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Decision-making model of generation technology under uncertainty based on real option theory

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ABSTRACT

The introduction of market competition and the increased uncertainty factors makes the generators have to decide not only on whether to invest generation capacity or not but also on what kind of generation technology to choose. In this paper, a decision-making model of generation technology investment is proposed. The irreversible investment concept and real option theory is introduced as the fundamental of the model. In order to explain the decision-making process of generator's investment, the decision-making optimization model was built considering two generation technologies, i.e., the heat-only system and the combined heat and power generation. Also, we discussed the theory deducing process, which explained how to eliminate the overrated economic potential caused by risk hazard, based on economic evaluation of both generation technologies. Finally, practical data from electricity market of Inner Mongolia was used to prove the validity of the model and the impact of uncertainties of electricity and fuel price fluctuation on investment was analyzed according to the simulated results.

1. Introduction

The traditional power system operated under the mode of integration where state-owned enterprise or the government can be regarded not only the owner but also the investor of whole power system. Most of the investment cost could be covered by sale price, and the rest investment cost was balanced by state subsidies or profit surrender [1]. Therefore, all the investment risk was borne by the nation. As most countries have been gradually introducing market competition, the power investment cost and profit distribution is no longer directly intervened by the nation. Electric market in Spain [2] and Britain [3] have been established since the early 20th century, which made power generators face fierce competition to get electricity contracts. In this situation, the consumer/supplier's surplus is mainly adjusted automatically by market mechanism.

The introduction of market competition makes the generators have to decide not only on whether to invest generation capacity or not but also on what kind of generation technology to choose. As competition originally selects the superior and eliminates the inferior, generators have to evaluate the revenue of investment in power market and analysis the economic efficiency of the generation technology in order to minimize the investment risk.

The liberalization and deregulation of power industry in most countries has originally changed the boundary conditions and brought much uncertainty of power system. Many factors, as electricity demand [4], power production, transmission and utilization as well as pollution emissions [5], have become major uncertainties associated with generation expansion planning. This makes the decision-maker to consider main influencing variables, relative risk and uncertainties.

Considering the significant change on the investment entity and the formation mode of revenue, traditional generation capacity investment and planning theory is no longer applicable as self-decision making, inter-competition and high uncertainty involved, so it is necessary to study the evaluating methods of revenue and risk of generation investment, and to model the generation investment problem to tell investors how to make their investment strategy.

The decision making of generation investment includes the capacity investment and technology investment. As the capacity investment study model is comparatively mature and investment signal can be easily captured by generation investors, so the method on generation technology investment is focused and studied in this paper.

As for thermal power generation, heat-only system (HO) and the combined heat and power generation (CHP) are recently becoming main technologies. In this circumstances, it is significant

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Nomenclature

K_t, K_t^*	actual capital stock and desired capital stock in term t
P_F, P_E	fuel price and electricity price
α_i, σ_i	constants of price drift and price fluctuation
du_1, du_2	irrelevant standard Brownian motion increment
ρ_{FE}	relevancy of P_F and P_E
δ_j	thermal efficiency
η	heat intensity (the heat of per kilowatt hour)
ξ_j	power consumption rate
C_{Π}	fixed operating revenue deriving from electricity/heat sales
k_{Fj}, k_{Ej}	cost factor
$V_j(t)$	present discounted value
θ	discount rate
S_T	spot market price
X	exercise price
P	option price
C_I	sunk cost
$(\widehat{p_{Fj}}, \widehat{p_{Ej}})$	boundary conditions with upper and lower value
$\overline{P_{Fj}}$	investment threshold value
A_{Fj}, B_{Fj}	parameters defined in equation deducing process
g, h	step width

to model the generation investment optimization, especially to optimize the generation technology-choose problem.

Many articles have studied the optimization of power investment. Ref. [6] proposed an investment decision-making model of generation based on linear programming method. Ref. [7] proposed a developed investor-dependent strategy which is based on stochastic real options analysis that enables to account for the additional value of waiting. Ref. [8] introduced and applied an improved multi-objective cuckoo search algorithm and a novel met-heuristic optimization algorithm based on cuckoo breeding behavior. In Ref. [9], a two-stage optimal planning and design method for combined cooling, heat and power micro-grid system was presented. Ref. [10] proposed generation expansion planning aims at maximizing the expected profit of all generation companies while considering security and reliability constraints in which wind farm uncertainty is considered.

In this paper, a dynamic stochastic model with main effective valuables considering relative risk and uncertainties is established, and the influence of investment risk and uncertainties from different sources is discussed. The theoretical basis of the model build in this paper is the irreversible investment theory under uncertainties. In order to explain the decision-making process of generator's investment, the decision-making optimization model was built considering two generation technologies, i.e., the heat-only system (HO) and the combined heat and power generation (CHP). Also, the theory deducing process, which explained how to eliminate the overrated economic potential caused by risk hazard, based on economic evaluation of both generation technology is discussed. Finally, practical data from competitive electricity market was used to prove the validity of the model.

2. Irreversible investment model under uncertainties

2.1. The theory of irreversible investment

Irreversibility means once the investment was made, it will be transferred into sunk cost which cannot be sold again. The irreversibility under uncertainties can be understood as an extreme manifestation of asymmetry of the investment costs of adjustment for investment [11]. So there exists differences between the actual capital stock and the desired capital stock, as can be seen in Fig. 1 (a) and (b). The typical manifestation of this differences is the company unwilling to sell its excess capital.

Many literatures have proved the existence of the irreversibility of investment. The reasons for investment irreversibility can be concluded as follows:

(1) There is almost no substitutability between capital goods or items which are of highly specialty [12].
(2) When one investor or manufacturer sell its capital goods, the other investors or manufacturers may also take the same choice as their reasonable decisions. Therefore, it explores the demand for second-hand capital goods even in same industry [13].
(3) The information asymmetry of second-hand market is also an obstacle for the sale of capital goods [14].

When the investment is completely irreversible, the actual investment can be expressed as follows Eq. (1), where K_t and K_t^* separately means actual capital stock and desired capital stock in term t.

$$K_{t+1} = \max(K_{t+1}^*, K) \tag{1}$$

Eq. (1) indicates that the capital stock of the current period is not lower than that of early levels as the capital depreciation rates is considered 0. In completely irreversible situation, investor cannot adjust its capital stock even the capital is overrated. So we can draw the conclusion that the actual investment volatility should be less than the desired investment volatility.

In practice, the investment is partly irreversible, as studied in literature [15]. Partly irreversibility (or semi-irreversibility) means the sale price of the current fixed assets is lower than its replacement price, which means the original investment is partly lost. The semi-irreversibility can be seen as a share option. The value of the share option is the opportunity cost of invested item. One thing should be mentioned is that the added investment is not continuous function of capital stock in semi-irreversible situation.

The theory of irreversible investment in this paper is mainly used to solve two problems: one is to figure out the corresponding conditions that should be satisfied for initial investment, while the other is for the investment adjustment. There are three essential characteristics for the irreversible investment model under uncertainties.

(1) The investment, especially for the long-term used equipment or facilities, need to pay the cost of irreversibility which transferred into sunk cost. This characteristic mainly stems from the feature of productive industry. Once the productive investment is made, or even partly made, it cannot be transferred to other industry or production. Even if the transformation is finally made, the original investment will be totally lost.
(2) The future revenue of fixed asset investment is of high uncertainty and risk. The irreversible investment theory underlines the uncertainties of the process of decision-making, where the future revenue can be seen as a stochastic variable. The combination of uncertainty and the irreversibility makes the decision-making a complex problem.