电力市场环境下基于电价互换的发电公司风险管理策略

李晓军[1,2], 颜汉荣[2], 余志伟[2], 钟志勇[2], 黄杰波[2], 谭忠富[1]

(1. 华北电力大学 电力经济研究所, 中国 北京 102206; 2. 香港理工大学 电机工程系, 中国 香港)

摘 要: 电力现货交易市场属于实物交易市场的一种, 具有很高的价格波动性, 给市场参与者带来风险; 考虑市场参与者不同的风险偏好和比较优势, 利用电力价格互换, 对冲电力价格波动的风险. 首先介绍了金融市场和效用理论学科中应用较多的互换工具, 并以此为基础建立了电力价格互换的风险对冲模型, 解释了在开放的电力市场中如何利用价格互换来对冲风险, 最后用算例分析表明价格互换工具可以有效地用于价格波动剧烈的市场中的风险控制, 也可以作为电力公司不同的风险组合策略.

关 键 词: 电力市场, 价格波动, 互换工具, 风险管理

中图分类号: TM 73; F 123.9　　文献标识码: A　　文章编号: 1673-9140(2008)03-0012-06

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

LI Xiao-jun[1,2], H. W. Ngan[2], C. W. Yu[2], C. Y. Chung[2], K. P. Wong[2], TAN Zhong-fu[1]

(1. Institute of Electricity Economics, North China Electric Power University, Beijing 102206, China;
2. Department of Electrical Engineering, The Hong Kong Polytechnic University, Hong Kong, China)

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.

Key words: electricity market; price volatility; swap tool; risk management

---

收稿日期: 2008-08-25

作者简介: 李晓军(1979-), 男, 博士, 主要从事电力技术经济、风险管理和电力市场的研究.

通讯作者: 颜汉荣, 男, 博士, 副教授; E-mail: eehwngan@polyu.edu.hk

© 1994-2014 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

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.

Swap 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.

$$U = E(R) - \partial\sigma(R). \qquad (1)$$

Where, $E(R)$ is the participant's expectation of return; $\sigma(R)$ is standard deviation of return; ∂ is risk attitude, '0' means risk-preference, '0.5' means risk-neutral and '1' means risk-aversion. So $\partial\sigma(R)$ 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.

© 1994-2014 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

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:

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

Then the respective return functions of A and B are:

$$R_A = q_A p_A - C_A(q_A); \qquad (3)$$

$$R_B = q_B p_B - C_B(q_B). \qquad (4)$$

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

$$U_A = q_A E(p_A) - C_A(q_A) - \partial_A q_A \sigma(p_A); \qquad (5)$$

$$U_B = q_B E(p_B) - C_B(q_B) - \partial_B q_B \sigma(p_A). \qquad (6)$$

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 apportioning 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-aversion and prefers fixed settlement price while B is more risk-taking and prefer 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-aversion and hates volatile price, i.e. $0.5 < \partial_A < 1$. B is risk-preference and wishes volatile price, $0 < \partial_B < 0.5$. 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.

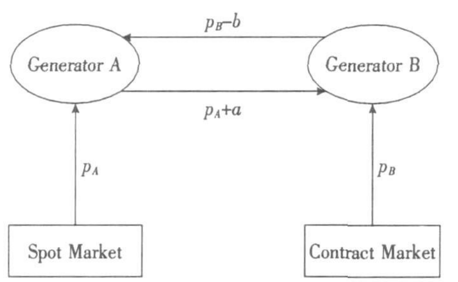

图 1 发电公司 A和 B之间的电价互换交易过程

Figure 1 Power price swap between A and B

The settlement power price of A after the swap is

$$p_A' = (p_B - b) + p_A - (p_A + a) = p_B - (a + b). \qquad (7)$$

and the settlement power price of B after the swap is

$$p_B' = (p_A + a) + p_B - (p_B - b) = p_A + (a + b). \qquad (8)$$

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

As $(p_B - (a + b)) + (p_A + (a + b)) = p_A + p_B$, 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 are 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

© 1994-2014 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

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 increase 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

$$U'_A = q_A E(p_B - (a + b)) - C_A(q_A) - \lambda_A q_A \sigma(p_B - (a + b)); \quad (9)$$

$$U'_B = q_B E(p_A + (a + b)) - C_B(q_B) - \lambda_B q_B \sigma(p_A + (a + b)). \quad (10)$$

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

So

$$U'_A - U_A > 0; \quad (11)$$

$$U'_B - U_B > 0. \quad (12)$$

From equation (5), (9) and (6), (10), we can get

$$q_A E(p_B - (a + b)) - C_A(q_A) - \lambda_A q_A \sigma(p_B - (a + b)) - q_A E(p_A) + C_A(q_A) + \lambda_A q_A \sigma(p_A) > 0; \quad (13)$$

$$q_B E(p_A + (a + b)) - C_B(q_B) - \lambda_B q_B \sigma(p_A + (a + b)) - q_B E(p_B) + C_B(q_B) + \lambda_B q_B \sigma(p_B) > 0. \quad (14)$$

As 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

$$\lambda_A q_A \sigma(p_A) - q_A(a + b) > 0; \quad (15)$$

$$q_B(a + b) - \lambda_B q_B \sigma(p_A) > 0. \quad (16)$$

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

$$\lambda_B \sigma(p_A) < a + b < \lambda_A \sigma(p_A). \quad (17)$$

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

$$(a + b) = \frac{\sigma(p_A)(\lambda_A q_A + \lambda_B q_B)}{q_a + q_B}. \quad (18)$$

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 a stochastic variable meeting with normal distribution of $E(p) = 28.356$, $\sigma(p)$ is 14.354, 8.652, 3.214 and 0 respectively. The simulation results are obtained and listed in Table 2~4.

1) From the result 1 of Table 1~4, with 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 fluctuate more severely in the electricity market, the power price swap will play more significant role in hedging the risk.

表 1　机组生产成本系数和出力限制

Table 1　Unit production cost coefficients and output limits

G_i	c_i	d_i	$P_{i\min}$/MW	$P_{i\max}$/MW
A	0.1218	13.6440	30	160
B	0.1086	13.4928	40	120

© 1994-2014 China Academic Journal Electronic Publishing House. All rights reserved.　　http://www.cnki.net

表 2 $\sigma(p)=14.354$时发电公司的互换电力价格

Table 2 $\sigma(p)=14.354$, power price swap of generation companies

	G_i	q_i	∂_i	$\sigma(p)$	$(a+b)$	ΔU_i
1	A	120	0.981	14.354	8.455	675.212
	B	80	0.001	–		675.212
2	A	120	0.823	14.354	8.943	344.496
	B	80	0.323	–		344.496
3	A	120	0.500	14.354	7.177	0.000
	B	80	0.500	–		0.000
4	A	120	0.612	14.354	9.933	–137.798
	B	80	0.812	–		–137.798

表 3 $\sigma(p)=8.652$时发电公司的互换电力价格

Table 3 $\sigma(p)=8.652$, power price swap of generation companies

	G_i	q_i	∂_i	$\sigma(p)$	$(a+b)$	ΔU_i
1	A	120	0.981	8.652	5.096	406.990
	B	80	0.001	–		406.990
2	A	100	0.823	8.652	4.958	216.300
	B	100	0.323	–		216.300
3	A	90	0.500	8.652	4.326	0.000
	B	110	0.500	–		0.000
4	A	120	0.612	8.652	5.933	–76.502
	B	70	0.812	–		–76.502

表 4 $\sigma(p)=3.214$时发电公司的互换电力价格

Table 4 $\sigma(p)=3.214$, power price swap of generation companies

	G_i	q_i	∂_i	$\sigma(p)$	$(a+b)$	ΔU_i
1	A	120	0.981	3.214	1.893	151.187
	B	80	0.001	–		151.187
2	A	100	0.823	3.214	1.842	80.350
	B	100	0.323	–		80.350
3	A	90	0.500	3.214	1.607	0.000
	B	110	0.500	–		0.000
4	A	120	0.612	3.214	2.204	–28.419
	B	70	0.812	–		–28.419

表 5 $\sigma(p)=0$时发电公司的互换电力价格

Table 5 $\sigma(p)=0$, power price swap of generation companies

	G_i	q_i	∂_i	$\sigma(p)$	$(a+b)$	ΔU_i
1	A	120	0.981	0	0	0
	B	80	0.001	–		0
2	A	100	0.823	0	0	0
	B	100	0.323	–		0
3	A	90	0.500	0	0	0
	B	110	0.500	–		0
4	A	120	0.612	0	0	0
	B	70	0.812	–		0

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 $\partial_A-\partial_B$ 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 $p_A'=p_B-(a+b)$ 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.

© 1994-2014 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

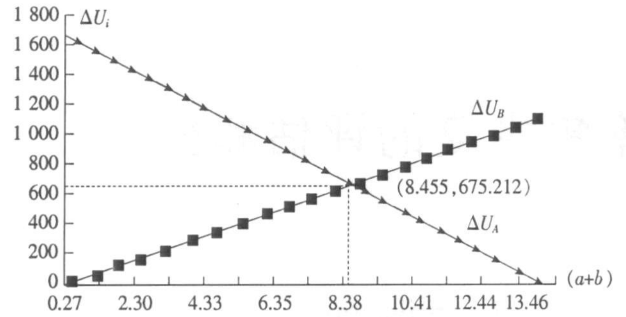

图 2　当 $\sigma(p) = 14.354$时, 价格互换后发电公司的 $(a+b)$和 ΔU值

Figure 2　When $\sigma(p) = 14.354$, $(a+b)$ and ΔU of generation companies after price swap

6　Conlusion

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 loss 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 observation 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 gaming process. Its success relies on participants obtaining equal utility value out of the risk-hedging process.

Acknowledgements

This work was supported by The Hong Kong Polytechnic University under the project "Risk Management Strategies Used in Electricity Market Design".

References

[1] Energy Information Administration. Derivatives and risk management in the petroleum, natural gas and electricity industries[R]. Washington(DC): Technical Report of US Department of Energy, 2002.

[2] ZENG Ci-ling, ZHANG Bu-Han, XIE Pei-Yuan. Risk management based optimal allocation of generation capacity between open access energy market and reserve market[J]. Power System Technology, 2004, 28(13): 70-74.

[3] WANG Ren, SHANG Jin-cheng, FENG Yang, et al. Combined bidding strategy and model for power suppliers based on CVAR risk measurement techniques[J]. Automation of Electric Power Systems, 2005, 29(14): 5-9.

[4] KANG Chong-qing, BAI Li-chao, XIA Qing, et al. Risk decision-making of generators in electricity market[J]. Proceedings of the CSEE, 2004, 24(8): 1-6.

[5] ZHOU Ming, NIE Yan-li, LI Geng-yin, et al. Long-term electricity purchasing scheme and risk assessment in electricity markets[J]. Proceedings of the CSEE, 2006, 26(6): 116-121.

[6] Liu Y A, Guan X H. Purchase allocation and demand bidding in electric power market[J]. IEEE Transactions on Power Systems, 2003, 18(1): 106-112.

[7] ZHOU Hao, ZHANG Fu-qiang. Calculation of short-term financial risk in electricity market by VaR historical simulation method[J]. Automation of Electric Power Systems, 2004, 28(3): 14-18.

[8] John Hull. Options, futures, other derivatives[M]. Beijing: Huaxia Publishing Company, 2006.

[9] QIAN Song-di, HU Yun-quan. Operation theory[M]. Beijing: Tsinghua University Press, 1997.

[10] GUO Jin, JIANG Wei, TAN Zhong-fu. Research on optimized power purchasing of power suppliers under risk condition[J]. Power System Technology, 2004, 28(11): 18-22.

[11] MA Xin-shun, WEN Fu-shuan, NI Yi-xin, et al. Development of optimal bidding strategies for generation companies with risk management[J]. Automation of Electric Power Systems, 2003, 27(20): 16-20.

© 1994-2014 China Academic Journal Electronic Publishing House. All rights reserved.　http://www.cnki.net