Financing Long-term Generation Capacity in a Reference Price Oriented Capacity Market

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Abstract

Many power markets around the world have been facing inadequacy with generation capacity investment to meet the growing demand. Among various frameworks directed towards this problem, capacity markets have emerged in major eastern US power markets. In this paper, a prototype capacity market is discussed which is consistent with the trend of convergence of market design. Based on this, the critical role of the reference capacity price is brought up, followed by a detailed explanation of its economic rationale and concerns. Noted with the necessity of a systematic pricing scheme to determine the value of the reference capacity price, a pricing model based on the general Black-Scholes contingent claim framework is proposed. In this model, the capacity value is treated as a path-dependent derivative with electricity prices and natural gas prices as underlyings. Numerical study is conducted to prove model validity with a lattice approach adopted.

1. Introduction

1.1 The long-term resource adequacy problem facing the power industry

Many power markets around the world are facing a shortage of generation capacity investment, and this issue has been seriously treated as a long-term generation resource adequacy problem [1] [2]. In contrast to the short-term adequacy problem which mainly relies on the spinning reserve to meet an unexpected demand increase, the long-term generation adequacy issue emphases on meeting the annual peak demand and should be ensured by a sustained investment in new capacity. In addition, a long-term market equilibrium implies an appropriate level of investment in generation capacity with right amount, right type, and right location.

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In a deregulated power industry, individual customer who benefits from a reliable system has no incentive to be responsible for system reliability. Consequently, customers would enjoy being free riders in the system rather than paying for reliability, which shows the public goods attribute of capacity [3]. In order to finance adequate generation addition, it is necessary to price capacity properly in the first place.

Market regulators around the world hold different perspectives toward this long-term investment adequacy issue. Proposed solutions include the capacity payment in power pools [4], the two-part price scheme in China, the energy only market design [5], the New Electricity Trading Arrangement (NETA) with a proper price cap in the UK [6] [7], the call option obligation scheme [8], and the capacity market proposal[9] - [11]. It is important to realize that the effectiveness of these proposed solutions should not be judged based on themselves alone, but on its harmony being fitted with other components in the industry, e.g. the primary energy market, the regulation depth, and the energy law, etc.

The focus of this paper is the capacity market proposal which has been implemented by three major Independent System Operators (ISOs) in eastern US namely NYISO, ISO-NE, and PJM.

1.2 The market place for trading long-term capacity

Although there are different versions of capacity market design, principally they tend to converge through time. A prototype capacity market mainly consists of a primary annual auction and some following adjustment auctions. Here, we only concentrate on the primary auction in which most transactions occur. In order to accommodate new projects into bidding as competitors with existing generating units, the auction should be conducted

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about 3 years before real time delivery to count for construction time. The commodity traded in the market is unforced capacity (UCAP), which is the installed capacity (ICAP) with forced outage in consideration. The market uses the pay-as-clearing scheme. On the supply side, each unit bid according to the net going forward cost of its capacity [12]. On the demand side, where the distinct feature of the capacity market emerges, all customers are collectively represented by a downward sloping demand curve which is determined by the ISO. This shows the strong regulatory role played by the ISO in the capacity market. Looking at the way that the demand curve is determined, the most critical point on the curve is a reference point which is set by a reference capacity quantity and a reference capacity price. The reference quantity is calculated as the forecasted annual peak demand of the delivery year with reserve margin considered. More complicated than setting the reference quantity, the reference price is determined according to the economics of a benchmark combustion gas turbine (GT). The reference capacity price orients the capacity market in a way that potential investors are informed with the system perspective on a reasonable capacity value.

Many distinguished researchers have contributed on the discussion of the microstructure of the capacity market [9]-[14]. Focusing on the reference capacity price, this paper aims to explain the economic rationale behind this reference price and to propose a pricing scheme to determine its value using financial engineering methods.

The following parts of this paper are arranged as: Part 2. The economic rationale behind the reference capacity price is explained and related concerns are raised; Part 3. A pricing model is proposed to calculate the reference price systematically; Part 4. A numerical example is implemented to show the validity of the pricing model; Part 5. The conclusion is drawn.

2. The reference capacity price: economic rationale and concerns

2.1. The reference price provide benchmark for capacity financing compensation

In the primary energy market, gas turbine (GT) normally becomes the type of marginal units when the demand reaches certain high level. Theoretically, GTs rely on electricity price spikes during those demand peaks to recover their fixed costs. Unfortunately, the price cap enforced on the electricity price has caused difficulty for GTs to fully recover their fixed costs solely by selling electricity. This difficulty in capacity financing is referred as the “missing money” problem. The emerging capacity market is expected to compensate for this “missing money” so as to help finance capacity. In the capacity market, the reference price is calculated as deducting from its amortized fixed cost the expected yearly profit of a peaking GT obtained in the Energy and ancillary service (E&AS) market. This formulation aims to use the corresponding cost of a GT as the compensation benchmark for capacity financing. In addition, in the annual capacity auction, the discrepancy between the final market clearing price and the reference price also tells investors about the situation of generation adequacy in the system. As we assume GTs take the role of benchmark, the incentive from this market would tend to add new GTs. There is a concern that the resulting generation mix could be vulnerable to the natural gas price risk.

The compensation is provided through a market mechanism while with regulatory body involved. This is because capacity for reliability is mixed good with both public and private properties. In [15], capacity is separated into two attributes, i.e. security as public good and adequacy as private good. The problem of mixed goods can date back to Samuelson’s initial exploration of the properties of public goods in [16].

2.2. The reference price helps smooth the investment cycle and improve economic efficiency

The provision of a reference capacity price intends to send a signal about more predictable revenue to potential investors. Consequently, the investment cycle experienced by the power industry is expected to be smoothed [17]. However, whether the investment signal sent by the ISO through the capacity market and the expectation from potential investors could match synchronously needs to be tested in reality. A similar case is with the capital market which also experiences cycles. Some researchers argue that due to monetary policy time lags, changes in the growth rate of the money supply indicated by a feedback rule can actually result in an increase in the size of the economic cycles. For this reason, monetary policy based on a feedback rule will not necessarily stabilize aggregate demand or inflation, although that is their intent [18]. The way that capacity market runs can be considered as a feedback-rule policy as well. In the capacity market, the price is adjusted yearly according to the feedback from the changing economic environment. Due to the time lag caused by construction time of power plants, when new capacity is built, the underlying economy may have changed far from the forecast made years ago. Hence, the time lag effect should be considered in the market design. In order to ensure reliable and predictable revenue, the reference price should be set at a rational value.

The capacity market also intends to achieve economically efficient resource allocation through inducing the optimal generation mix. Within an uncertain reliability environment, the tradeoff between the protection of reliability and the added costs must be balanced in the market design.

2.3. The reference price enforces the pooling function

The use of a single reference price in the capacity market shows the perspective that all capacity contributes the same to system long-term reliability. Rather than depending on individual generation company (Genco) to finance new capacity separately, the ISO could be regarded as playing the fund-raising role for the whole system through the capacity market. In the capacity market, the ISO pools together both the Gencos' capacity and the demand of customers who are represented by load serving entities (LSEs). This pool function helps finance new capacity projects in the system. The clearing of the forward capacity market results in customers paying for using capacity, but this payment is made year by year rather than a one time payment to recover the capital cost of capacity. This inter-temporal borrowing and lending arrangement is similar to a lease payment. All material things can be lent, so does capacity. While, it is reasonable to question on the fact that base units obtain the same capacity price as peakers in the capacity market. In fact, base units normally have no difficulty to recover their fixed costs from the energy market even before the capacity market was introduced. Although generally we regard base units providing the same long-term capacity value as peakers, the profit earned from the capacity market is windfall profit for base units.

3. A general contingent claim pricing model for the reference price

As discussed in the above section, the reference capacity price is a critical factor, if not the most critical one, in the capacity market. Hence, a systematic pricing scheme should be in place to determine its value. As mentioned before, the reference price is determined according to the economics of a benchmark GT. More specifically, the reference price (assume monthly payment) is calculated as deducting the E&AS revenue from the amortized capital cost of a typical peaking GT and then divided by 12. Currently, the industry practice roughly uses a cost recovery model to estimate the reference price, where the revenue from E&AS markets is projected from previous years.

In this paper, a systematic pricing model based on the Black-Scholes contingent claims pricing framework [19] is proposed. As we know, the value of capacity traded in the capacity market originates from the generation asset. This leads to the rationale to treat capacity value as a fictive contingent claim on parts of the value of the generation asset. In this pricing model, the right to sell 1MW-month capacity in the annual capacity market is treated as an option. For simplicity, we don't consider the 3-year time lag which exists in the real market. The payoff of the option is defined as equal to the reference capacity price if the option is exercised, and is zero if it is abandoned. This option is a path-dependent derivative, because its payoff function involves calculating a GT's expected annual profit from the energy market, which depends on the entire paths of the electricity price and natural gas price of the year.

The hourly electricity price $\tilde{P}_e(t)$ and the hourly natural gas price $\tilde{P}_g(t)$ are chosen as the underlying state variables of this option. These two underlyings are assumed as following two correlated Geometric Brownian Motions (GBMs). Considering the non-storable feature of the spot electricity, a hypothetical hourly forward electricity price $\tilde{P}_e^f(t)$ is used for hedging, which is assumed as derived from the spot price $\tilde{P}_e(t)$. We define the spot price dynamics satisfy $d\tilde{P}_e = \mu_e \tilde{P}_e dt + \sigma_e \tilde{P}_e d\tilde{z}_e$

Inspired by [20] [21], the hourly forward price dynamics should satisfy

$$d\tilde{P}_e^f = (\mu_e - \lambda_e \sigma_e^f)\tilde{P}_e^f dt + \sigma_e^f \tilde{P}_e^f d\tilde{z}_e$$

$$where\ \lambda_e = \frac{\mu_e - r}{\sigma_e^f},\ \text{and}\ \sigma_e^f = \sigma_e \cdot e^{-\alpha t},$$

In which λ_e is the market price of risk, and α models the effect that the volatility of a forward price is lower than the corresponding spot volatility. Similarly, we define the GBM for the natural gas price process as

$$d\tilde{P}_g = \mu_g \tilde{P}_g dt + \sigma_g \tilde{P}_g d\tilde{z}_g$$

The correlation is modeled as $d\tilde{z}_e d\tilde{z}_g = \rho dt$

where ρ is the correlation coefficient between these two underlying processes.

Define $\tilde{F}$ as the value of the option, i.e. the right to sell 1MW-month capacity in the capacity market, which will be worth the value of this amount of capacity if it is exercised and no value if it is abandoned. Apply Ito's lemma on $\tilde{F}$ with respect to P_e^f and P_g, we get

$$d\tilde{F} = (\frac{\partial F}{\partial P_e^f}(\mu_e - \lambda_e \sigma_e^f)\tilde{P}_e^f + \frac{\partial F}{\partial P_g}\mu_g \tilde{P}_g + \frac{\partial F}{\partial t}dt + \frac{1}{2}\sigma_e^{f2}\tilde{P}_e^{f2}\frac{\partial^2 F}{\partial P_e^{f2}} + \frac{1}{2}\sigma_g^2 \tilde{P}_g^2 \frac{\partial^2 F}{\partial P_g^2} + \rho\sigma_e^f \sigma_g \tilde{P}_e^f \tilde{P}_g \frac{\partial F}{\partial P_e^f \partial P_g})dt + \frac{\partial F}{\partial P_e^f}\sigma_e^f \tilde{P}_e^f dz_e + \frac{\partial F}{\partial P_g}\sigma_g \tilde{P}_g d\tilde{z}_g$$

Define a portfolio $\tilde{\pi} = -\tilde{F} + \frac{\partial F}{\partial P_e^f}\tilde{P}_e^f + \frac{\partial F}{\partial P_g}\tilde{P}_g$, then

$$\begin{aligned} d\tilde{\pi} &= -d\tilde{F} + \frac{\partial F}{\partial P_e^f}d\tilde{P}_e^f + \frac{\partial F}{\partial P_g}d\tilde{P}_g \\ &= (\frac{\partial F}{\partial t}dt + \frac{1}{2}\sigma_e^{f2}\tilde{P}_e^{f2}\frac{\partial^2 F}{\partial P_e^{f2}} + \frac{1}{2}\sigma_g^2 \tilde{P}_g^2 \frac{\partial^2 F}{\partial P_g^2} \\ &\quad + \rho\sigma_e^f \sigma_g \tilde{P}_e^f \tilde{P}_g \frac{\partial F}{\partial P_e^f \partial P_g})dt \end{aligned}$$

According to the no-arbitrage assumption, we have

$$d\tilde{\pi} = r\tilde{\pi}dt = -r(\tilde{F} - \frac{\partial F}{\partial P_e^f}\tilde{P}_e^f - \frac{\partial F}{\partial P_g}\tilde{P}_g)dt$$

By equating the above two equations, we get the Black-Scholes formula for F:

$$\frac{\partial F}{\partial t} + r(\frac{\partial F}{\partial P_e^f}P_e^f + \frac{\partial F}{\partial P_g}P_g) + \frac{1}{2}\sigma_e^{f2}P_e^{f2}\frac{\partial^2 F}{\partial P_e^{f2}} + \frac{1}{2}\sigma_g^2 P_g^2 \frac{\partial^2 F}{\partial P_g^2} + \rho\sigma_e^f \sigma_g P_e^f P_g \frac{\partial^2 F}{\partial P_e^f \partial P_g} = rF$$

Assume we are at t=0 with t hourly indexed and the time to maturity is one year. Then, we denote F(T) as the value of F at maturity. We have the boundary conditions for the above Black-Scholes formula as:

$$F(T) = \max[(C - R_e - R_a)/12, 0],$$

$$R_e = \sum_{t=1}^{T} e^{-rt}E^Q[\max(P_e^f(t) - H \cdot P_g(t), 0)],$$

where C is the annualized capital cost of a GT. H is the heat rate of the GT. R_e and R_a are the expected revenue of a GT earned from the energy market and the ancillary market respectively. Both C and R_a are assumed constants. The superscript Q means the expectation is taken under the risk-neutral measure.

In practice, due to the exotic feature of this option, numerical methods are normally adopted to solve the Black-Scholes formula through its discrete approximation. One approach is to construct a recombining lattice, which is suitable when the derivative has a look-back feature. Various methods to build a lattice with two correlated underlying variables have already been proposed. Among them, the BEG method [22] is considered as the benchmark, in which the number of states at step n is $(n+1)^2$. Another method was proposed in [23], which was also used in [24] for its spark spread real option valuation model. The most recent method was by [25], which is considered more efficient and is chosen for implementation of the pricing model in this paper.

Following the method in [25], for any given time t, possible next hour prices are defined as

$$\begin{bmatrix} \ln P_{e,1}^f(t+\Delta t) & \ln P_{g,1}(t+\Delta t) \\ \ln P_{e,2}^f(t+\Delta t) & \ln P_{g,2}(t+\Delta t) \\ \ln P_{e,3}^f(t+\Delta t) & \ln P_{g,3}(t+\Delta t) \end{bmatrix}$$

$$= \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \times \begin{bmatrix} \ln P_e^f(t) + (r - \frac{\sigma_e^{f2}}{2})\Delta t \\ \ln P_g(t) + (r - \frac{\sigma_g^2}{2})\Delta t \end{bmatrix}' + \begin{bmatrix} r_x\hat{x}_1 & r_y\hat{y}_1 \\ r_x\hat{x}_2 & r_y\hat{y}_2 \\ r_x\hat{x}_3 & r_y\hat{y}_3 \end{bmatrix}$$

where

$$\begin{bmatrix} r_x\hat{x}_1 & r_y\hat{y}_1 \\ r_x\hat{x}_2 & r_y\hat{y}_2 \\ r_x\hat{x}_3 & r_y\hat{y}_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ \frac{\sqrt{3}}{2} & \frac{-1}{2} \\ \frac{-\sqrt{3}}{2} & \frac{-1}{2} \end{bmatrix} \times \frac{1}{\sqrt{1+\tan^2\phi}} \begin{bmatrix} 1 & \tan\phi \\ \tan\phi & 1 \end{bmatrix}$$

in which $\phi = (\sin^{-1}(\rho))/2$ and the probability is assumed as equal for each state at a specific stage of the tree.

4. Numerical Example

4.1. Data description

A prototype peaking GT is dispatched for $\beta \cdot 8760$ hours in a year, where the capacity factor β is varying with different load zones. For example, according to [26], β is ranging from 12% to 16% for New York City （NYC）, but is around only 2% for Rest of State (ROS) in the New York State control area. We also set the economic parameters based on [24] for a typical GT, see Table 1.

Table 1 Economic parameters of a typical GT

Ancillary profit R_a (\$/MWh-year)	Capital cost C_F (\$/MW)	Recovery period (years)	Fixed operating Cost (\$/MW-year)
10000	831000	15	38850

In order to implement the lattice to get the numerical solution for the Black-Scholes differential equation, the processes of the two underlying variables are set according to statistical data. Hourly volatility and correlation parameters are referenced to [27] as $\sigma_e = 0.15, \sigma_g = 0.16, \rho_{eg} = 0.42, \alpha = 0.3$, and these estimates are based on the natural log of prices. The initial value of the natural gas price $P_g(0) = \$8/MMBtu$. This is based on the NYMEX Henry Hub 12-month strip price, which was $8/MMBtu in 2007. Heat rate H =9MMBtu/MWh. The initial value of the electricity price $P_e(0) = \$65/MWh$. This is based on the price duration curve of the reference bus price in New York State from 2005 to 2007.

4.2. Numerical results

The capacity market is an annual auction market, so the reference capacity price calculated through the model above is fixed for a whole year. We construct different scenarios as shown in the table below in order to see the sensitivity of the result.

Table 2: Numerical results with different parameter settings

Reference Capacity Price (\$/KW-month)	$\sigma_e = 0.18$, $\sigma_g = 0.17$, $\rho_{eg} = 0.42$	$\sigma_e = 0.18$, $\sigma_g = 0.16$, $\rho_{eg} = 0.42$	$\sigma_e = 0.18$, $\sigma_g = 0.15$, $\rho_{eg} = 0.42$
r= 0.03	5.87	5.34	3.46
r=0.04	5.43	4.92	1.87
r=0.05	5.51	4.58	1.86

The results show that with the decrease of the difference between the volatilities of electricity price and gas price, the reference price increases, because the profit from the energy market decreases. When this difference is large enough, the revenue from the energy market will be adequate to cover the fixed cost recovery, which results in zero of capacity price.

The reference price determined by this systematic approach plays a critical role in the current capacity market design, e.g. in the NYISO capacity market. The discrepancy between the market clearing price and the reference price sends sound economic signals to potential investors about the under/over capacity condition in the system, which serve for investment decisions.

4.3. Comparison with real market data

The reference capacity prices set by the NYISO for different delivery years are shown in table 3.

Table 3: Reference price set by the NYISO

NYISO NYCA ROS (\$/KW-month)			
	2005/2006	2006/2007	2007/2008
ICAP Ref.	6.78	6.98	7.19

The result calculated in our example is relatively lower compared with the real reference price set by the ISO. This is probably caused by an overestimate of the profit that a GT could earn from the energy market. For simplicity here, the profit is counted in if the electricity price is higher than the gas price.

5. Conclusion

At the emerging stage of capacity markets, many distinguished researchers have been working on how to make better design of the market microstructure. In response to that, the qualitative part of this paper explains the underlying economic rationale behind the capacity market in a more fundamental and critical sense. The quantitative part of this work devotes efforts on proposing a general contingent claim pricing model for capacity valuation. This approach is distinct from other real option models in the sense that, rather than starting by checking whether the capacity value could be treated as a financial option, it starts from the very general form of the Black-Scholes contingent claims framework. Consequently, the thought flow in this approach could be utilized to value other power assets even without an option feature.

A capacity market is targeting on long-term sustainable generation investment. While due to its relatively young age, it will take time to see how much of its theoretical effectiveness could be justified in reality. In addition, with the progressive penetration of renewables into the system, possible adjustments on the capacity market structure is also worth to be considered.

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