation investment risk decision-making can be regarded as a dynamic and complex system, and the target of investment decision is to coordinate each subsystems of this dynamic system, to ensure the whole system to play a maximum efficiency and function, to control risk effectively and improve investment performance.

The dynamic behavior pattern of any system is generated by the interaction of the elements within the system boundaries. We must set a certain limit firstly to build the renewable energy power generation system dynamic model of investment risk decision, and the determination of system boundary is mainly based on the modelling objectives of the system and the feedback mechanism of the renewable energy generation investment risk decision-making. After the boundary of the system is defined, the endogenous and exogenous variables of the system are determined. The scope of this paper includes three models: renewable energy power generation investment risk model, risk control strategy model and investment performance model. Variable factors in the first model mainly include the risk factors in the process of renewable energy power generation investment, as well as the key measurement factors that influence these risks and the key elements which bring these risks and these risks will affect the investment performance ultimately. Variable factors in the second model mainly include risk control strategies in the process of renewable energy power generation investment. The implementation intensity of these strategies is influenced by the investment performance of renewable energy and will have an effect on the investment risk control rate of renewable energy eventually. Variable factors in the third model mainly include renewable energy power generation investment performance which is influenced by the investment risk and will influence the risk control strategies eventually.

B. Cause-and-effect Diagram

B1. Causality diagram of the system

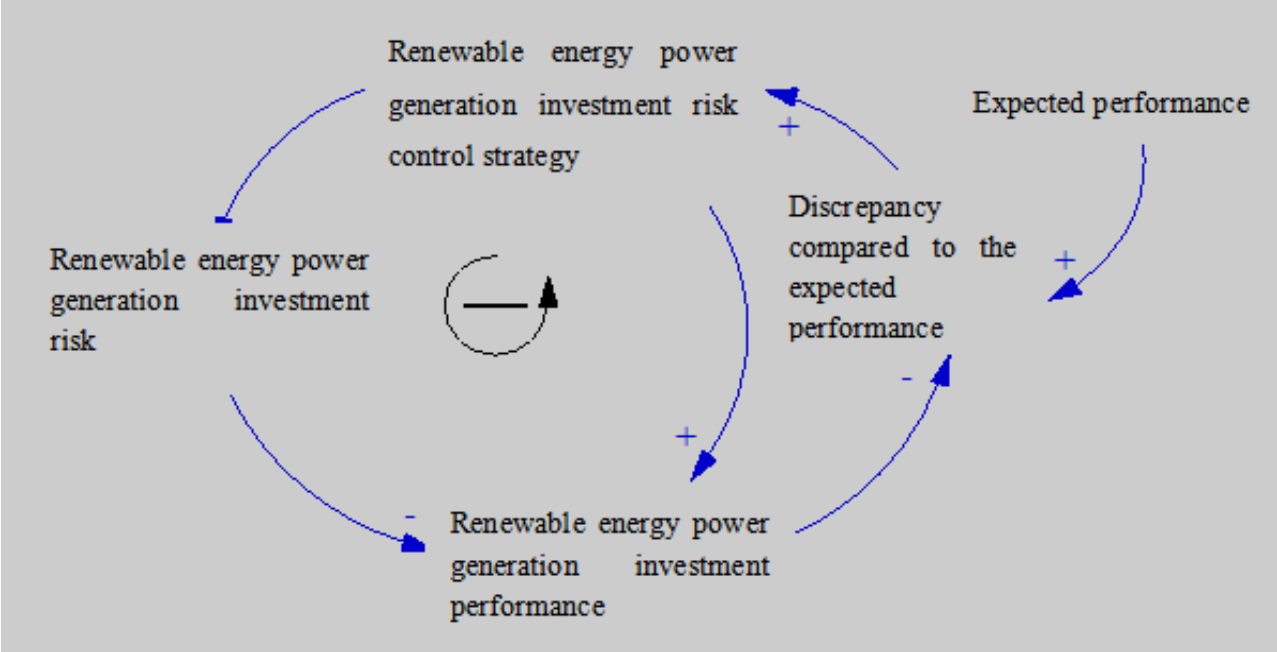

Figure. (1). Renewable Energy Power Generation Investment Risk Decision-making System Overall Causality Diagram

According to the relationship and the overall structure of risk, risk control and investment performance in the renewable energy power generation investment risk decision-making system, we can obtain the overall causality diagram of the renewable energy power generation investment risk decision-making system (as is shown in Figure. (1)). Based on the theory of system dynamic, the renewable energy power generation investment risk decision-making system is a recycle-back blend system. The whole system is composed of 3 basic units, such as expected performance, positive and negative deviation and system state. As is shown in Fig. (1), in this system, when the investment risk in renewable energy power generation increasing, it will have a negative impact on the renewable energy generation investment performance, and will make renewable energy generation investment performance deviated from the expected performance gradually; while the increase of the deviation degree will prompt investment enterprises to strengthen the implementation of risk control strategy and gradually reduce the investment risk of renewable energy power generation, so that they can increase the investment performance. This is a negative feedback loop and the system will tend to steady state eventually. So we can see that the risk has been the main limiting factors for the performance of enterprise investment and only when the investing enterprises control the risk of each stage of investment in a certain range and inhibit the increase of risk factors, can they gain much more benefits. For this reason, the following will analyze the risk factors in the process of renewable energy power generation investment firstly, and then determine the causal relationship between the risk factors.

B2. Subsystem of the renewable energy power generation investment risk

There has been the investment risk evaluation index system of renewable energy power generation in section 2 and the causality of these risk factors is shown in figure .(2). From the diagram we can see that the investment risk of renewable energy power generation includes 10 kinds of risks and 43 key measuring factors.

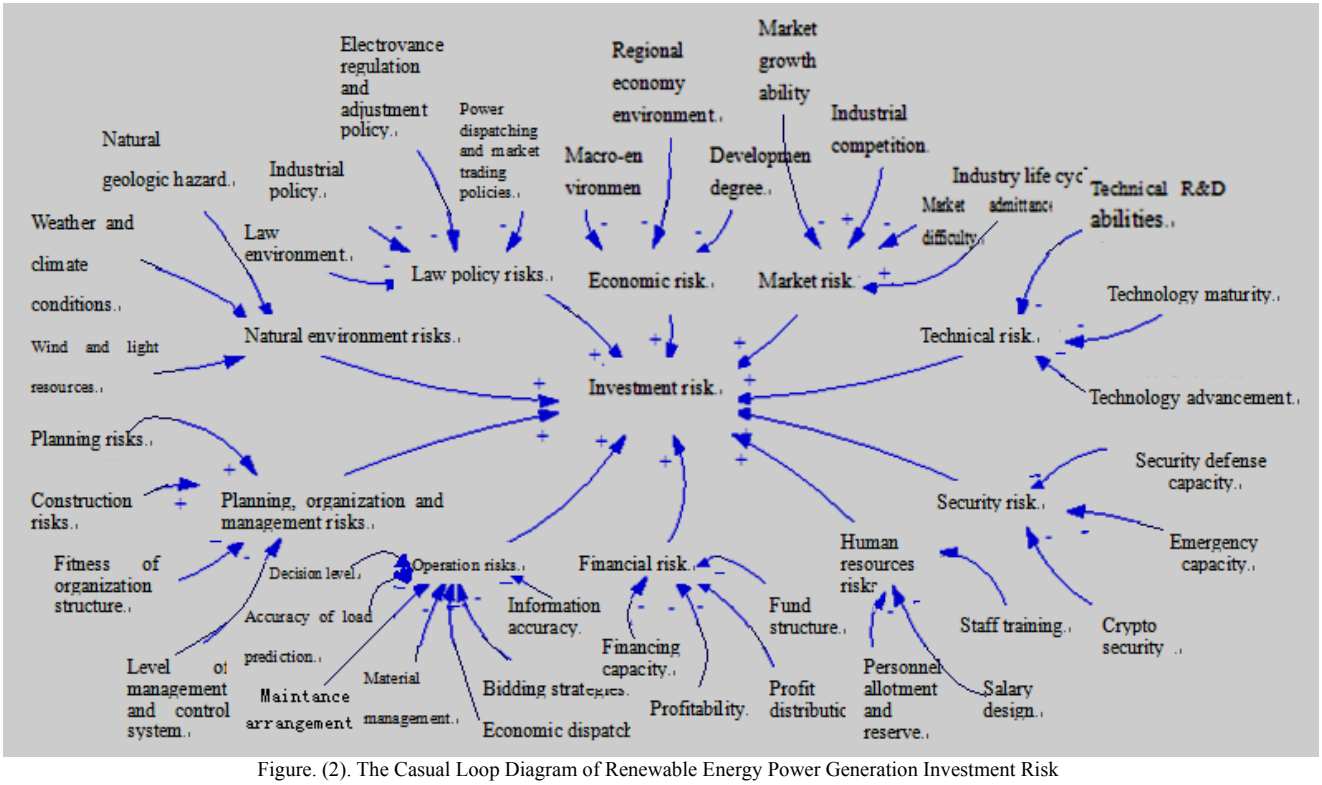

Figure. (2). The Casual Loop Diagram of Renewable Energy Power Generation Investment Risk

B3. Investment risk control subsystem of the renewable energy power generation

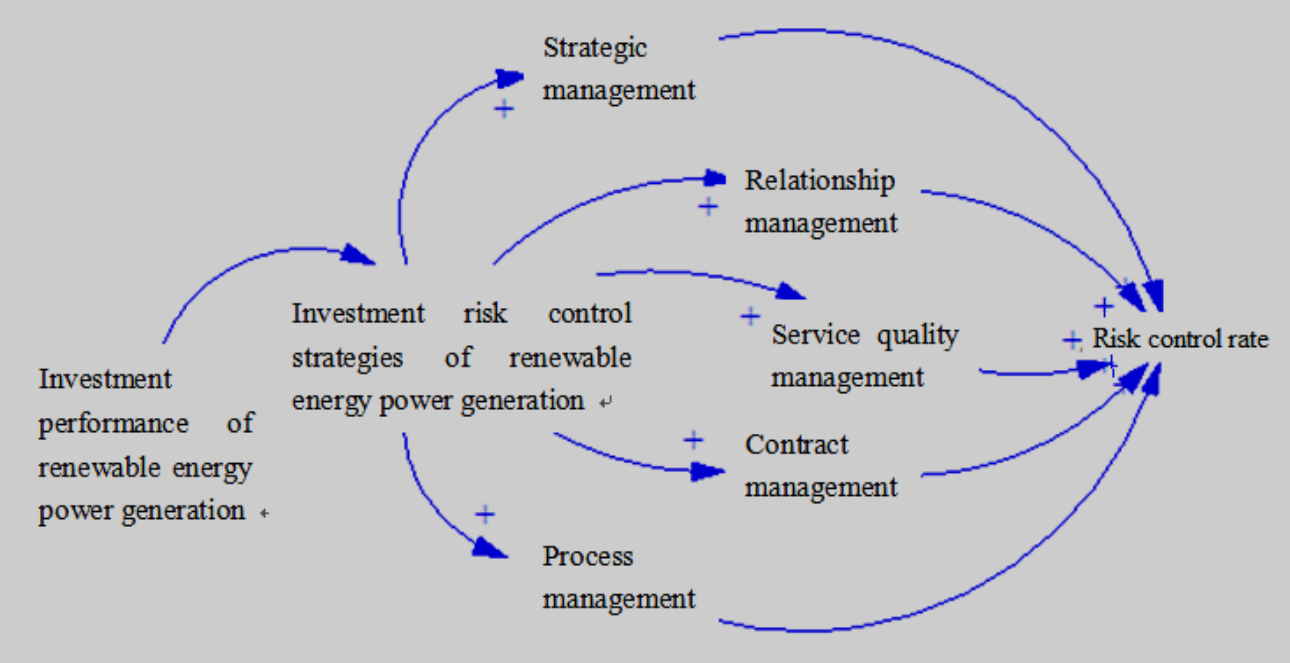

Figure. (3). The Casual Loop Diagram of The Renewable Energy Power Generation Investment Risk Control Strategies Subsystem

From the whole casual loop diagram mentioned above we can see that the investment risk will influence investment performance and the deviation between investment performance and expected performance will determined the control of investment risk directly. Figure. (3) is the casual loop diagram of the renewable energy power generation investment risk control strategy subsystem. Figure shows that investment risk control strategies are determined by investment performance and there will be five kinds of control strategies, such as strategic management, relationship management, management of service quality, contract management and process management.

These five kinds of strategies can influence the risk control rate of variety risks from different aspects, in order to reduce the incidence rate of various types of risks. Strategic management includes a series of control activities of achieving the goal of electric power enterprises, and will affect the 10 types of risk control rate of the renewable energy power generation investment; Relationship management is mainly aimed to improve the relationship with power consumers and is related to the risk control rate of the planning and management risk, operational risk, financing risk and human resource risk of the internal risks; management of service quality is mainly aimed at the protection and supervision of power consumer service quality and is corresponded with the risk control rate of planning and management risk, operational risk and human resource risk of the internal risks; contract management is the overall management of all symbiosis in the process of the renewable energy power generation investment and it will run through the whole process of the power enterprises' project from construction to operation, so it is related to all 10 types risk control rates; process management lists the main resources and activates in the power enterprises as the process in order that they can plan as a whole and will influence the risk control rate of the planning and management risk, operational risk, financing risk and human resource risk of the internal risks. These five kinds of renewable energy power generation investment strategies can influence the risk occurrence rate from different degree and these interaction relations will be incorporated into the system dynamics model below.

B4. Renewable energy power generation investment performance control subsystem

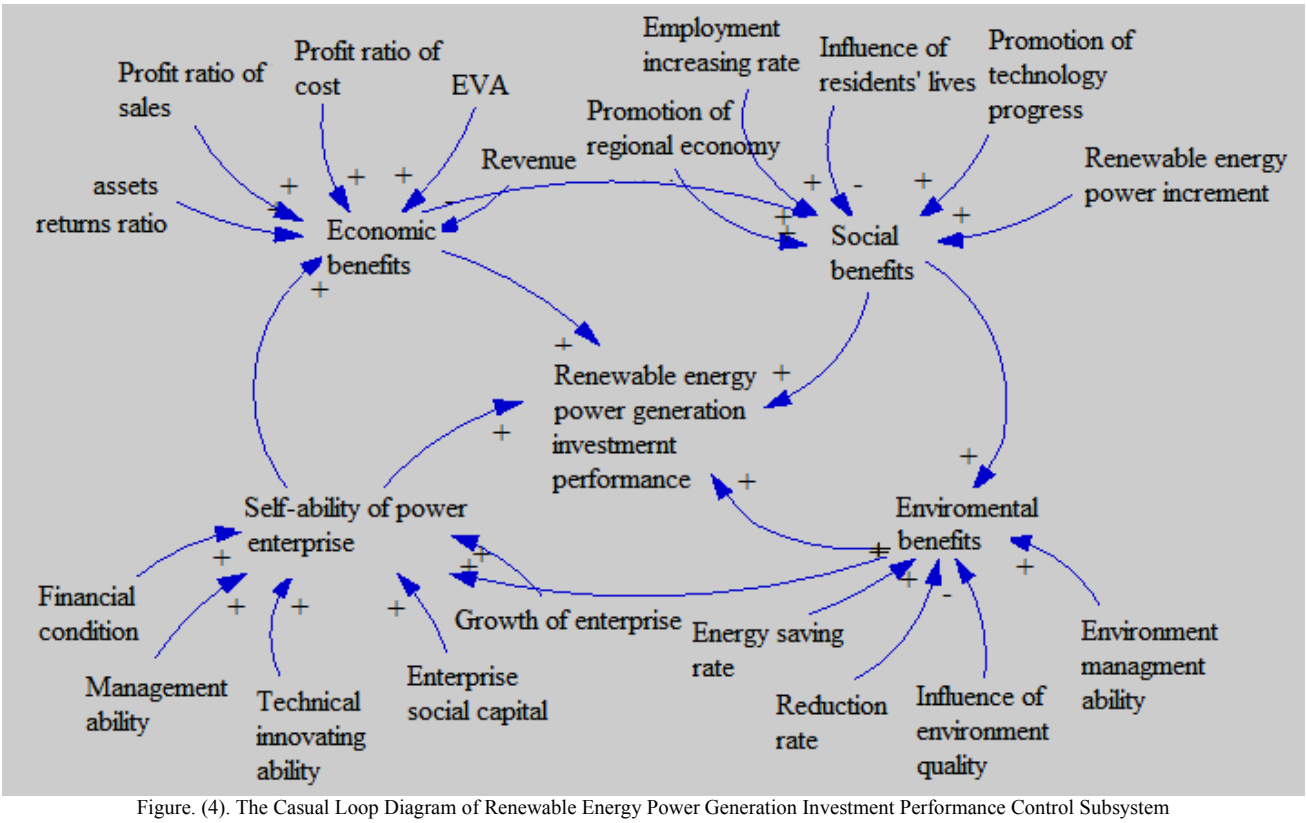

Figure. (4). The Casual Loop Diagram of Renewable Energy Power Generation Investment Performance Control Subsystem

There has been the investment performance evaluation index system of renewable energy power generation in section 2 and the causality diagram of renewable energy power generation investment performance subsystem is shown in figure. (4). In this paper, we adopt expert scoring method, and we can see from the diagram that experts can measure the economic benefits of investment by net assets income rate, profit ratio of sales, ratio of profits to cost, EVA and taxes after renewable energy projects invested; and experts can measure the social benefits of investment according to the renewable energy generation projects impact on the regional economic development, employment increase contribution rate, impact on the lives of the residents, the push to industrial technology and renewable energy power increments. and measure the environmental benefits of investment according to the energy saving contribution, emission reduction contribution, impact on regional environment quality and environmental management capacity of renewable energy power generation investment projects; and measure the abilities of power enterprises themselves according to the financial condition, management ability, technological innovative ability, social capital and growth of power enterprises; all of these four aspects together constitute the power enterprise's renewable energy power generation investment performance. In this process, experts empower and score the comprehensive indicators in four aspects of power enterprise based on specific evaluation indicators, and calculate the total investment performance value ultimately.

IV. SD MODEL AND CORRELATION ANALYSIS OF SYSTEM FACTORS

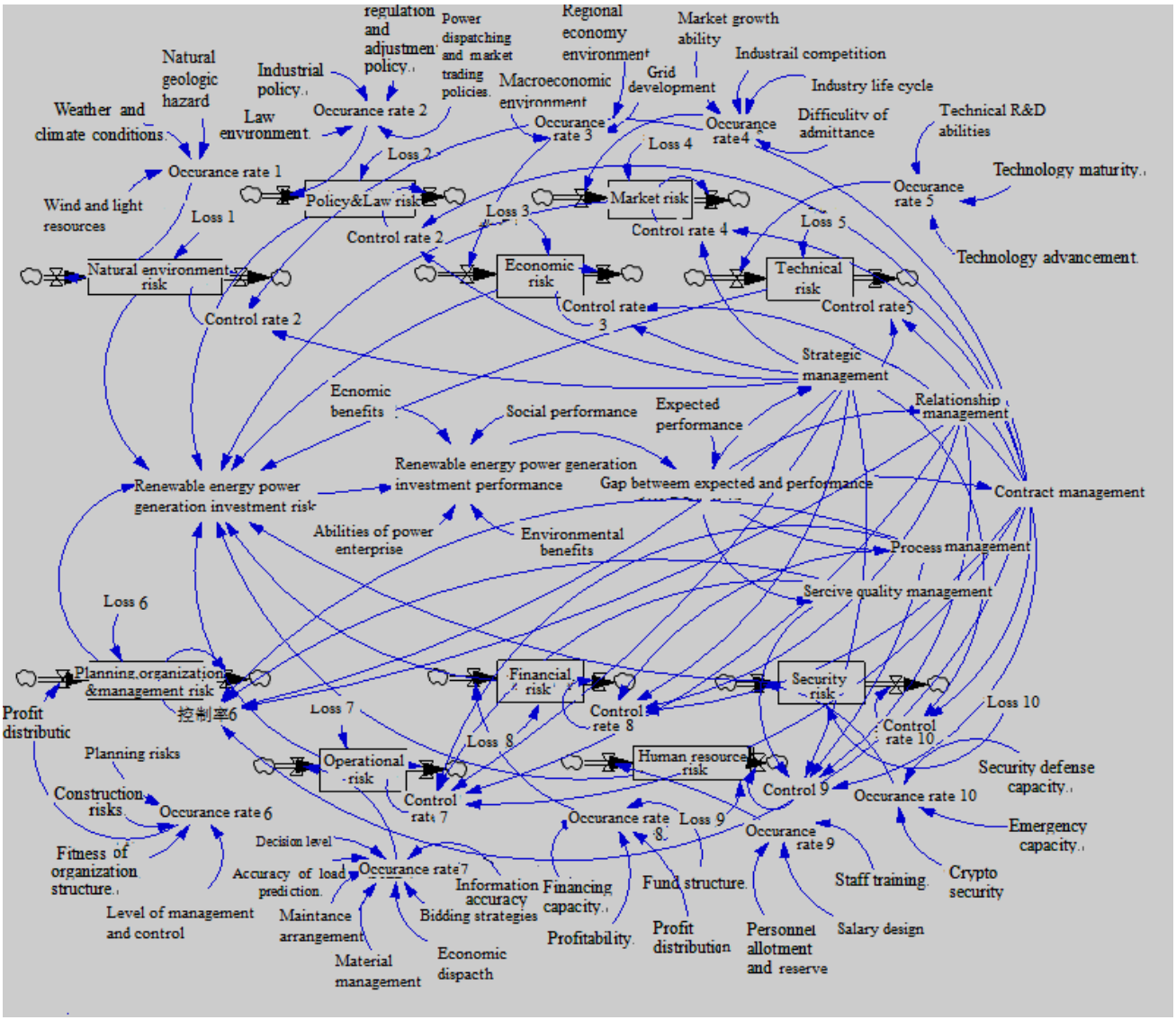

Figure. (5). SD Model of Renewable Energy Power Generation Investment Risk System

According to the deep analysis of renewable energy power generation investment risk performance integrated system and the causal relationship between each subsystem within the system, this paper established the system dynamic model of renewable energy power generation investment risk performance and the detail is shown in figure 4-1. From the figure we can see that three subsystems are incorporated into the SD model, and the feedback mechanism is formed by the interaction between the subsystems. Its specific mechanism of action is as follows: both under extraneous risks and inner risks form the investment risk of renewable energy power generation; the risks influence the performance meanwhile the performance is determined by both the economic benefits, social benefits, environmental benefits of investing enterprises and the abilities of power enterprises themselves; while the deviation of investment performance and expected performance decides the strength of risk control, the enterprise will control the risk through five kinds of risk control strategies, and ultimately reduce the incidence of risk, and then reduce the investment risk, improve the investment performance.

From the figure 4-1 we can see that the increase of occurrence rate of natural geological disaster, weather and climate change, as well as the change of wind, light and other resources will leas to the increase of natural environmental risks, so that it will increase renewable energy generation investment risk and the reduction of renewable energy generation investment performance, and thus expected performance value gap becomes larger,

resulting in renewable energy generation investment risk control efforts to increase.

Thus, the control rate of strategic management, relationship management, contract management, process management, service quality management and other control strategies are increased. For example, the increase of the control rate of strategic management will reduce the risks of natural environmental risks, policies and laws risks, economic risks, market risks, technical risks to further reduce the investment risks of renewable energy power generation, and increase the renewable energy power generation investment performance. Consequently, it is the positive correlation between the renewable energy power generation investment performance and natural geological disaster, weather and climate change, as well as the change of wind, light and other resources in the whole system of renewable energy power generation investment risk. Similarly, in this system, the change of the occurrence rate of other risks will also affect the investment performance of the renewable energy power generation investment risk and then affect its performance, risk control strategy, which in turn increases or reduces the investment risk, and ultimately plays a positive or negative role in the investment performance.

Equally, as an exogenous variable, economic benefit will lead to the increase of the investment performance of the renewable energy power generation. In the case of unchanged expected performance, the gap between investment performance and expected performance will be reduced, and then it will reduce the control strength of the renewable energy power generation investment. So that it will reduce the control rate of strategic management, relationship management, contract management, process management, service quality management and other control strategies. For example, the reduction of relationship management control will increase the control of planning and management risks, operational risks, financial risks, human resource risks and other inner risks, and then increase the investment risks and decrease the investment performance of renewable energy power generation. And thus increase the gap of expectations performance, and lead to renewable energy generation investment risk control strength increases, increase the control rate of risk control strategy, reduce the investment risk, and ultimately improve the renewable energy generation investment performance. Therefore, from this cycle we can see the correlation between economic benefit and other factors in the whole system. Similarly, the correlation of social benefit, environmental benefit, power enterprise own ability and other external factors in the system can be seen.

If expected performance increased, the gap between investment performance and expected performance of renewable energy power generation in the original system will be increased, and the control of renewable energy power generation investment risk increased. Furthermore, the control rate of strategic management, relationship management, contract management, process management, service quality management and other control strategies will be increased, and reduce the investment risk of renewable energy power generation, increase the renewable energy power generation investment performance. Consequently, it is also a positive correlation between expected performance and investment performance of the renewable energy power generation in the whole renewable energy power generation investment risk system.

V. CONCLUSIONS

In this paper, using the theory of system dynamics, and researching on the renewable energy power generation investment risk, we established the index system of investment risk. Identify the renewable energy power generation investment's internal risk factors and external risk factors and we establish the evaluation index system of renewable energy power generation investment performance. Evaluate it from the aspects of economic benefits, social benefits, environmental benefits and the ability of power enterprise itself. On the basis of these, the investment risk model, the risk control strategy model and the investment performance model of the renewable energy power generation are established, and the causality diagram of each system and the system dynamics diagram of the whole system are obtained. According to analyzing the mechanism of action of various factors in the system, coordinate each subsystems of whole dynamical system to ensure the overall system to maximize the efficiency and function, control the risk efficiently and improve the investment performance. Due to the limited space, there isn't a simulation test to the model, and the next step research will use simulation to simulate and analyze the risk, risk occurrence rate, risk control rate and the development tendency of investment performance in the process of renewable energy power generation investment decision-making. So that the investment risk control strategies of renewable energy power generation can be more targeted.

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