Research Journal of Applied Sciences, Engineering and Technology 4(14): 2222-2226, 2012
ISSN: 2040-7467
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Submitted: March 10, 2012 Accepted: April 04, 2012 Published: July 15, 2012

Risk Analysis Simulation Model of Economic Evaluation in Hydroelectric Engineering Project

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Abstract: In this study, we propose a risk analysis simulation model for economic evaluation of hydroelectric engineering project. This model takes annual energy outputs as risk elements. It submits to Pearson-III distribution similar with the annual runoff. Take data from three typical years to estimate the distribution parameters and then yearly benefits can be simulated in given period. By discounting all the annual benefits to their present values and summing them up, the total benefit present value is worked out. Simulating the process for a large number of times, the probability distribution is obtained. And the Net Present Value (NPV) distribution can be figured out as well.

Key words: Economic evaluation, hydropower project, net present value, risk analysis, simulation model

INTRODUCTION

Under the circumstance of energy saving and emission reduction, the Low-carbon economic growth model plays a more and more important role in reducing CO2 emission. The power industry of China has also been increasing the development of the low-carbon renewable energy. In the current world energy structure, the investment and construction of hydropower is of very profound significance.

Before building a hydroelectric project, we need to analyze the feasibility of the project, including economic evaluation, social evaluation and environmental evaluation. So it is important to propose a procedure for judging whether a sustainable plant can be installed in complicated situation within three basic dimensions: social, economical and environmental (Theocharis *et al*., 2007). Besides these three dimensions, technical and policy issues of the master plan for the renewable hydro and geothermal energy resources are considered (Hreinsson, 2007). Hence, as an important aspect, economic evaluation is mainly based on the analysis of total costs and revenues of a certain project, which is using economic indicators such as net present value (Nordgard *et al*., 2005), internal rate of return and so on. While the general investment project evaluation focuses on Net Present Value (NPV). In most cases, NPV is a static analytic tool, namely to obtain a fixed value by the analysis of NPV. However, because of many uncertainties modeled by fuzzy evaluation (Wu *et al*., 2003; Yang and Ma, 2011; Ram *et al*., 2009) and risks exist in hydropower engineering projects (Bingsheng *et al*., 2010), only a single fixed number can not reflect the true feature of NPV changes in a planning project. While the changes of the total revenue present value in a hydroelectric project are mainly determined by the annual power generation (Li, 2009; Huang *et al*., 2007; Yang *et al*., 2005). The annual power generation is affected by the other random factors such as runoff of the river where the station is located.

To deal with this kind of random changes, reasonable economic calculation and evaluation methods are introduced. In the case of analyzing the random factors above, this study will make a risk analysis simulation model to evaluate the economic feasibility of hydropower projects.

METHODOLOGY

Risk analysis of the benefit of hydroelectric power: In calculation of power generation benefit of hydropower projects, the annual benefit is mainly decided by the annual power generation and the annual power generation is determined by the reservoir scale, installed capacity, annual available power generation, runoff process and head process of a river. But in different years, the runoff process and head process is not same, especially the year in which the climate changes severely. So the runoff change is a kind of random variable following the laws of occasionality. In the current generation rights trading background, the hydropower station could almost do their maximum power generation capacity to generate

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electricity (i.e., power grid dispatches hydropower preferentially). And the hydroelectric power generation is mainly determined by the amount of water inflow. Therefore, the annual power generation and annual water inflow have similar random variation characteristics. Under the condition of fixed hydropower purchase price, the generation efficiency of hydroelectric power station and the annual power generation also have the similar random variation characteristics.

Annual benefit calculation and risk analysis: In the case that normal storage level, dead storage level, the annual water inflow in the reservoir and the installed capacity of hydropower station are fixed. Take theory price method to calculate annual power generation benefits, the formula is as follows:

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

$$E = \Delta t \sum_{i=1}^{T} \overline{N}_i = \Delta t \sum_{i=1}^{T} A \overline{Q}_i \overline{H}_i \tag{2}$$

In the formula: B is the annual power generation benefit; a is the effective coefficient; E is the annual power generation (kw.h); $E_L$is line loss per unit; $E_p$is consumption rate of the power station; V is the theoretical purchase price; Δt is the calculation interval hourage; T is the computation number in a year (= 8760/Δt); N_i is average output during the i-th time interval in a year (kw) (i = 1, 2, …, T); A is output coefficient (= 9.81η, η, means overall efficiency); $\overline{Q_i}$ is average flow rate during the i-th time (m^3/s) (i = 1, 2, …, T); is average net water head (Li, 2009).

Considering the regulation capacity of reservoir, in the calculation of the electricity generating capacity of the hydropower station, the change of water inflow used to generate electricity can be approximated by P-III (Pearson Type) distribution (Lao and Zhang, 2003). P-III type distribution is recommended to analyze and calculate water statistics law in some rivers in China (Huang *et al*., 2003).

In this study, this distribution can be used to simulate the runoff character of available electricity generation. Annual power generation and annual runoff almost have same simultaneously characteristics of random variation. Namely the distribution of annual power generation is similar to that of annual runoff. On the basis of the analysis about the historical data of runoff in three typical years, the output of three typical years can be calculated by using time-adjusting method. The parameters of probability distribution can be estimated out by means of three-point method and then simulating the process of power generation further in the next several years with random numbers of the probability distribution.

- **P-III type distribution density function and parameters:** P-III type distribution density function is (Gui, 2008):

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

In the formula, α_0, α, β > 0 are parameters. The mathematic expectation of X is E(X):

$$E(X) = (\alpha/\beta)+\alpha_0 \tag{4}$$

Coefficient of variation is C_v. $C_V = \dfrac{\sqrt{\alpha}}{\alpha + \beta a_0}$

Coefficient of skewness is C_s. $C_s = \dfrac{2}{\sqrt{\alpha}}$

Thus, the three parameters α, β , α_0, can be expressed by the basic parameters E(X) , C_v, C_s, as follows:

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

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

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

- **Three-point method of high-normal-low flow period:** Frequency P_1, P_2, P_3 of three years can be fixed by the range of Hydrological data occupied frequency. But 3-50-97%, 5-50-95% or 10-50-90% are generally used in hydrological calculation.

First, determine the annual power generation value of three typical points (years) E_{P1}, E_{P2}, E_{p3} by the hydrological frequency and the regulation by periods of a year. Second, according to the value of three points, the three parameters of annual power generation distribution can be estimated by means of three-point fitting method. Third, carry out simulation analysis on the situation of the next several years.

Three spots in the curve meet the following condition:

$$\begin{cases} E_{P_1} = \overline{E}(\Phi_1 C_V + 1) \\ E_{P_2} = \overline{E}(\Phi_2 C_V + 1) \\ E_{P_3} = \overline{E}(\Phi_3 C_V + 1) \end{cases} \tag{8}$$

Solution of the three simultaneous equations is:

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

$$\overline{E} = \frac{E_3\Phi_1 - E_1\Phi_3}{\Phi_1 - \Phi_3} \tag{10}$$

$$C_V = \frac{E_1 - E_3}{E_3\Phi_1 - E_1\Phi_3} \tag{11}$$

S is coefficient of skewness. We can get C_s through the correspondence table between S and C_s. Coefficient of dispersion ϕ_i is the function of cumulative frequency P_i and coefficient of skewness C_s. And that can be checked in a table. With C_s C_V $\overline{E}$, we can calculate the value of three parameters α, β, α_0. By known these three parameters, we can use random number generated by adopting acceptance-rejection sampling method, that follows P-III type distribution of three parameters α, β, α_0, to simulate the power generation in the next several years. We can learn specific proof method about acceptance-rejection sampling method of P-III type distribution from the literature (Gui, 2008).

The total benefits and risk analysis model: In the N years of economic calculation period of hydroelectric engineering, we set annual power generation benefits series as B_1, B_2, …, B_n, thus the present value of total benefits Z can be calculated by formula (12):

$$Z = \frac{B_1}{1+r} + \frac{B_2}{(1+r)^2} + ... + \frac{B_n}{(1+r)^n} \tag{12}$$

In the formula, *r* is the discount rate. $(1 + r)^i$ (i = 1, 2, …, n) is the unit risk transfer coefficient.

From annual power generation series generated by simulation above, the benefit series in the next several years can be worked out by formula (1) and then the present value of total benefits can be got by formula (12). Through N times (N>10000) stochastic simulation, we can get the present value of total benefits and then carry out statistical analysis, finally, Density function and distribution curve of the present value of total benefits could be obtained by fitting analysis to the data.

The calculation of net present value and risk simulation analysis: The net present value is determined by the present value of total benefits and total costs in a planning hydropower engineering project. According to the analysis above, we can conclude that total benefits which are affected by annual benefit and other random factors, are also having random variable characteristics. Through several simulation processes we can obtain the random sequences of annual benefits and then the values of several total benefits can be calculated by formula (12), through variable-fitting, the total benefits probability distribution curve can be drawn.

The total cost of the project is uncertainty as well, but it is mostly affected by human factors. Random features are not obvious, so they can be regarded as constants. If necessary, sensitivity analysis is enough.

Set the present value of the total cost as I_P, according to the total benefits sequences derived from Monte Carlo simulation, each present value of total benefits minus the present value of the total cost can get a NPV, NPV(= Z - I_P) and probability distribution of the net present value can be figured out, then NPV curve can be drawn out.

According to the net present value distribution, we can analyze the feasibility of a planning project.

From the NPV distribution characteristics, we can get some information such as NPV expectation value, loss probability of hydropower project and so on. This can provide more comprehensive information than a single net present value.

By taking simulation method, this paper analyses the probability distribution features of the NPV in a planning hydropower project, regarding the annual power generation as a random variable which obeys a certain distribution.

The random variation characteristics of these factors such as the price, engineering cost and so on are not obvious. Therefore, sensitivity analysis can be used. Specifically, in the simulation, each of these factors is set as a different value respectively and then the probability distribution curve of NPV under different factors can be obtained respectively. So that we can obtain the project earns probability or the loss probability and other information under different factors values. In this way, we can carry on comprehensive analysis of the influencing factors affecting the NPV of a hydropower project, thus providing the reliable basis for rational decision making.

CASE STUDY

Planning to build a hydropower station, the present value of total project costs is RMB 1.45 billion. Installed capacity is 400 megawatts, line loss per unit is E_l, the Power consumption rate is 7 and 2% respectively, set effective coefficient as 1.0, take the purchase price V as RMB 0.25, take social discount rate as 10%, consider economic calculation period as 40 years.

The calculation of present value of total benefits and risk analysis: Currently 30 years of hydrological data

Table 1: Runoff and probable power generation in the three typical years

Frequency	5%	50%	95%
Annual runoff (10^8m^3)	2360	1084	501
Annual energy output (10^8kwh)	17.6	10.2	5.9

about hydropower station site is known, analyses the historical data by means of statistical analysis method and take the regulation which the reservoir play on the runoff into consideration. Then the frequency and runoff in three typical years are obtained as follows (Table 1):

Obtained by the formula (9):

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

Lookup table of Three-point method about P-III type distribution--correlation chart between S and C_s, deduce C_s = 0.936.

Lookup table of Three-point method about P-III type distribution--correlation chart between C_s and ϕ_P, deduce $\phi_{5\%}$ = 1.86 $\phi_{50\%}$=0.15 $\phi_{95\%}$ = -1.34 from C_s= 0.936.
Obtained by the formula (10):

$$\overline{E} = \frac{E_3\Phi_1 - E_1\Phi_3}{\Phi_1 - \Phi_3} = \frac{5.9 * 1.86 - 17.6 * (-1.34)}{1.83 - (-1.34)} = 10.80$$

Obtained by the formula (11):

$$C_V = \frac{E_1 - E_3}{E_3\Phi_1 - E_1\Phi_3} = \frac{17.6 - 5.9}{5.9 * 1.86 - 17.6 * (-1.34)} = 0.34$$

As $\overline{E}$, C_V, C_s is known, we can deduce α = 4.57, β = 0.58, α_0 = 2.99 by the formula (5)-(7). And we can obtain the value of power generation in the 40 typical years by adopting Acceptance-Rejection sampling method. Using the formula (11), the present value of total benefits can be obtained. If the simulation times are big enough, it can approximately represent the distribution of total benefits in the next several years. This study simulates 20000 times and forms the present value of total benefits, of which the total number is 20000. Then use the Matlab statistical toolbox to fit the data and the fitting probability density chart is shown in Fig. 1. Using a log-normal distribution to fit them, the estimated log-normal distribution parameters μ = 3.164, σ = 0.326, standard error are 0.0023 and 0.0016, respectively. The typical value E(Z) = 24.96, the standard deviation is 8.36. As we can see in Fig. 1 that a lognormal distribution can fit the simulation results preferably.

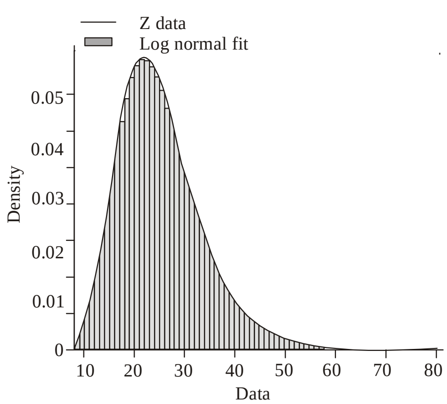

Fig. 1: Simulation probability density fitting chart of the present value of total benefits

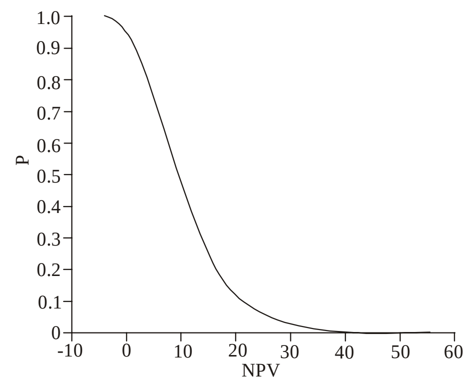

Fig. 2: The probability distribution of NPV

The risk analysis of NPV: The expectation value and unbiased variance of NPV respectively are:

$$NPV = Z - I_P \tag{13}$$

$$I_P = 1.45 \text{ billion Yuan}$$

According to formula (12), each interval of the cumulative probability about present value of the total benefit minus the present value of the total cost equals cumulative distribution of NPV. The curve is shown in Fig. 2.

As Fig. 2 shows, the probability of earnings (which means the project NPV is greater than zero) is 94.0%. Namely the loss probability (which means the project NPV is less than zero) is 6.0%. The expectation value of NPV is RMB 1.046 billion. The expectation value of NPV and the probability of profitability are relatively large, so the project is feasible.

Sensitivity analysis: Set different power purchase prices and the present values of the total cost to carry out the sensitivity analysis. First set electricity price, the power purchase price and the present value to be variable one by one, setting the total costs as a fixed value. So, in the case that the set price is higher than the above price, the curve of net present value will move to the upper and right direction. In the case that setting present value of the total cost as a bigger one, the curve of net present value will move to the lower and left direction. Through sensitivity analysis we can see the variation rules of NPV under different situations. Then we can determine the economic feasibility of the project reasonably.

CONCLUSION

Statistical simulation method and Monte Carlo simulation is used into economic evaluation in hydroelectric engineering project. Based on analysis of annual runoff in a special river, an economic evaluation model is formed in order to analyse the future condition. The runoff of a river can be obtained through simulating via P-III (Pearson Type) distribution. And then the annual revenue is worked out by using theory price method. Assuming the cost is a fixed number, so the NPV of operating period could be figured out. The decision maker can determine whether to invest the project from the NPV probability distribution. This method is proved to be highly feasible through an example.

ACKNOWLEDGMENT

The authors wish to thank the helpful comments and suggestions from my teachers and colleagues in Institute of Enterprise Management and Informatization in North China Electricity Power University. This research was supported by the National Natural Science Foundation of China under Grant 71071054 and “211 Project” of North China Electric Power University.

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