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A combined thermal power plant investment decision-making model based on intelligent fuzzy grey model and ito stochastic process and its application

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ABSTRACT

Uncertainties are often involved in the investment decision making of the coal-fired power plant. They are often characterized by diversity and fuzziness. In order to minimize their adverse effects on the evaluation of investment, we proposed a novel combined thermal power plant investment decision-making model. This model takes the Net Present Value(NPV) as the objective function, and takes the predictions of revenue and cost as the center. With regard to revenue prediction, Self-adapting Intelligent Grey prediction Model (SIGM) combined with Interval Grey number Prediction Model based on the Triangular whitenization weight function(IGPM_T) model is employed to forecast the changing tendency of the on-grid price, which is the decisive factor for revenue of power plant. With respect to cost prediction, Ito stochastic process theory is utilized to simulate the variation tendency of the operating cost of power generation. In order to acquire the key drift and floating coefficients in the formula of Ito process, the combinatorial simulation experiment is conducted, and by visual comparison, rational coefficient combination is determined. Finally, the reliability and validity of the proposed combined model are verified through an example of a coal-fired power plant, and results show that the proposed model can provide satisfactory evaluation for thermal power plant investment.

1. Introduction

Coal-fired power still accounts for a large proportion in power generation combination, accounting for 41% in the energy market [1]. As expected earnings increase, the proportion of coal electricity increases year by year, but the investment risk is also increased accordingly. The existing research shows that Carbon Capture and Storage(CCS) combined with coal-fired power generation will become a new way of generating electricity [2]. In other words, coal is still an irreplaceable form of power, and there is still a lot of room for coal-fired power investment, but both the return and the risk of investment coexist. The investment is irreversible characterized by large amount of initial fund, long cost recovery period, more unknown factors, complicated geographical environment and economic environment [3]. As a consequence, it is of great significance to analyze and evaluate uncertainties occurred in process of risk assessment and investment decision making.

For project evaluation problem, it is challenging to deal with the uncertainties of capital input [4]. Multi-factor, multi-objective and multidisciplinary comprehensive analyses are needed. The commonly used classical analytical methods include the static evaluation methods such as the modern cost benefit analysis(MCBA) [5], the payback period(PP) method [6], and the dynamic evaluation methods such as the net present value(NPV) [7], the benefit cost ratio(B/C) [8] and the internal rate of return(IRR) method [9]. The static analytical methods do not consider the time value of the fund, and completely ignore the cash flow after the payback period [10]. For the power plant projects with high risk, the time value of capital can not be ignored because the investment is generally huge accompanied by long construction time, and usually it will take long time for payback. Therefore, static analysis is not suitable for investment evaluation of power plant projects. The dynamic evaluation method which fully considers the time value of the fund has been widely studied [11]. Compared with other dynamic methods, the NPV method has outstanding

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advantages [12], which reflects its net contribution to investors [13], but it is difficult to establish the discount rate in a given period. The same problem with static analysis is that both the revenue and the cost must be computable, and meanwhile the exact values are required for calculation. As a matter of fact, uncertainties affecting the investment return and cost cannot be completely determined. Specifically, some parameters are fuzzy, numerical ranges of which can only be estimated by experience or experts' knowledge [14].

There exist more popular methods such as cash flow [15], decision tree [16], Monte Carlo simulation [17] and real option method [18], which are often used today in project investment and evaluation. Theory studies and practical applications have spread in many domains. [19]. analyzed the economic benefit of 6×600 MW newly built purely condensing coal-fired power plants distributed in 6 provinces by cash flow method, and it emphatically analyzed the uncertainties of remaining cash flow. Base on Monte Carlo stochastic simulation [20], provides an energy-saving benefit evaluation method for daily electricity generation, which puts forth an approach to calculate the volatility of the price. An improved decision tree method, DCF decision tree, is put forward by Ref. [21] to analyze the carbon dioxide capture from coal-fired power plants, in this manner, primary and secondary influencing factors characterized by uncertainties are investigated. The real option method is adopted by Ref. [22] to detail thoroughly the costs and potentials of energy conservation induced by price uncertainties in China's coal-fired power industry.

Before the project starts, it is often necessary to assess the time value of the benefits and risks [23]. And yet NPV takes into account the cash flow that is converted to the starting point of the investment from the annual output and annual cost, reflecting directly the net income after deducting investment [24]. Therefore, NPV is the preferred criterion for investment evaluation [25]. It is known that the direct factors that affect the power plant's revenue include installed capacity, electricity price, line loss, electricity consumption in power plant, industry discount rate and so on [26]. While the direct factors that affect the cost of power plants involve the coal price, state tax, labor cost, competitive energy and the fluctuation of the macroeconomic environment. Because the number, scopes and weights of the influencing factors are indeterminate and fuzzy, it is impossible to describe the return and cost with accurate mathematical model [22]. However, the calculation of net present value can be achieved by artificial intelligent algorithms such as neuro-fuzzy net, support vector machine. In paper [27], the net present value of wind power plant is solved by adaptive neural fuzzy method, and the article [28] uses least square support vector regression method to estimate the pollutants in the air. A large number of sample data are required to guarantee the accuracy of evaluation. The evaluation with high volatile parameters can be achieved by stochastic method, such as the mean regression method, but to determine the values of the parameters in regression progress, a large amount of historical data and the corresponding complex regression analysis are needed too [29]. In order to overcome this limitation, the grey theory can be used to predict the evolution trend of the system with insufficient information and indeterminate models [30]. Since Deng's proposal [31], it has been proven in theory and practice that high accuracy prediction can be achieved with at least 4 data, especially suitable for medium and short term [32].

Most of the influence factors related to benefit and cost are not exact numerical values, but shows a certain degree of fuzziness [33], so they can be expressed as the fuzzy interval numbers, or denoted as interval grey numbers [34]. Hence, the interval grey number theory can be employed to solve the decision problem with poor information very well [32,35]. In this work, we proposed an combined investment decision-making model which incorporates the uncertainties occurred in decision making into the prediction: the self-adapting intelligent grey prediction model(SIGM) [36] is used to predict the on-grid price of the electricity; the dynamic characteristics of operating costs are simulated by the ITO stochastic process [37]. By Interval Grey number Prediction Model based on the Triangular whitenization weight function of central points(IGPM_T) [38], the forecasting of interval grey numbers can be converted into prediction of real numbers without information missing. The other risk factors, such as initial investment, line loss, annual power utilization rate, and industry discount rate can all be expressed as interval grey numbers deduced by experience or experts' knowledge. When these interval grey numbers are included in the NPV calculation, we get the interval-valued NPV, which is the risk value of the project, as the basis for decision making.

The rest of the paper is organized as follows: λ level set and fuzzy interval theory is investigated in detail in Section 2, which is the basis of investment decision. Evaluation methods is given in Section 3, which mainly focus on revenue forecasting and cost prediction based respectively on Self-adapting Intelligent Grey prediction Model(SIGM) [36] and Ito process theory. In Section 4, a coal-fired power plant investment example is given to verify the reliability and validity of the proposed combined decision-making model. Finally, in Appendix, matlab codes used in this paper are provided to facilitate application of the study achievements.

The main contributions include:

- A novel combined thermal power plant investment decision-making model is proposed. The model takes the NPV as the objective function, and takes the predictions of on-grid price and operating cost as the center. And it can achieve better performance with small samples only.
- Based on λ level set and the fuzzy interval theory, we provide the conversion method from the triangular fuzzy number to grey interval number, which is the basis of interval-valued grey number prediction.
- On-grid prices in China from year 2020–2024 are predicted by interval-valued grey theory. Specifically, the up-to-date SIGM combined with the IGPM_T model is employed in process of prediction. And results show that prediction error is much smaller than traditional GM(1,1) model.
- Variation tendency of power generation cost is simulated by Ito stochastic process. We put forward a novel combinatorial experimental method to obtain the optimal combination of drift and floating coefficients. What's more, the cost matrix based time dimension is presented to facilitate the cost evaluation.

2. λ level of fuzzy set $\tilde{A}$ and fuzzy interval theory

Definition 1. The λ level of a fuzzy set $\tilde{A}$ is defined as $\tilde{A}^{\lambda} = \{x \in X | \mu_{\tilde{A}}(x) \geq \lambda\}(\lambda > 0)$ or $\tilde{A}^{\lambda} = \mathrm{cl}\{x \in X | \mu_{\tilde{A}}(x) > 0\}(\lambda > 0)$, i.e., the closure of fuzzy support [39].

Gasilov [40] made a point that the fuzzy set $\tilde{A}$ is a fuzzy number if and only if the λ level is a nonempty compact interval $[A_l^{\lambda}, A_h^{\lambda}]$. The fuzzy number can be represented completely by two functions $A_l : [0,1] \rightarrow X$, $A_h : [0,1] \rightarrow X$. Then, end points of λ level can be defined