Risk management strategy based on price swap for generation companies in electricity market environment

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Abstract
Electricity spot market is one of the commodity markets having high price volatility, which may expose participants to various types of risk. Subject to different risk preference and comparative advantage, participants can make use of power price swap as an effective tool to hedge the power price volatility risk. This paper presents a power price swap risk-hedging model based on swap tool in finance market and utility theory. It explains how the price swap can be used to hedge risk in open electricity market. Example of analysis is included to show the effect of the swap-based tool in cases of high price volatility market and different risk-taking profile of the utilities.

Keywords: electricity market, price volatility, swap tool, risk management
1 Introduction

Electricity market reform involves unbundling the vertically integrated electricity industry and introduces competition into the market operation. Generation companies get their market share by open bidding and customers can opt to choose their service providers. As electricity is a unique commodity for it cannot be stored, spot balance between generation and consumption has to be maintained. Its operation can be regarded as risk due to exposure of high price volatility of the electricity commodity and financial risk associated with the capital investment. Risk management such as by making use of forward, future, and option contracts is commonly used to safeguard interests of the market participants. In references [1~4], generation companies manage to build stochastic optimization model, develop optimal investment portfolio and perform all kinds of statistical analysis for achieving their bidding objectives. While in [5~7], they derive a mechanism for allocating their power generation capacity between spot market and contract market.

Swaps tool is often referred as a kind of risk managing tool in the finance markets. Participants agree to exchange their currency kind, rate basis and other financial asset during a period. The basis of swap relies on comparative benefit of participants in carrying out the swap activity[8]. For example, Company A has comparative advantage of having fixed rate to get capital while Company B's comparative advantage is on variable rate. If they have opposite demand, Company A and B can decrease their capital cost by using the rate swap. In the electricity market, participants may have different risk preference, which means different participants bear different power price volatility risk. Risk-aversion participants would like a fixed power price and risk-preference participants wish variable price. Hence they can come up with some sort of price swap contract to hedge the power price volatility risk. It differs from the traditional long term contract because the entire power quantity and market-clearing price do not change after the power price swap only the settlement prices of participants taking part in swap change. Participant initially having fixed price may have variable settlement price after swap. Power price swap can benefit swap participants so after swap participants' utility will increase and risk will decrease.

The remainder of this paper is arranged as follows. Section 2 briefly describes utility theory and risk attitude. The utility function of a generation company in electricity market is discussed in Section 3. The power price swap hedging-risk model is presented in Section 4. Simulation result is shown in section 5. Section 6 concludes this paper.

2 Expected Utility Theory and Risk Attitude

Expected Utility Theory states that the decision maker chooses between risky prospects by comparing their expected utility values, i.e., the weighted sums obtained by adding the utility values of outcomes multiplied by their respective probabilities. Utility values are judged as merit of carrying out the decided activity and they depend much on the decision makers' yardstick. Hence utility value can be used to measure participant's subjective value attitude or preference for some decision [9].

According to the investment portfolio theory, the Utility Function (U) of a participant is defined as follows:

\[ U = E(R) - \sigma^2(R). \] (1)

Where \( E(R) \) is the participant's expectation of return, \( \sigma^2(R) \) is standard deviation of return. \( \sigma \) is risk attitude. "0" means risk-preference, "0.5" means risk-neutral and "1" means risk-aversion. So \( \sigma^2(R) \) can be seen as the risk born by participant.

3 Utility Function of Generation Companies in Electricity Markets

Generation companies can participate by entering the contract market and spot market. In this paper, we assume that the generation company attends only one market for simplicity of consideration.
By using the following notations:

- \( p \): Market clearing price
- \( q \): Power quantity
- \( C \): Cost function of power generation
- \( A \): A generation company on spot market
- \( B \): A generation company on contract market
- \( c, d \): Unit production cost coefficients

The generation cost has a relationship with power quantity, \( C(q) \) can be defined as follows:

\[
C(q) = \frac{1}{2} cq^2 + dq.
\]  

Then the respective return functions of \( A \) and \( B \) are:

\[
R_A = q_A p_A - C_A(q_A); \quad R_B = q_B p_B - C_B(q_B).
\]

From equations (1), (3) and (4), we can obtain the utility functions of \( A \) and \( B \) as follows:

\[
U_A = q_A E(p_A) - C_A(q_A) - \beta_A q_A \sigma(p_A); \quad U_B = q_B E(p_B) - C_B(q_B) - \beta_B q_B \sigma(p_B).
\]

4 Power Price Swap Hedging-risk Model

Electricity transaction risk exists mainly due to the power price volatility in the spot market. Although participants can hedge the risk through the contract market by fixing the settlement price beforehand, they lose the market opportunity to buy or sell electricity with more appropriate price in the spot market. Hence one concern is how to draw a balance in the hedging process by appointing the power transaction in between the two markets [10, 11]. Power price swap is considered a way out to solve this problem by making use of the comparative advantage of the participants. Both \( A \) and \( B \) are benefited by arbitrating their risk preference as \( A \) is more risk-averse and prefers fixed settlement price while \( B \) is more risk-taking and prefers to take more risk for more profit.

In respect of the high risk associated with the price volatility in the spot market, participants want to hedge the risk and maximize their profit. \( A \) is risk-averse and hates volatile price, i.e., \( 0 \leq \beta_A < 1 \). \( B \) is risk-preference and wishes volatile price, \( 0 < \beta_B < 0.5 \). Due to that the risk attitude of \( A \) and \( B \) are opposite, they can use price swap to obtain their goal. Since the utility function of the generation companies relates to both power price and risk attitude, the price swap must be able to satisfy the risk enduring capability of the generation companies as well.

In the paper, we assume that each generation company enters only one market mode at a time and hence it has different type of risk exposure. As \( A \) enters the spot market that has variable settlement power price, it expects to swap with \( B \) to get a fixed price deal. \( B \) trades in the contract market and has no involvement in the spot market. Hence \( B \) wants to make use of variable price to sell power but not to endure too much risk. \( A \) and \( B \) swap their power price as illustrated in Figure 1. After the power price swap, \( A \)'s settlement price becomes fixed price and that for \( B \) is variable.

\[
A \text{ and } B \text{ swap their power price as illustrated in Figure 1. After the power price swap, } A \text{'s settlement price becomes fixed price and that for } B \text{ is variable.}
\]

Where, \( a \) and \( b \) denote the swap price constants determined by participants' negotiation.

As \((p_A - (a + b)) + (p_B + (a + b)) = p_A + p_B\), electricity customers will not pay more for their electricity. But for generation companies, they get their goal and decrease the risk.

After the power price swap, the settlement price of \( A \) and \( B \) is converted into fixed price and variable price respectively. Their market transaction positions are virtually exchanged and the associated transaction risks are also swapped. But the power price swap is not
just the simple exchange between contract price and spot price. By comparing the fixed price $p_A$ of A with the original fixed price $p_B$, the price is reduced by $(a + b)$. From this viewpoint of analysis, although A gets the fixed price deal, it still bears part of the price volatility risk. Similarly, by comparing with $p_A$, the variable price $p_B$ of B increases by $(a + b)$. It means compared with A, the price volatility risk of B in the spot market is reduced by $(a + b)$.

The utilities of A and B after the power price swap are

\[ U'_A = q_i E (p_B - (a + b)) - C_A (q_i) - \hat{a} q_i \sigma (p_B - (a + b)); \tag{9} \]
\[ U'_B = q_i E (p_B + (a + b)) - C_B (q_B) - \hat{a} q_i \sigma (p_B + (a + b)); \tag{10} \]

Owing to that the swap is a kind of transaction benefiting participants, the utilities of A and B will increase.

So

\[ U'_A - U_A > 0; \tag{11} \]
\[ U'_B - U_B > 0. \tag{12} \]

From equation (5), (9) and (10), we can get

\[ q_i E (p_B - (a + b)) - C_A (q_i) - \hat{a} q_i \sigma (p_B - (a + b)) - q_i E (p_A) + C_A (q_i) + \hat{a} q_i \sigma (p_A) > 0; \tag{13} \]
\[ q_B E (p_B + (a + b)) - C_B (q_B) - \hat{a} q_B \sigma (p_B + (a + b)) - q_B E (p_B) + C_B (q_B) + \hat{a} q_B \sigma (p_B) > 0. \tag{14} \]

$E (p_B)$ denotes the contract price determined in advance. $p_B$ can be taken as a constant. Then $E (p_B) = p_B$. $D (p_B) = 0$. During the contract transaction process, participants negotiate for a contract price based on the forecast of spot price, so we can take $p_B = E (p_A)$. Simplifying equation (13) and (14) as follows

\[ \hat{a} q_i \sigma (p_A) - q_i (a + b) > 0; \tag{15} \]
\[ q_B (a + b) - \hat{a} q_B \sigma (p_B) > 0. \tag{16} \]

So from equation (15) and (16), we can calculate the range of swap price $a + b$ determined by participants’ negotiation.

\[ \hat{a} \sigma (p_A) < a + b < \hat{a} \sigma (p_B). \tag{17} \]

Based on the principle of sharing risk and gains together, A and B should get equal utility incremental value after the swap.

Hence

\[ U'_A - U_A = U'_B - U_B, \]

then calculating with equation (15) and (16), we can get the optimal swap price

\[ (a + b) = \frac{\sigma (p_A) (\hat{a} q_A + \hat{a} q_B)}{q_A + q_B}. \tag{18} \]

From equation (18), we can see that the optimal swap price depends on the spot power price volatility, risk attitude and power quantity. As shown from equations (17) and (18), if $\sigma (p_A) = 0$, $(a + b)$ would not be greater and less than zero at the same time implying that the power price could not be worked out. If $\sigma (p_A) = 0$, it means that the spot power price would be held constant and the market is not risky.

5 Analysis of Simulation

Assume that A swaps with B to hedge the power price volatility risk as explained in the Section 4. The unit production cost coefficients and output limits are listed in Table 1. The contract price of B is 28.356 $/MWh and spot price $p_A$ is stochastic variable meeting with normal distribution of $E (p) = 28.356$ $/MWh$. The simulation results are obtained and listed in Table 2–4. The results in Table 1–4 show the increasing of market risk, that is $\sigma (p)$ increase, A and B get more utility value from the power price swap. And when the spot power price keep constant $\sigma (p) = 0$, the incremental utility value of A and B is zero as shown in Table 5. It shows when the power price fluctuates more severely in the electricity market, the power price swap will play more significant role in hedging the risk.

<table>
<thead>
<tr>
<th>$G_i$</th>
<th>$c_i$</th>
<th>$d_i$</th>
<th>$P_{i,m}/MW$</th>
<th>$P_{i,m}/MW$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.1218</td>
<td>13.6440</td>
<td>30</td>
<td>160</td>
</tr>
<tr>
<td>B</td>
<td>0.1086</td>
<td>13.4928</td>
<td>40</td>
<td>120</td>
</tr>
</tbody>
</table>

2) The result in Table 2 shows how the different risk attitude of generation companies produces different incremental utility value in the power price swap. With $\tilde{\sigma}_i - \tilde{\sigma}_0$ reducing, the incremental utility value from the power price swap also reduces. It means the comparative advantage (risk attitude) between participants affect the utility value. More opposite risk preference attitude will get more utility value out of the power price swap. As seen from the result 4 in Table 1~4, the generation company cannot get more utility value out of the risk hedging process. Hence, absence of comparative advantage will reduce the utility function of generation companies after the power price swap.

3) Result 1 in Table 1~4 tells us that participants need more swap power price when the power price volatility risk becomes higher. By analyzing the result 1, when spot price volatility $\sigma(p) = 14.354$, A and B need to set the swap power price $(a + b) = 8.455$ to obtain equal utility value. Here, the swap power price $(a + b)$ can be any value between $(0.014354, 14.081274)$. After calculating the utility values with different swap power price, we can obtain different incremental utility values shown in Figure 2. With the increasing of swap power price $(a + b)$, the fixed settlement price $\hat{p}_i = p_i - (a + b)$ decreases and A obtains less utility value from the swap and endures more risk. B gets more utility value by enduring less risk with the increasing of the swap power price $(a + b)$. Only at the point $(8.455, 675.212)$, they get equal utility value.
6 Conclusion

Severe fluctuation of the power price in the spot market contributes to the power price volatility risk as explained in the paper. It causes losses to generation companies, retailers, and customers and damages the stable operation of the electricity market. Using long-term contract can be an effective tool to stabilize the power price and hedge the spot price risk for participants in the electricity market. As illustrated in the simulation analysis, when the risk-aversion participant chooses contract market to trade, he may lose opportunity benefits out of the spot market; vice versa, risk-preference participant trading in the spot market may not be able to hedge risk through the contract market if he only enters the spot market. Making use of both the spot and contract markets appear a logical way out but it needs a thoughtful strategy to apportion the power quantity into the two markets. Seeing that the power price needs not be considered in this problem and natural existence of different risk attitudes of participants, the power price swap is justified to be feasible for hedging the risk exposure in both the spot and contract markets for various market participants including generation companies, retailers, and consumers. In the execution of the price swap, the following observations are noted:

1) The larger the scale of the power price fluctuation, the higher of the utility value can be effected.

2) The power price swapping functions only with participants of opposite risk-taking attitude.

3) Simulation result shows that the power price swap is a gaining process. Its success relies on participants obtaining equal utility value out of the risk-hedging process.

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References


