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Hydropower Project Economic Evaluation Risk Element Transmission Model and its Application

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Abstract

The electric power industry is one of the basic industries of the national economic development. It has the char-acters of capital-intensive and technology-intensive. Because of the runoff and water quantity, risk management in hydroelectric power is particularly complex. In this thesis, risk factors influenced the overall goal were called risk elements. A series of risk elements transmission models of hydroelectric power industry were built via analyzing the mathematical characteristics, and the transmission characteristics of these risk elements. Establishing the total value of benefits and NPV economic evaluation model of hydropower project to evaluate the economic feasibil-ity of hydroelectric projects.

Keywords

Risk Elements; Model; Economic Evaluation; Value of Benefits.

1. Introduction

With the deepening of energy conservation and emission reduction, low-carbon economy and other applications, China's power industry is also increasing the development and utilization of low-carbon renewable energy. As one of the main low-carbon renewable energy, hydropower is of great significance under the current world energy structure. Before the construction of hydropower project, it is necessary to carry out feasibility analysis, economic evaluation and social evaluation to determine the economic and social benefits of the project. At the same time, the project risk of hydropower enterprises includes not only the general enterprise risk, such as macro factors, economic cycle, financial policy, but also the unique risk of hydropower enterprises, such as load forecasting risk, economic dispatch risk, etc. In traditional risk management research, the identification and analysis of risk factors only consider the possibility and loss of risk factors, while risk element redefines risk factors from the perspective of transmission theory. Transmission has become another important feature of risk factors in modern risk management research.

Economic evaluation is mainly the analysis of the total cost and total income of the investment and construction program, which can be evaluated by economic indicators such as net present value and internal rate of return. Among them, the change of the present value of the total income of hydropower projects is mainly determined by the annual generating capacity, which is affected by random factors such as the water discharge of the river where the hydropower stations are located.

Balta et.al (2018) proposed a buffer sizing methodology based on fuzzy risk assessment which can be used to calculate time buffers accurately for concrete gravity dam and hydroelectric power plant projects by considering the vulnerability of activities to various risk factors as well as their interdependencies [1]. Li and Wang (2020) analyzed the dangerous factors of the construction project

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to give a specific explanation for the possible safety risk factors, and carried out the safety design around the existing risk factors [2]. Chen et.al (2020) proposed a novel probabilistic cost estimation model integrating risk allocation and claim considering the uncertain construction of hydropower projects and fierce market competition [3]. Roy and Roy (2020) negotiated a trade-off between insurance companies and investors in the small hydropower (SHP) sector [4]. Song et.al (2020) proposed a Construction Diversion Risk (CDR) assessment method for the sediment-rich hydropower development environment, which can assess CDR basing on the cofferdam overtopping probability through simulating flood evolution and sediment impact during diversion [5].

Previous studies have analyzed the risks involved in hydroelectric power projects in all aspects, but most of them adopted mature financial methods or relatively mature comprehensive evaluation methods. There are few articles on the economic evaluation of hydropower projects from the perspective of risk element. Therefore, from the perspective of risk element transmission, this paper discusses the transmission of risk in hydropower construction projects, and establishes a risk element transmission model to evaluate the economic feasibility of hydropower projects.

2. Risk element

Risk refers to the uncertainty of the actual result relative to the expected result. Risk element refers to the uncertainty factors of the actual results in some specific circumstances and in a specific period of time [6].The understanding of the concept of risk element should include the following three aspects.

(1) The risk elements may be different in different environments and different time periods, that is, the basic uncertainty factors affecting the target may be different.

(2) Once the concept of risk element is mentioned, different definitions should be given according to specific problems. Since the factors affecting the target may be random factors, fuzzy factors, or other types of factors, the types of risk element may be different in different environments.

(3) For a specific problem, when determining the risk element, due to the volatility of risk, the main risk element (the main risk element affecting the target) is often listed, and some minor or very small risk factors affecting the target are either not considered, or they are regarded as sensitive factors, and a certain range of fluctuation is given artificially to demonstrate the sensitivity. Whether it is the risk element of the problem is determined according to its sensitivity. A specific problem may also have multiple risk elements at the same time. Under normal circumstances, man-made risk elements are independent of each other, but sometimes the correlation between each other needs to be considered.

Corresponding to the risk management of electric power enterprises, the research problem of the risk element transmission theory of electric power enterprises can be regarded as the change of some risk domains causes the change of other risk domains, that is, the risk change of some research objects causes the risk change of target objects. Generally speaking, the domain of argument is $U=\{x_1,x_2,\ldots,x_i,\ldots,x_n\}$, where x_i represents the object of risk study and is an uncertain value. The risk element transfer has the following definition.

Definition 1: For the target object y, if there is a corresponding relationship f such that x_i satisfies $y=f(x_i)$, then x_i is the risk element that affects the target object y, and the corresponding relationship f is called the risk element transfer function.

3. Risk element transfer simulation model of economic evaluation index of hydroelectric power

When calculating the power generation benefits of hydropower projects, the annual benefits are mainly determined by the annual power generation capacity, which is determined by the scale of reservoirs, installed capacity, the annual available power generation runoff process and the water head process. The runoff process and water head process are different in different years, especially in the years with severe climate change, so the runoff change is a random variable subject to the law of

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chance. In the context of current power generation rights transactions, hydropower stations can almost do their best to generate power (the grid gives priority to dispatching hydropower), and the power generation of hydropower stations mainly depends on the amount of incoming water, while the annual power generation has similar random variation characteristics with the annual water volume. In the case of fixed on-grid tariffs for hydropower, the power generation benefits and annual power generation of hydropower plants also have the characteristics of random variation.

3.1 Annual benefit calculation and risk analysis

When the normal storage level, dead water level, annual water volume and installed capacity of hydropower stations have been determined, the formula for calculating annual power generation benefits using the theoretical price method is:

$$B = aE(1 - E_L - E_P)V \tag{1}$$

$$E = \Delta t \sum_{i=1}^{T} \overline{N\iota} = \Delta t \sum_{i=1}^{T} \overline{AQ\iota H\iota} \tag{2}$$

Where: B is the annual power generation benefit. a is the effective coefficient. E is the annual power generation, kWh. $E_L$is the line loss rate. $E_P$is the power consumption rate of the power plant. V is the theoretical on-grid price. Δt is the calculation period hours. T is the calculation within the year time period, T=8706/Δt. Ni(i=1,2,3,...,T) is the average output of the i-th period of the year, kW. A is the output coefficient, and A=9.81η, where η is the total efficiency of the unit. $\overline{Q\iota}$(i=1 ,2,...,T) is the average flow in the i-th period, m3/s. $\overline{H\iota}$(i=1,2,...,T) is the average net head in the i-th period, m.

For the calculation of power generation capacity of hydropower station, due to the regulation capacity of reservoir, the P-III distribution (Pearson III) can be used to calculate the variation of available power generation inflow. The distribution of annual power generation is similar to that of annual runoff because the annual power generation and annual runoff have the characteristics of almost synchronous random variation. The power generation of three typical years is calculated by adjusting time period method. The probability distribution parameters of the three-point method are determined, and the generation process in the future is further simulated by the distribution.

(1) The density function and parameters of P-III distribution. The density function of P-III distribution is:

$$\mathrm{f}(x) = \frac{\beta^\alpha}{\Gamma(\alpha)}(x - a_0)^{\alpha-1} e^{-\beta(x-a_0)} (x > a_0) \tag{3}$$

Where, a_0, α, β are parameters, all greater than 0.

The mathematical expectation $\mathrm{E(X)}$ is:

$$\mathrm{E(X)} = \frac{\alpha}{\beta} + a_0 \tag{4}$$

The variation coefficient C_V and the skewness coefficient C_S are $C_V = \frac{\sqrt{\alpha}}{\alpha+\beta a_0}$ and $C_S = \frac{2}{\sqrt{\alpha}}$.

Thus, the three parameters α, β, a_0 can be expressed as basic functions $E(X), C_V, C_S$.

$$a_0 = E(X)(1 - \frac{2C_V}{C_S}) \tag{5}$$

$$\alpha = \frac{4}{C_S^2} \tag{6}$$

$$\beta = \frac{2}{E(X) C_V C_S} \tag{7}$$

(2) Three point method of abundance, flatness and dryness. The frequencies P_1, P_2, P_3 of the three points can occupy the frequency range according to the incoming water data. Three typical annual power generation values $E_{P_1}, E_{P_2}, E_{P_3}$ are determined by water inflow frequency and adjustment of time period in a year. According to the values of three points, three parameters of annual power generation distribution are estimated by three-point fit line method. Then, the power generation in the future years is simulated and analyzed.

The three points $\mathrm{E_{P_1}}, \mathrm{E_{P_2}}, \mathrm{E_{P_3}}$on the curve meet the following conditions.

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$$\begin{cases} E_{P_1} = \bar{E}(\phi_1 C_V + 1) \\ E_{P_2} = \bar{E}(\phi_2 C_V + 1) \\ E_{P_3} = \bar{E}(\phi_3 C_V + 1 \end{cases} \tag{8}$$

The three equations are solved simultaneously as follows.

$$S = \frac{E_{P_1} + E_{P_2} - 2E_{P_3}}{E_{P_1} - E_{P_3}} \tag{9}$$

$$\bar{E} = \frac{E_3\phi_1 - E_1\phi_3}{\phi_1 - \phi_3} \tag{10}$$

$$C_V = \frac{E_1 - E_3}{E_3\phi_1 - E_1\phi_3} \tag{11}$$

Where, S is the skewness coefficient. C_S is the asymmetry coefficient, which can be obtained from the corresponding table of S and C_S by using the three-point method.

The deviation coefficient ϕ_i is a function of the cumulative frequency P_i and the asymmetry coefficientC_S. According to $C_V, \bar{E}, C_S$ can calculate the values of α, β, a_0 which can be randomly generated by the rounding sampling method. The random number of P-III distribution is used to simulate the future annual power generation.

3.2 Total benefit risk element transmission model

In n years of economic calculation period of hydropower project, the annual power generation benefit series is set as $B_{1,}B_2, \dots, B_n$. Then the total benefit present value Z is:

$$Z = \frac{B_1}{1+r} + \frac{B_1}{(1+\mathrm{r})^2} + \cdots + \frac{B_1}{(1+r)^n} \tag{12}$$

Where, r is the discount rate, and $(1+\mathrm{r})^i\ i = 1,2, \dots, n$ is the unit risk transmission coefficient.

Take the mathematical expectation and variance of Equation (12) respectively to obtain

$$\mathrm{E(Z)} = \frac{E(B_1)}{1+r} + \frac{E(B_2)}{(1+\mathrm{r})^2} + \cdots + \frac{E(B_n)}{(1+\mathrm{r})^n} \tag{13}$$

$$\mathrm{D(Z)} = \frac{D(B_1)}{[1+\mathrm{r}]^2} + \frac{D(B_2)}{[(1+\mathrm{r})^2]^2} + \cdots + \frac{D(B_n)}{[(1+\mathrm{r})^n]^2} \tag{14}$$

Equation (14) is called the transmission model from annual return risk element to total benefit risk.

For the annual generation series generated by the above simulation, the benefit series $B_{1,}B_2, \dots, B_n$ can be obtained by Equation (1), and then the present value of the total benefit can be obtained from Equation (12). Through N (N>10000) times of random simulation, N total benefit present values can be obtained. Through statistical analysis of N total benefit present values, the probability density function and distribution curve of total benefit present values can be obtained by analyzing and fitting the data.

3.3 Net present value calculation and risk simulation model analysis

The size of net present value is determined by the present value of total benefit and present value of total cost of hydropower project. The analysis shows that the total benefits of hydropower projects are affected by random factors and have the characteristics of random changes. After a random sequence of annual returns is obtained through several simulations, several values of total benefits can be calculated by formula (12), and the probability distribution curve can be obtained by fitting the variables. Although the total cost of the project has certain uncertainty, this uncertainty is affected by the factors considered. The random characteristic is not particularly obvious. It can be regarded as a constant. If necessary, as long as the sensitivity analysis is carried out.

Suppose the present value of the total cost I_P, according to the total benefit sequence obtained by the Monte Carlo model, subtract the present value of the total cost from the present value of each total benefit to obtain $NPV(NPV = Z - I_P)$, and then the probability distribution curve of net present value can be obtained. With the probability distribution curve of net present value, the feasibility of

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economic evaluation results can be analyzed. From the expected value and variance of NPV, and then using the general formula of relational risk element transfer, this paper studies the risk element transfer of hydropower project, and gives the probability of profit and loss of hydropower project, which is more comprehensive and detailed than the information provided by only calculating the net present value, and has more scientific value for the economic evaluation index of hydropower project.

The simulation method is used to analyze the probability distribution characteristics of the net present value of hydropower projects, and only the annual power generation is regarded as a random variable subject to a certain distribution. For the electricity price, project cost, benefit and other factors, the sensitivity analysis method is adopted because the random variation characteristics of these factors are not obvious. Specifically, different values are set for these factors during the simulation calculation, so as to obtain the probability distribution curve of the net present value under different factor values, so that information such as the probability of project profit or loss under different factors can be obtained. In this way, a comprehensive analysis of the factors influencing the net present value of hydropower projects can be carried out, and a reliable basis can be provided for reasonable project decisions.

4. Case analysis

It is planned to build a hydropower station, and the present value of the total project cost is 1.45 billion yuan. The total installed capacity is 400MW, the line loss rate E_L and the factory power E_P are 7% and 2% respectively, the effective coefficient a is 1.0, the on-grid power price V is 0.25 yuan, the social discount rate r=10%, and the economic calculation period n is 40 years.

4.1 Total benefit present value calculation and risk analysis

It is known that there are 30 years' hydrological data at the site of a hydroelectric power plant, and the frequency and runoff of three typical years can be obtained by using statistical analysis method to analyze the historical data and considering the regulating effect of reservoir on the inflow flow. On the basis of the runoff of three typical years, the annual power generation of these three typical years can be calculated by adjusting time by time with the graphic method, as shown in Table 1.

Table 1. Runoff and potential generation in three typical years

Frequency	5%	50%	95%
Annual runoff (billion m^3)	2360	1084	501
Annual power generation (100 million kWh)	17.6	10.2	5.9

From equation (9), it is concluded that:

$$S = \frac{E_{5\%}+E_{95\%}-2E_{50\%}}{E_{5\%}-E_{95\%}} = \frac{17.6+5.9-2*10.2}{17.6-5.9} = 0.265$$

Check the table of the three-point method of P-III distribution - the relation table between S and C_S, C_S=0.936 can be obtained.

Check the table of the three-point method of P-III distribution - the relation table between C_S and ϕ_p, $\phi_{5\%}$=1.86, $\phi_{50\%}$=-0.15, $\phi_{95\%}$=-1.34 can be obtained from C_S=0.936 .

From equation (10), it is concluded that:

$$\bar{E} = \frac{E_3\phi_1-E_1\phi_3}{\phi_1-\phi_3} = \frac{5.9*1.86-17.6*(-1.34)}{1.83-(-1.34)} = 10.80$$

From equation (11), it is concluded that:

$$C_V = \frac{E_1-E_3}{E_3\phi_1-E_1\phi_3} = \frac{17.6-5.9}{5.9*1.86-17.6*(-1.34)} = 0.34$$

Known $C_V, \bar{E}, C_S$ can calculate $\alpha = 4.57, \beta = 0.58, a_0 = 2.99$. 40 typical annual electricity generation values are randomly obtained by using the method of selective sampling, and then a total

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benefit present value can be obtained by using equation (12). Simulate 20,000 times to form 20,000 present values of total benefits, and use the log-normal distribution in the Matlab statistical toolbox to fit the formed data. The estimated lognormal distribution parameters $\mu = 3.164, \sigma = 0.326$, and the standard errors are 0.0023 and 0.0016, respectively. The mean $E(Z) = 24.96$ and the standard deviation is 8.36, which has a good fitting simulation results.

4.2 Risk calculation and analysis of net present value

According to the expression of NPV

$$NPV(NPV = Z - I_P) \tag{15}$$

Given that $I_P = 14.5$ billion yuan, from equation (12), the current value of the total cost is uniformly subtracted from each interval of the probability cumulative curve of the current value of the total benefit, and the cumulative distribution curve of the NPV of the net present value can be obtained, as shown in the figure 1.

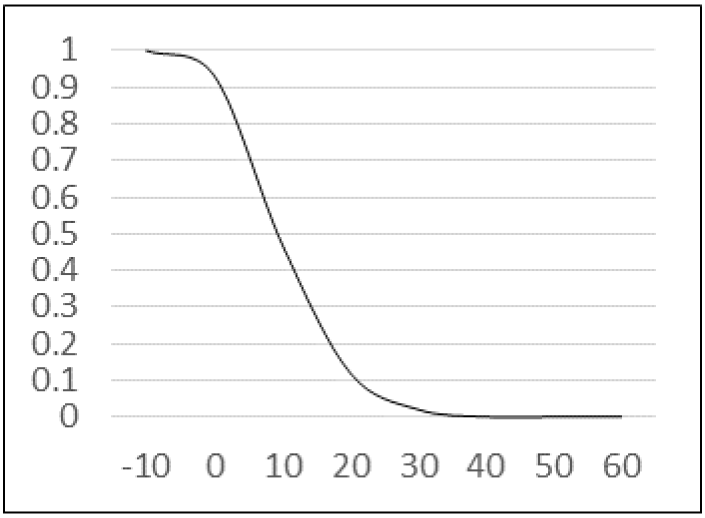

Figure 1. Net present value cumulative distribution chart

It can be seen from Figure 1 that the probability of project profitability (that is, the project's net present value is greater than 0) is 94.0%, which means that the probability of project loss (the project's net present value is less than 0) is 6.0%, and the expected net present value is 1.046 billion yuan. The expected net present value of the project and the probability of profitability are relatively large, which proves that the program is feasible.

The curve completely describes the law of random changes in the net present value. According to this curve, information such as the approximate range of the net present value change, the distribution center, the probability of profit, and the risk rate of loss can be grasped. Compared with the unique definite value obtained by traditional calculation methods, this considers many risk factors, which is more in line with the actual situation and provides a comprehensive and more accurate scientific basis for decision-makers to make reasonable decisions.

5. Conclusion

There are many factors that affect the risk, especially the risk of water conservancy and power generation industry. The influencing factors are complex. Sometimes, the economic evaluation of the risk becomes particularly complex. From the perspective of risk element and risk element transmission, the quantitative analysis of uncertain factors of economic risk of hydropower projects can effectively predict, analyze and evaluate the economic feasibility of hydropower projects, provide theoretical basis for project decision-making, and achieve the purpose of saving costs and optimizing resources.

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