Preventing Over-offering Behavior in Capacity Markets

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Abstract: - Capacity markets provides additional revenue stream for the power suppliers. In a capacity-energy combined market environment, suppliers have incentives to deliberately over-offering their capacities in the capacity market while bid very high price in the energy and ancillary markets to avoid operation. This paper analyzes the risks and profits of this capacity-over-offering behavior, and develops a method for computing non-operable penalty level which can prevent the capacity-over-offering behavior. It is found that the effective penalty level is highly correlated with the stochastic characteristics of supplier's profit streams and supplier's risk attitudes. Two types of suppliers are suggested as the potential cheaters in the analysis. The methodology and the results are potentially useful for the operation and mitigation in a capacity-energy market environment.

Key-Words: - Capacity Market; Over-offering; Risk Analysis; Non-operable Penalty; Prospect Theory; Monte-Carlo Simulation

1 Introduction

Capacity market is one approach to address the long-term generation resource adequacy problem [1]-[22]. In northeast US, capacity markets have been in operation for almost ten years [23][24][25]. Capacity market is an explicit mechanism for pricing resource reliability, which yields an explicit/separate price signal for generation investment. A capacity market also provides generators with additional revenue stream besides energy/ancillary markets. These revenues are important for peaking generators which have "missing money" problem [26][27][28]. The disadvantage of capacity market approach is its administrative essence. Some argue that creating capacity markets will delay the development of a sufficient demand response, which is the right way to ultimately address resource adequacy problem. They believe in other approaches, such as forward contracts and call options to ensure generation investment [29][30][31][32].

In a capacity-energy combined market environment, the strategies of power suppliers will be different from those in the energy-only market environment, due to the change of their money streams.

In this paper, we focus on issues in capacity-energy combined market environment. The capacity requirement is calculated by anticipated peaking load plus a certain amount of margin, the generation capacities cleared in the capacity market is always higher than the real peaking load. Then, a large volume of generation capacities will not operate indeed. Therefore, suppliers may cheatingly offer more capacity than they really have, and bid high price in the energy market to avoid operation. This strategy can bring generators additional revenue without costs, but may cause serious operation problems for the system operator.

From a supplier's viewpoint, over-offering can bring additional revenue stream, but on the other hand, this strategy may also incur penalty when disclosed as non-operable in operation. The real peak load during the capacity period can be much higher than predicted. Moreover, other circumstances such as the outage of a large generator, the emergency start need from a local blackout, may also require unexpected operation of the cheating capacity, no matter how high their bidding price in the energy/reserve market is. When called for operation and revealed as non-operable, the cheating supplier will suffer penalty.

Therefore, whether the strategy of over-offering is profitable depends on a number of factors, including the non-operable penalty level, the load forecast accuracy, the probability of potential operation, the capacity market price, the system capacity adequacy requirement and the risk attitudes of the suppliers.

This paper analyzes the potential return and associated risk of the over-offering strategy, as well as their relationship with the above factors. The motivation is to find a penalty mechanism that can make this strategy less profitable and more risky for the potential cheaters to exercise.

The remaining sections are organized as follows. Section 2 first analyzes the risks and profits of this capacity-over-offering behavior, and then develops a method of computing non-operable penalty level which can prevent the capacity-over-offering behavior of suppliers with different risk attitudes. In Section 3, simulation results of three different types of suppliers are presented and discussed, it is found that risk-neutral penalty level can be either too high or too low for suppliers with different cash streams. In Section 4, some conclusions are drawn.

2 Methodology

In this section, the profits and risks of the capacity-over-offering behavior are analyzed and the methods for setting non-operable penalty level under different risk attitudes are developed. This section consists of three subsections, Subsection 2.1 focuses on formulating the random characteristics of the money stream of the capacity-over-offering behavior. Subsection 2.2 deduces the analytical form of a penalty level which can prevent capacity-over-offering behavior for risk-neutral participants. Subsection 2.3 develops a penalty setting algorithm for risk-averse and risk-seeking participants.

2.1 Formulating effective penalty mechanism

Assume a supplier offer *x* (MW) cheating capacity in the capacity market. It will receive $\tilde{p}_C \cdot x$ extra revenue, where $\tilde{p}_C$ denotes the capacity price. Since the supplier should decide x before the capacity market clears, $\tilde{p}_C$ has uncertainty, so an upper-swung-dash is used to express that capacity price is a random variable.

Therefore the profit of over-offering can be formulated as:

$$\tilde{\pi}_c = \tilde{p}_C \cdot x - \tilde{B} \tag{1}$$

where $\tilde{B}$ denotes the total penalty ($) the cheater will suffer. The term $\tilde{B}$ is related with the amount of cheating capacity which will be revealed, here we use $\tilde{y}(x,t)$ to denote the revealed capacity in operation interval *t* when offering *x* cheating capacity. Then we have:

$$\tilde{B} = \sum_{t=1}^{TOI} \mathrm{M}(\tilde{y}(x,t)) \tag{2}$$

where $\mathrm{M}(\bullet)$ denotes the penalty mechanism. *TOI* denotes the number of total operation intervals.

The next step is to formulate $\tilde{y}(x,t)$. The formulation of $\tilde{y}(x,t)$ may differ significantly in different market designs and market rules. Usually, the revealed capacity $\tilde{y}(x,t)$ is correlated with scarcity/shortage pricing mechanisms in operation. For adequacy and security concern, electricity markets normally have or are moving toward a certain form of scarcity/shortage pricing mechanisms, which will be effective in tight supply-demand conditions. The scarcity/shortage pricing mechanisms usually require all system capacities to follow operation orders and to be compensated with an administrative level of payment (often very high, in US, the scarcity prices are near price cap; in Australia, the scarcity prices are close to the VOLL (value of lost load)) if called for operation. Scarcity pricing programs in different electricity markets are triggered by different conditions. In Northeast US, all plants receiving capacity payments must be available when the price hits the price cap or be penalized. While in the proposed East China power market, the scarcity pricing programs are triggered in shortage situations. Here we simply assume that the scarcity pricing program is triggered when the system reserve is lower than a certain percentage $\underline{r}$ of system load, all the capacities in the system will be under central operation and receive an administrative price p_{SC} for each MW generation.

Under this scarcity pricing program, $\tilde{y}(x,t)$ can be classified into three categories. When demand is less than scarcity threshold, or $\tilde{D}(t) \le C/(1+\underline{r})$, cheating capacity has no risk to be revealed, or $\tilde{y}(x,t)=0$; when demand is higher than total system capacity, or $\tilde{D}(t) \ge C$, all cheating capacity will be called for operation, or $\tilde{y}(t)=x$. When demand lies between scarcity threshold and system capacity, or $C/(1+r) < \tilde{D}(t) < C$, certain amount of cheating capacity has certain probability of revelation, or $\tilde{y}(t)$ is a random variable following hypergeometric distribution. In the above, $\underline{r}$ denotes the threshold percentage of system reserve and *C* denotes the system capacity. Here we just consider a short run market in which there is no investment in new capacity, otherwise, *C* should be replaced with *C(t)* in the formulations. This is close to the situation of electricity markets in China, where the lack of historical statistics and the level forecasting techniques restrict the application of a long term capacity market.

Therefore, $\tilde{y}(x,t)$ can be formulated as:

$$\tilde{y}(x,t)= \begin{cases} 0 & , \quad \tilde{D}(t)\le C/(1+r) \\ \sim H(\tilde{D}(t)-C/(1+r),\, x,\, C-C/(1+r)) & , \quad C/(1+r)<\tilde{D}(t)<C \\ x & , \quad \tilde{D}(t)\ge C \end{cases} \tag{3}$$

where $H(\alpha,\beta,\tau)$ denotes the hypergeometric distribution function with the parameters α, β and τ. Here $\alpha=\tilde{D}(t)-C/(1+r)$, $\beta=x$, $\tau=C-C/(1+r)=C\cdot r/(1+r)$. Intuitively, this means choosing $\alpha=\tilde{D}(t)-C/(1+r)$ from all the available capacity $C\cdot r/(1+r)$, in which x is cheating.

Substitute (3) and (2) into(1), we can get the analytical formulation of the cheating profit:

$$\tilde{\pi}_c=\tilde{p}_C\cdot x-\sum_{t=1}^{TOI}\mathrm{M}(\tilde{y}(x,t)) \tag{4}$$

where $\tilde{y}(x,t)$ follows(3).

The classical method to compare the preference of random money stream is the Expected Utility Theory (EUT) [33]. It is assumed in EUT that an investor's objective is to maximize the expected utility, i.e., the expected value of his utility function. Based on EUT, the problem of over-offering prevention can be expressed as: Finding an optimal mechanism $\mathrm{M}^*(\bullet)$, to ensure $\forall x>0$,

$$\mathrm{E}[\mathrm{U}(W_{0,i}+\tilde{\pi}_{n,i}+\tilde{\pi}_c)]<\mathrm{E}[\mathrm{U}(W_{0,i}+\tilde{\pi}_{n,i})] \tag{5}$$

To show the penalty mechanism explicitly, inequality (5) can be rewritten as:

$$\mathrm{E}[\mathrm{U}(W_{0,i}+\tilde{\pi}_{n,i}+\tilde{p}_C\cdot x-\sum_{t=1}^{TOI}\mathrm{M}(\tilde{y}))]<\mathrm{E}[\mathrm{U}(W_{0,i}+\tilde{\pi}_{n,i})] \tag{6}$$

(6)is the criteria for an effective penalty mechanism. Here $\mathrm{E}[\bullet]$ denotes the mathematical expectation, $\mathrm{U}(\bullet)$ denotes the utility function, $W_{0,i}$ denotes the wealth level of supplier i when making the decision (or initial endowment), generally, $W_{0,i}$ can be formulated as:

$$W_{0,i}=A_i-L_i \tag{7}$$

where A_i denotes the present value of total assets and L_i denotes the present value of total liabilities.

In(6), $\tilde{\pi}_{n,i}$ denotes the normal profit of supplier *i*. The normal profit is a random variable based on the prices of energy and ancillary services. For example, the normal profit of a thermal generator *j* participating in capacity market, spot energy market and fixed contract may read as:

$$\tilde{\pi}_{n,j}=\tilde{p}_C\cdot C_j+p_{FC}\cdot P_{FC}+\tilde{p}_{SP}\cdot P_{SP}-\mathrm{f}_{c,j}(P_{FC}+P_{SP}) \tag{8}$$

$$s.t.\ \ P_{FC}+P_{SP}\le C_j \qquad (9)(6)$$

where P_{FC} and P_{SP} denotes the generation in fixed contract and spot market, C_j denotes the cleared capacity of the generator, $\mathrm{f}_{c,j}(\bullet)$ denotes the cost function, the most widely used forms are linear and quadratic cost functions. Equations (8)-(9) demonstrate a simple example of modeling suppliers' normal profit and associated constraints. A more complicated model can include incomes from other ancillary services [34] and more sophisticated multi-trading strategies [35].

$\tilde{\pi}_{n,j}$ can be different for different generators under different market rules, but the $\tilde{\pi}_{n,j}$ usually is a random variable due to the uncertainty of energy and ancillary services prices. And suppliers usually lack corresponding financial instruments to fully hedge the uncertainties/risks in $\tilde{\pi}_{n,j}$, due to the incompleteness of electricity markets.

2.2 Deducing Risk Neutral Penalty

The solution of the problem of preventing over-offering, or optimal penalty $\mathrm{M}^*(\bullet)$ could have various forms. Within them, the commonly applied mechanism is to penalize each unit of inoperable capacity by a fixed penalty *b*, or, $\mathrm{M}(\tilde{y})=b\cdot\tilde{y}$, then (6)can be written as:

$$\mathrm{E}[\mathrm{U}(W_{0,i}+\tilde{\pi}_{n,i}+\tilde{p}_C\cdot x-b\cdot\sum_{t=1}^{TOI}\mathrm{E}[\tilde{y}]]<\mathrm{E}[\mathrm{U}(W_{0,i}+\tilde{\pi}_{n,i})] \tag{10}$$

Generally, the lowest penalty level can be expressed as:

$$\underline{b}=\inf\left\{\begin{aligned} & b\in\mathbb{R},\quad \forall x>0:\ W_0+\mathrm{E}(\tilde{\pi}_{n,i})+\mathrm{E}(\tilde{p}_C)\cdot x \\ & -b\cdot\sum_{t=1}^{TOI}\mathrm{E}(\tilde{y})\le W_0+\mathrm{E}(\tilde{\pi}_{n,i}) \end{aligned}\right\} \tag{11}$$

where $\inf\{\bullet\}$ denotes the inferior limit.

For risk-neutral suppliers, we can have a more attractive form of $\underline{b}$. Notice that $\mathrm{U}(\bullet)$ is monotonically increasing, and for a risk-neutral supplier, $\mathrm{E}[\mathrm{U}(\tilde{W})] = \mathrm{U}(\mathrm{E}[\tilde{W}])$. Therefore, condition (10) can be rewritten as:

$$W_0 + \mathrm{E}[\tilde{\pi}_{n,i}] + \mathrm{E}[\tilde{p}_C]\cdot x - b\cdot\sum_{t=1}^{TOI}\mathrm{E}[\tilde{y}] < W_0 + \mathrm{E}[\tilde{\pi}_{n,i}] \quad (12)$$

Or equivalently:

$$\mathrm{E}[\tilde{p}_C]\cdot x - b\cdot\sum_{t=1}^{TOI}\mathrm{E}[\tilde{y}] < 0 \quad (13)$$

Notice that:

$$\begin{aligned}
&\mathrm{E}[\tilde{y}]\\
&= \Pr(\tilde{D}(t) \le \frac{C}{1+\underline{r}})\cdot 0 + \Pr(\frac{C}{1+\underline{r}} < \tilde{D}(t) < C(t))\\
&\cdot\mathrm{E}[\frac{\tilde{D}(t) - C/(1+\underline{r})}{C - \tilde{D}(t)}\cdot x \,\Big|\, \frac{C}{1+\underline{r}} < \tilde{D}(t) < C] + x\cdot\Pr(\tilde{D}(t) \ge C)\\
&= \left\{\begin{array}{l}\Pr(\frac{C}{1+\underline{r}} < \tilde{D}(t) < C)\cdot\mathrm{E}[\frac{\tilde{D}(t) - C/(1+\underline{r})}{C - \tilde{D}(t)} \,\Big|\, \frac{C}{1+\underline{r}} < \tilde{D}(t) < C]\\ + \Pr(\tilde{D}(t) \ge C)\end{array}\right\}\cdot x
\end{aligned}$$

(14)

Where $\mathrm{E}[\bullet|\bullet]$ denotes conditional expectation. By substituting (14) in(13), we have:

$$\left\{\begin{array}{l}\mathrm{E}[\tilde{p}_C]\\ -b\cdot\sum_{t=1}^{TOI}\left\{\begin{array}{l}\Pr(\frac{C}{1+\underline{r}} < \tilde{D}(t) < C)\\ \cdot\mathrm{E}[\frac{\tilde{D}(t) - C/(1+\underline{r})}{C - \tilde{D}(t)} \,\Big|\, \frac{C}{1+\underline{r}} < \tilde{D}(t) < C]\\ + \Pr(\tilde{D}(t) \ge C)\end{array}\right\}\end{array}\right\}\cdot x < 0$$

(15)

Since $x > 0$, (15) is equivalent to:

$$b > \mathrm{E}[\tilde{p}_C] / \sum_{t=1}^{TOI}\left\{\begin{array}{l}\Pr(\frac{C}{1+\underline{r}} < \tilde{D}(t) < C)\\ \cdot\mathrm{E}[\frac{\tilde{D}(t) - C(t)/(1+\underline{r})}{C(t) - \tilde{D}(t)} \,\Big|\, \frac{C(t)}{1+\underline{r}} < \tilde{D}(t) < C]\\ + \Pr(\tilde{D}(t) \ge C)\end{array}\right\}$$

(16)

Hence, the lower limit of non-operable penalty level which can prevent risk-neutral participants' capacity-over-offering behavior has been obtained. In this paper, $\underline{b}_{RN}$ is used to denote this level, then we have:

$$\underline{b}_{RN} = \mathrm{E}(\tilde{p}_C) / \sum_{t=1}^{TOI}\left\{\begin{array}{l}\Pr(\frac{C}{1+\underline{r}} < \tilde{D}(t) < C)\\ \cdot\mathrm{E}[\frac{\tilde{D}(t) - C/(1+\underline{r})}{C - \tilde{D}(t)} \,\Big|\, \frac{C}{1+\underline{r}} < \tilde{D}(t) < C]\\ + \Pr(\tilde{D}(t) \ge C)\end{array}\right\}$$

(17)

A penalty higher than $\underline{b}_{RN}$ can ensure that any risk-neutral supplier suffers a loss when bid a non-zero cheating capacity in the capacity market. Therefore, a rational risk-neutral supplier will not cheat in the capacity market under $\underline{b}_{RN}$ penalty. In this aspect, we call $\underline{b}_{RN}$ the risk-neutral-secure penalty (RNS penalty).

Notice that $\underline{b}_{RN}$ depends only on the expectation of capacity market price $\mathrm{E}[\tilde{p}_C]$, demand level $\tilde{D}(t)$, scarcity threshold r and system capacity level C, while not relate to $\tilde{\pi}_{n,i}$ or C_i or any other individual parameters of supplier *i*. In other words, one control area requires only one uniform RNS penalty to prevent cheating behavior, rather than requires different penalty levels for different suppliers.

3.3 Analysis for diverse risk-attitudes

In the above subsection, the minimal penalty level of a risk-neutral supplier is deduced. This RNS penalty can ensure the rational risk-neutral supplier to behave honesty in the capacity market.

However, risk-neutral assumption is too strong for all suppliers at all times. Risk-neutrality equivalently means that all suppliers concern only about their expected profit no matter what the risk is. This is not always the situation, some suppliers do concern about their risks. The more general case is that suppliers concern about their expected profit as well as the associated risk. Therefore, this RNS penalty may be too high or too low for risk-averse and risk-seeking suppliers.

The most widely accepted theorem concerning risk attitudes is the Prospect Theory [1]. Prospect Theory by experimental methodology discovered

(30)

[1] Prospect Theory is established by American economist Daniel Kahneman and Amos Tversky. The winning of 2002 Nobel Prize was regarded as a milestone of the worldwide acknowledgement of Prospect Theory.

that decision-makers are risk-averse for gains and risk-seeking for losses. Readers can refer to [36] for more details about Prospect Theory.

In electricity markets, most suppliers are making money, so they perform risk-averse in decision-making. Base-load/ intermediate suppliers will not offer cheating capacity under the RNS penalty, because cheating capacity will incur an extra volatility to their stable normal revenue stream. Under the RNS penalty, the cheating behavior is highly risky. If seldom called for operation, the cheating behavior will not be revealed and cheating supplier will receive extra payment from the capacity market with no fixed or variable cost. But if frequently called for operation, the cheating capacity cause huge penalty. This "gambling" behavior is hence not preferred by risk-averse base-load suppliers.

There are two types of potential cheaters. The first type is the profit-losing base-load/intermediate suppliers. They are risk-seeking and inclined to take a more risky strategy such as the cheating behavior.

The second type is profit-making peaking-load suppliers (peakers), because their normal profit is negatively correlated with their cheating profit. When the real demand is higher than expected, peakers will generate more and gain higher than expected normal profit; meanwhile their cheating profit will also be lower than expected, because the probability of disclosure of their cheating bidding will be higher than expected due to the high demand. When the real demand is lower than expected, peakers will generate less and gain less normal profit, meanwhile the probability of the potential penalty is also less, resulting in more cheating profit. In this manner, peakers' normal profit is negatively correlated with their cheating profit and the total profit (cheating plus normal profit) will be more stable. This stable revenue stream is preferable for risk-averse suppliers, even though the expected profit is theoretically the same under RNS penalty. Therefore, peakers will more probably (than baseload suppliers) offer a certain amount of cheating capacity in the capacity market, to stabilize their money stream.

The general model for extracting a secure penalty level under various risk attitudes is formulated as the following:

$$\min_b \max_i b \tag{18}$$

$$s.t. \ \forall 0 \le x \le \bar{x},$$

$$\mathrm{E}[\mathrm{U}(W_{0,i} + \tilde{\pi}_{n,i} + \tilde{p}_C \cdot x - b \cdot \sum_{t=1}^{TOI} \tilde{y})] < \mathrm{E}[\mathrm{U}(W_0 + \tilde{\pi}_{n,i})] \tag{19}$$

The risk-averse/ risk-seeking degree is implied in the concavity/convexity of the utility function $\mathrm{U}(\bullet)$. If the utility function is concave, it embodies risk-averse. If the utility function is convex, it embodies risk-seeking.

Here, since $\mathrm{U}(\bullet)$ is nonlinear, $\mathrm{E}[\mathrm{U}(\tilde{W})] \neq \mathrm{U}(\mathrm{E}[\tilde{W}])$, the random variables $\tilde{S}_0$, $\tilde{p}_C$ and $\tilde{y}(t)$ can not be easily decoupled and it is impossible to derive an analytical form of secure penalty.

However, (18)-(19) can still be solved through numerical algorithms. In this paper, we use a Monte-Carlo simulation to obtain numerical solutions of secure penalty under general risk attitudes. The Flow Chart of the proposed algorithm is illustrated in Fig. 1.

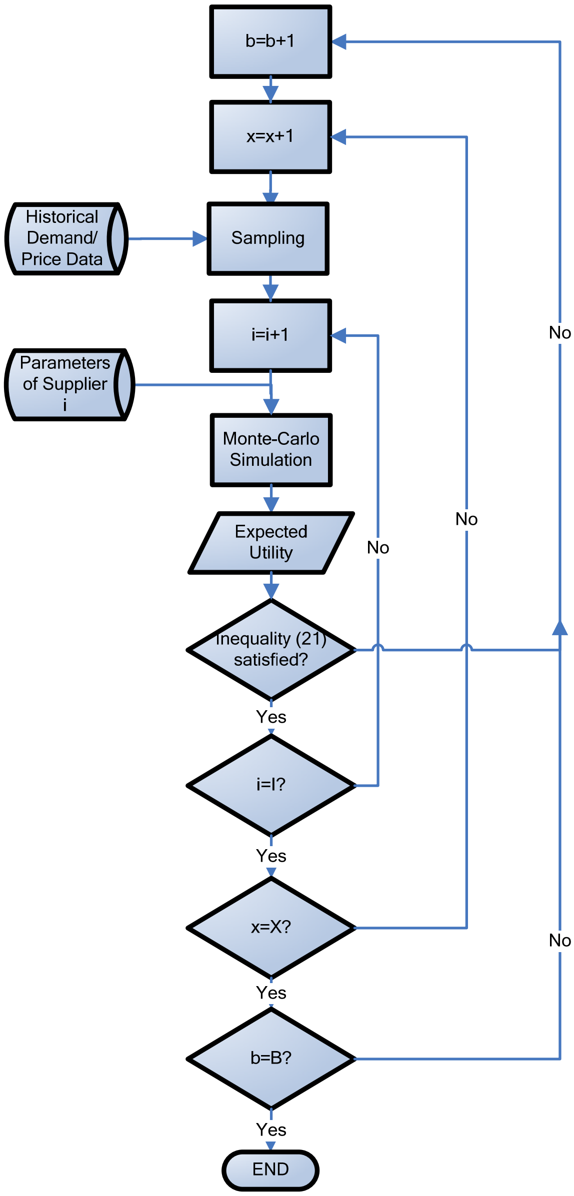

Fig. 1. Flow Chart of the Proposed Algorithm (I: number of suppliers; x: upper limit of cheating capacity; B: upper limit of penalty level)

3 Numeric Examples

In the previous section, the problem of participant's cheating behavior is formulated, the analytical form of secure penalty under risk-neutral assumption is deduced and a simulation algorithm for calculating secure penalty under general risk attitudes is developed.

Previous section also pointed out two potential cheaters. In this section, the proposed approaches for calculating a secure penalty will be tested based on real market data. The expected value and volatility of different suppliers' cheating and normal profit will be compared. The numerical examples presented in this section are illustrated in a scenario of monthly capacity market.

Assume there are three GenCos in the market. GenCoA owns two 100MW gas-fueled peaking generators. Due to the high gas price, his strategy is to generate only in the scarcity periods.

GenCoB owns a 300MW coal-fired generator. Due to its very low fuel cost and high startup cost, its strategy is to generate full capacity as continuously as possible. So it has signed fixed price contract with full capacity.

GenCoC owns a 100MW off-shore wind farm. It has no fuel cost and little operation cost. Most of its cost comes from the annualized depreciation charge. But the rise of the cost of anti-corrosion coatings caused by the soaring crude oil price results in the unexpected high maintenance cost.

In this section, the cost of the GenCos are divided as three parts, depreciation charge c_D, which is assumed fixed and calculated as $/MWy, Operation and Maintenance cost c_{OM} which is assumed fixed and calculated as $/MWy, and the fuel cost c_F, which depends on the output (MW) and calculated as $/MWh.

Based on the above setup, the normal profit of the three GenCos are formulated as:

$$\tilde{\pi}_{n,A} = \tilde{p}_C \cdot C_A - c_{D,A} - c_{OM,A} + \sum_{t=1}^{TOI} (p_{SP}(t) - c_{F,A}) \cdot \tilde{z}(t)$$

$$\tilde{\pi}_{n,B} = \tilde{p}_C \cdot C_B - c_{D,B} - c_{OM,B} + (p_{FC,B} - c_{F,B}) \cdot C_B \cdot T_{O,B}$$

$$\tilde{\pi}_{n,C} = \tilde{p}_C \cdot C_C - c_{D,C} - c_{OM,C} + \sum_{t=1}^{TOI} (p_{SP}(t) - c_{F,C}) \cdot \tilde{P}(t)$$

where

$$\tilde{z}(t) = \begin{cases} 0 & , \quad \tilde{D}(t) \le C/(1+r) \\ \sim H(\tilde{D}(t) - C/(1+r), C_i, C - C/(1+r)) & , \quad C/(1+r) < \tilde{D}(t) < C \\ C_i & , \quad \tilde{D}(t) \ge C \end{cases}$$

For comparison, it is assumed that (1) the present value of assets minus liabilities, or $W_{0,i}$ of the three suppliers are the same; (2) the utility functions of the three suppliers are the same:

$$\mathrm{U}(\tilde{W}) = \begin{cases} 1 - e^{-3\cdot(\tilde{W} - W_0)/W_0}, & \tilde{W} \ge W_0 \\ e^{3\cdot(\tilde{W} - W_0)/W_0} - 1, & \tilde{W} < W_0 \end{cases}$$

where $\tilde{W} = W_0 + \tilde{\pi}_n + \tilde{\pi}_c$. This utility function denotes risk-averse in gain and risk-seeking in loss. **Fig. 2** illustrates this utility function.

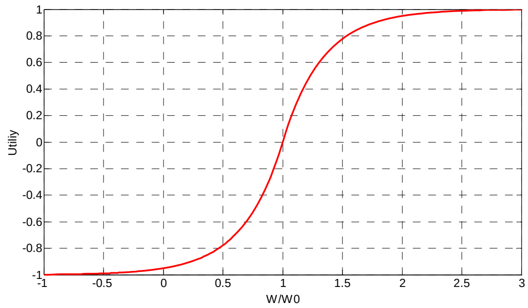

Fig. 2 utility function

In this simulation, the parameters are set as: $W_{0,A} = W_{0,B} = W_{0,C} = 3\times10^6\$$, $p_{SC} = 1000\$/MWh$, $T_{O,B} = 7000$, $C_A = 200MW$, $C_B = 300MW$, $C_C = 100MW$, $p_{FC,A} = 50\$/MWh$, $c_{D,A} = 20000\$/MWy$, $c_{D,B} = 40000\$/MWy$, $c_{D,C} = 60000\$/MWy$, $c_{OM,A} = 10000\$/MWy$, $c_{OM,B} = 20000\$/MWy$, $c_{OM,C} = 30000\$/MWy$, $c_{F,A} = 60\$/MWh$, $c_{F,B} = 45\$/MWh$, $c_{F,C} = 0\$/MWh$.

The capacity and load data are based on a regional market in China. Fig.4 shows the load distribution profile. The operable capacity is 28329 MW.

From(17), the RNS penalty level can be calculated. The result is $\underline{b}_{RN} = 1325\$/MWh$.

However, if $\underline{b}_{RN}$ is used for penalty level, GenCoA and GenCoC will choose the cheating strategy. Fig.3 shows the utilities of normal profits of GenCoA, GenCoB and GenCoC when cheating capacity vary from 0MW to 30MW. We can see that the optimal strategy for GenCoA is to offer 13MW cheating capacity in the capacity market and for GenCoC is to offer 30MW cheating capacity. While for GenCoB, the optimal strategy is not to offer any cheating capacity. The green line for comparison shows the utility level of each GenCo when the cheating capacity is 0, or the level of normal utility.

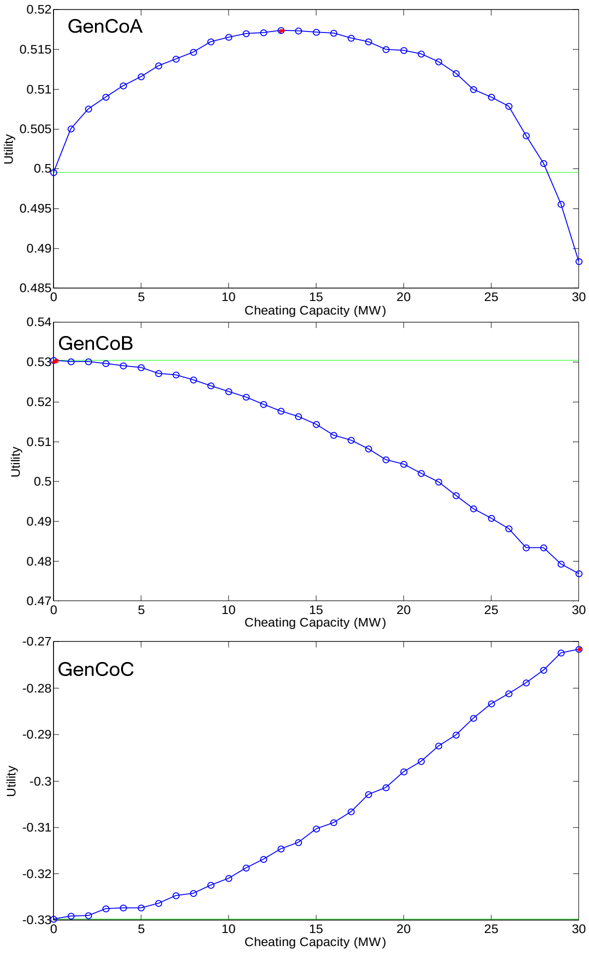

Fig.3 Utility versus Cheating Capacity

We can find from (17) that the expected profit is always the same under $\underline{b}_{RN}$ whatever the cheating capacity is. Then why the utility differs significantly under different cheating capacity? The answer is that their risks are different. Fig. 3 depicts the level of two risk measures (variance and Value at Risk (VaR)) of GenCoA, GenCoB and GenCoC.

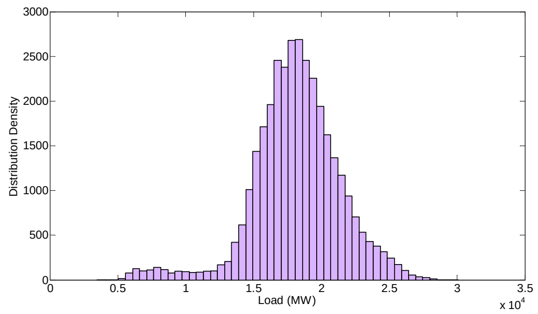

Fig.4 Load Distribution

VaR is percentile-based measure, defined as $\mathrm{VaR}_c = \inf\{L \in \mathbb{R}: \mathrm{Prob}(\Delta Loss < L) \le 1-c\}$, where $\mathrm{Prob}(\bullet)$ denotes conditional probability function, $\Delta Loss$ denotes the potential loss, and c denotes the confidence level (set as 95% in this simulation).

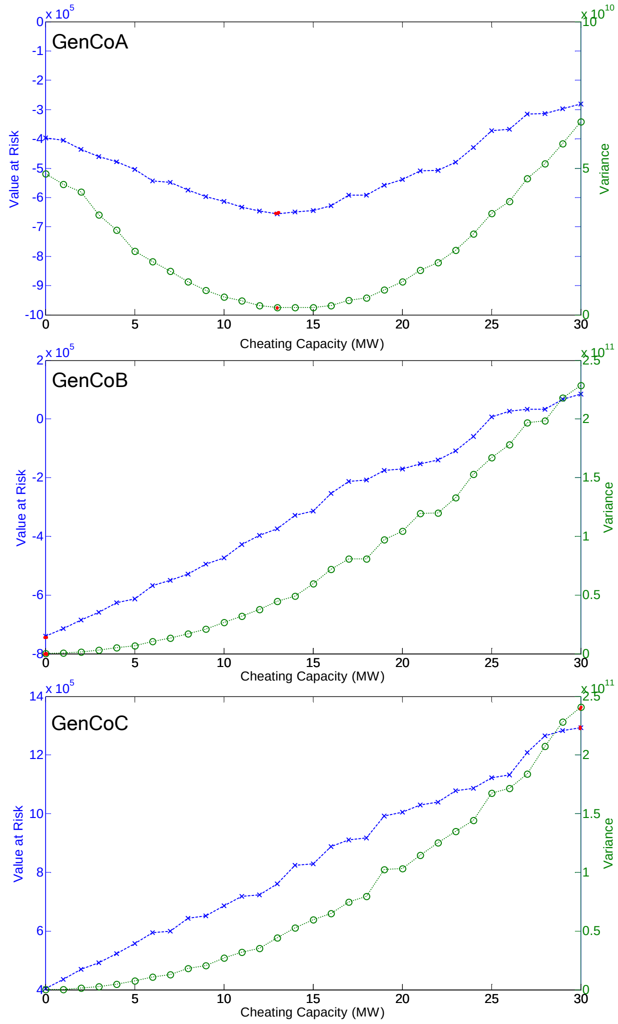

Fig. 3 Risk versus Cheating Capacity

We can see in Fig. 3 that although variance and VaR are different risk measures, they represent almost the same shapes when cheating capacity varies. GenCoA initially can lower its risk by offering more cheating capacity, but after 13 MW, its risk will rise with more cheating capacity. The minimal risk point (13MW) is the same with the maximal utility point (13MW). The risk of GenCoB and the risk of GenCoC will always rise by offering more cheating capacity. But while GenCoB's wealth is at the risk-averse section and GenCoC's wealth is at the risk-seeking section of the utility function, their optimal cheating capacities are 0MW and 30MW, respectively.

The next question is why GenCoA can lower its risk by offering more cheating capacity while GenCoB and GenCoC can not?

To answer this question, we can take a closer look at the probability distribution of their profits before and after cheating, or $\tilde{\pi}_n$ and $\tilde{\pi}_n + \tilde{\pi}_c$. Fig. 4 compare the distributions of pre-cheating (normal) profit and post-cheating (normal+cheating) profit of GenCoA, at the optimal cheating capacity 13MW. We can see that the post-cheating profit is significantly less widely distributed than the pre-cheating profit. In other words, the cheating profit partly hedged the risk in normal profit. The correlation coefficient between normal profit and cheating profit is -0.9819.

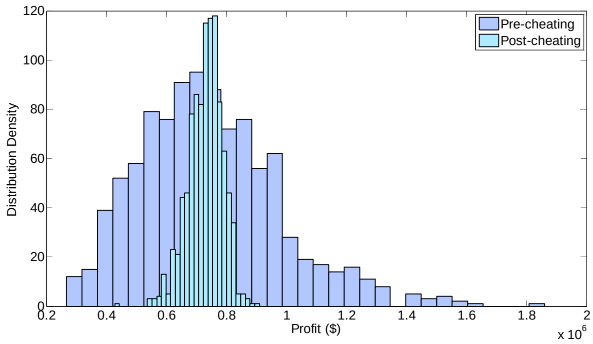

Fig. 4 Comparison between Sample Distribution of GenCoA's Profits before and post cheating

For GenCoB and GenCoC, the correlation between normal profit and cheating profit are all close to zero, 0.0018 and 0.0033 respectively. Fig. and Fig. show the distribution of GenCoB and GenCoC, we can see that the cheating behavior significantly increases the volatility of their profit stream.

To ensure these three GenCos all abandon the cheating behavior, the algorithm described in Fig.1 can be used to calculate the penalty level. The result is that the penalty level should be lifted to 1482$/MWh, where 1396$/MWh can ensure GenCoA's non-cheating and 1482$/MWh can ensure GenCoC's non-cheating.

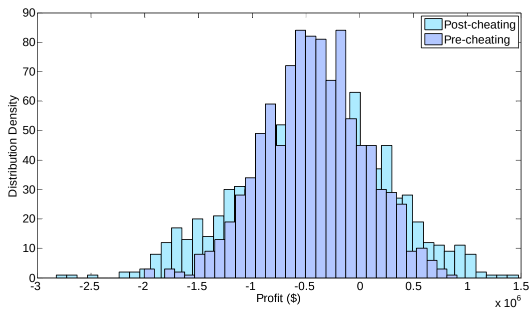

Fig. 7 Comparison between Sample Distribution of GenCoC's Profits Before and Post Cheating

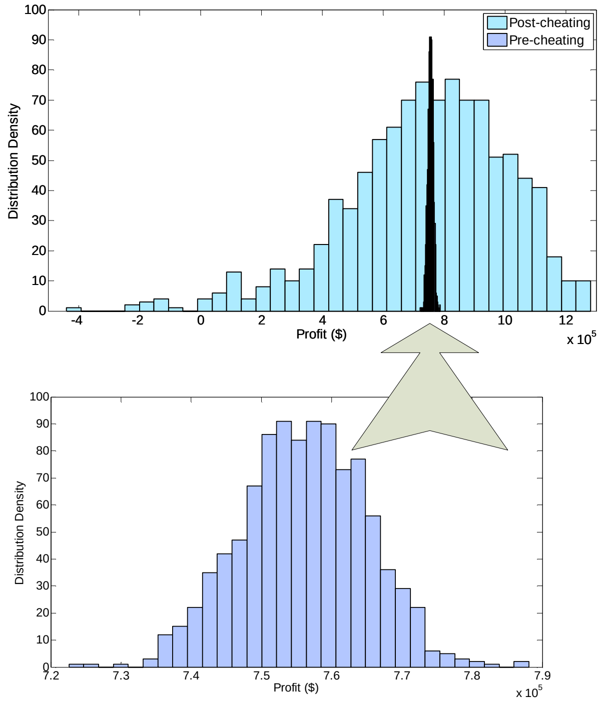

Fig. 8 Comparison between Sample Distribution of GenCoB's Profits before and post cheating

4 Conclusions and Discussions

The introduction of capacity market provides additional (often considerable) revenue for power suppliers. Suppliers' strategies under the capacity-energy combined market environment may vary accordingly, so are suppliers' profits and risks. New strategies can be developed and excised by suppliers, some of which are potentially threatening to the reliability of power systems.

In this paper, the strategy of capacity-over-offering is analyzed. For preventing this potentially threatening behavior, the analytical form of risk-neutral non-operable penalty is deduced. An analysis including the correlation between cheating profit and normal profit, as well as the risk attitudes is conducted. A Monte-Carlo simulation embedded computer program was developed for solving the problem. The results suggest that profit-losing base-load/intermediate suppliers and the profit-making peaking-load suppliers still have incentives to over-offering in the capacity market under risk-neutral penalty level. Although the penalty mechanism and the scarcity pricing mechanism adopted in this work are simplified, the methodology suggested is rather general.

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Vitae

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