

Important Role of Power Exchange in Conducting Futures Market for Stabilizing Electric Power Industry in Transition

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Abstract - At present the electric power industry in Korea is going through a major restructuring process. The restructuring is motivated by a desire to reduce electricity supply costs, to attract new investment in modern generation, transmission and distribution facilities, and to stimulate innovation in the wholesale production and the retail supply of electricity. The experience to date shows that restructuring of electric power industry in the US, however, is marred with a number of problematic market performances including unreasonably high prices at wholesale. This paper investigates the important role of Power Exchange for stabilizing electric power industry in transition by offering various financial products. These financial products are used for risk hedging by the market participants. The paper focuses on the risk hedging by an individual supplier and derives an explicit decision rule that incorporates the attitude towards the risks. In addition to providing the financial products for risk hedging by market participants, the Power Exchange plays another very important role of financial safeguard system. Because of its unique characteristics, the Power Exchange is well suited for financial surveillance where it performs the early detection of unsound financial (and to a large extent operational) practices on the part of any system users and protect the system integrity and the market participants from the consequences of a default in the clearing structure.

Keywords: forward contracts, futures market, mean-variance cost function, unit commitment, risk management

1. Introduction

At present the electric power industry in Korea is going through a major restructuring process. In this process an institutional change is taking place where decentralized entities and electric (transmission and distribution) network sectors are replacing the vertically integrated utility, i.e. Korea Electric Power Corporation (KEPCO), which has served as the backbone of old industry structure. The ensuing regulatory change consists of the competitive market-driven supply of electric energy by decentralized entities and new forms of regulation imposed on transmission and distribution instead of traditional regulation levied on the vertically integrated utilities. These changes are motivated by a desire to reduce electricity supply costs, to attract new investment in modern generation, transmission and distribution facilities, and to stimulate innovation in the wholesale production and the retail supply of electricity.

Concurrently, there is a clear evidence of steady increase in electricity consumption and a concomitant requirement for higher reliability and power quality throughout Korea as a result of gradual shift of developed economies from manufacturing and natural resources toward telecommuni-

cation, information, financial, computer and other services. For these reasons the successful implementation of restructuring electric power industry is synonymous with creation of an electricity supply infrastructure that supports broader economic growth and development.

Table 1 California Power Exchange Day-ahead Prices (\$/MWh: Weighted Average 7 x 24)

	1998	1999	2000	2000(CEC)*
January	-	21.6	31.8	27.7
February	-	19.6	18.8	24.1
March	-	24.0	29.3	23.3
April	23.3	24.7	27.4	20.0
May	12.5	24.7	50.4	18.5
June	13.3	25.8	132.4	18.8
July	35.6	31.5	115.3	28.0
August	43.4	34.7	175.2	40.9
September	37.0	35.2	119.6	45.3
October	27.3	49.0	103.2	32.2
November	26.5	38.3	179.4	31.6
December	30.0	30.2	385.6	30.7
Average	30.0	30.0	115.0	28.5

*: California Energy Commission forecasts, 3/13/00

The experience in the US to date shows, however, that restructuring of electric power industry is marred with a number of problematic market performances including un-

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Received December 7, 2002 ; Accepted January 8, 2003.

reasonably high prices at wholesale. Table 1 shows the day-ahead (wholesale electricity) prices of power exchange in California in 1998, 1999, and 2000 [12].

The last column of the table shows the forecast prices for 2000 as published by the California Energy commission in March 2000. It can be seen from the table that the wholesale price behavior in California wholesale market was highly erratic in months following May 2000 when the market prices rose to unprecedented levels; as much as 13 times the forecast!

In addition, the progress in retail competition has been also extremely slow instead of delivering on the promise of customer choices. Combining the unreasonably high prices at wholesale and slow progress in retail competition has left a number of utilities insolvent.

The purpose of this paper is to investigate the important role of Power Exchange for stabilizing electric power industry in transition by offering various financial products. These financial products are used for risk hedging by suppliers, i.e. generation plant owners, and consumers, i.e. load serving entities. It is noted that the failure to anticipate and mitigate market performance problems can result in missed opportunities for taking advantage of new technologies. Moreover, the errors in market design, implementation and regulation can lead to very costly consequences whose adverse effects reach throughout the economy. The paper focuses on the risk hedging by an individual supplier and derives an explicit decision rule that incorporates the attitude towards the risks.

This paper is organized as follows:

Section 2 defines the forward contract for electricity and the role of Power Exchange as the corresponding futures market. In addition, the interpretations are given for the forward price of the commodity. Section 3 presents the two-stage model for profit of electricity suppliers, as a function of generation cost, revenues from sales, and the gain or loss due to forward contract commitments. The production- and marketing-decision rules are solved using the dynamic programming (DP) technique given the mean-variance cost function in Section 4. Concluding remarks are made in Section 5.

2. Forward Contracts and Futures Market

The production- and marketing-decisions by a supplier whose product is subject to a price uncertainty have been a topic of extensive studies in the literature. This problem is of a particular interest in commodity markets where there may be a significant volatility in spot prices. A spot price is the price at which a commodity is traded for immediate delivery. We refer the marketplace where the spot prices prevail as a spot market.

One of the most common methods used to deal with this spot price uncertainty is the risk hedging through forward (delivery) contracts which are the contracts to buy or sell the commodity at a fixed time in the future at a pre-specified price. We call this pre specified price, a forward price, and the marketplace where the commodity is traded based on forward contracts, a futures market. In a futures market, suppliers can commit some or all of their outputs at the forward price before the actual production. By entering into forward contracts, the risks on profit stemming from the uncertainty in spot prices can be eliminated for the amount of output committed in the contracts.

The merit of a futures market lies on its ability to provide a risk management tool called forward contracts through which buyers and sellers can reduce parts of their profit that is exposed to the risks from the volatility in spot prices. For example, suppose an agricultural supplier, i faces a price uncertainty in the spot market for the crop that he plants in the spring and sells in the following fall. It is assumed that his only production cost is the one time investment he makes for planting in the spring, C_i :

$$C_i(Q_i) = a_i Q_i^2 + b_i Q_i + c_i \quad (1)$$

where Q_i is the quantity of the crop he produces in the fall as the result of his investment, C_i . Not surprisingly the cost of investment is a function of the output. Suppose the spot market for this particular crop is perfectly competitive; i.e., no one supplier can alter the spot prices by changing his output.

Without the presence of futures market, the amount of crop the farmer, i , sells in the spot market, Q_i , is equal to his entire output, Q_i . For the profit-maximization cost function, his optimal output may be derived by solving

$$\min_{Q_i} E\langle C_i(Q_i) - p_s Q_i \rangle, \quad (2)$$

which yields

$$Q_i^* = \frac{1}{2a_i} [E\langle p_s \rangle - b_i] \quad (3)$$

where $E\langle \cdot \rangle$ denotes the expected value operator.

Suppose the spot market price has the log-normal probability distribution, i.e.

$$f_{p_s}(p_s) = \begin{cases} \frac{1}{\sqrt{2\pi\sigma p_s}} \exp\left[-(\ln p_s - \alpha)^2 / (2\sigma^2)\right] & \text{if } p_s > 0 \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

Then, the optimal production amount is given by

$$Q_i^* = \frac{1}{a_i} \left[\exp\left(\alpha + \frac{1}{2}\sigma^2\right) - b_i \right] \quad (5)$$

since $E\langle p_s \rangle = \exp\left(\alpha + \frac{1}{2}\sigma^2\right)$.

If the farmer, i , makes the investment corresponding to the optimal output given in Eq. (3), then his profit, $\pi_i = p_s Q_i - C_i(Q_i)$ also has the log-normal distribution whose expected value and the variance are given by

$$\begin{aligned} E\langle \pi_i \rangle &= Q_i^* E\langle p_s \rangle - C_i(Q_i^*) \\ &= \frac{1}{a_i} \left[(a_i - 1) \exp(2\alpha + \sigma^2) \right. \\ &\quad \left. + 2b_i \exp\left(\alpha + \frac{1}{2}\sigma^2\right) + b_i^2 - a_i c_i \right] \end{aligned} \quad (6)$$

and

$$\begin{aligned} \text{var}(\pi_i) &= (Q_i^*)^2 \text{var}(p_s) \\ &= \frac{\exp(\sigma^2)}{a_i^2} \left[\exp\left(\alpha + \frac{1}{2}\sigma^2\right) - b_i \right]^2 \left[\exp(\sigma^2) - 1 \right] \end{aligned} \quad (7)$$

since $\text{var}(p_s) = \exp(\sigma^2) [\exp(\sigma^2) - 1]$.

Suppose the farmer now has an option that he can sell any amount of his output at the futures market in the spring for the delivery in the following fall. With the introduction of futures market, the profit-maximization cost function in Eq. (2) is modified to include the amount of crop sold at the futures markets as

$$\min_{Q_i, Q_f} E\langle C_i(Q_i) - p_f Q_f - p_s(Q_i - Q_f) \rangle \quad (8)$$

where p_f and Q_f represent the forward price and the amount of crop sold at the futures market, respectively. The solution to Eq. (8) is given as

$$Q_i^* = \frac{1}{a_i} \left[\exp\left(\alpha + \frac{1}{2}\sigma^2\right) - b_i \right] \quad (9)$$

$$Q_f^* = \begin{cases} +\infty & p_f > E\langle p_s \rangle \\ \frac{1}{a_i} \left[\exp\left(\alpha + \frac{1}{2}\sigma^2\right) - b_i \right] & p_f = E\langle p_s \rangle \\ -\infty & \text{otherwise} \end{cases} \quad (10)$$

From Eq. (9) we note that the optimal output does not depend on the presence of futures market. Intuitively, this implies that the decision of supplier can be decoupled as production- and marketing-decisions. When making the

production decisions, a supplier is only concerned with the probability distribution of spot prices and not of forward prices. On the other hand, the marketing decisions are determined based on the *relationship* between the forward prices and the expected value of spot prices as shown in Eq. (10). Suppose the forward prices are set above the expected value of the spot prices. In this case the optimal (marketing) decision rule prescribes for an infinite amount of sales at the futures market. Even though he does not produce an infinite amount of crops himself, the assumption regarding the perfect competition at the spot market made earlier in the section allows the supplier to supply the amount committed in the forward contracts with the purchase of an infinite amount of crop at the spot market on the delivery day, which approach yields the expected value of the supplier's profit to be an infinity. When the forward prices are set below the expected spot prices, the supplier can again obtain the expected value of an infinite profit by buying at the futures market and selling at the spot market. The above are the classic examples of a well-known arbitrage opportunity created by the price discrepancies between spot and futures markets. This suggests, in a mature market environment, the forward prices have to have the interpretation of being the expected value of spot prices.

After making the assumption that forward prices and the expected value of spot prices are equal, we deduce that the optimal decision for a supplier is

$$\begin{aligned} Q_i^* &= \frac{1}{a_i} \left[\exp\left(\alpha + \frac{1}{2}\sigma^2\right) - b_i \right] \\ &= Q_f^* \end{aligned} \quad (11)$$

The expected value and the variance of the supplier's profit are given by

$$\begin{aligned} E\langle \pi_i \rangle &= \frac{1}{a_i} \left[(a_i - 1) \exp(2\alpha + \sigma^2) \right. \\ &\quad \left. + 2b_i \exp\left(\alpha + \frac{1}{2}\sigma^2\right) + b_i^2 - a_i c_i \right] \\ &= \pi_i \end{aligned} \quad (12)$$

and

$$\text{var}(\pi_i) = 0 \quad (13)$$

i.e., the profit is a deterministic value as all of supplier's output is sold at the futures market before production. With the use of forward contracts, the suppliers are able to eliminate the risks associated with the volatility in spot prices.

In the electricity industry where there is no practical

means for storage, the volatility in spot prices is quite significant. Thus, most market scenarios for the deregulation of electricity anticipate the development of a futures market, including basic call and put options [7], forward contracts [14], callable forwards [9], and bid-based power pools [10]. Interruptible contracts [16], also known as recallable contracts or non-firm contracts, may be treated as callable forwards.

The closest to the futures market for electricity in the US has been the New York Mercantile Exchange (NYMEX) where various electricity futures and options contracts were traded in the late 90's. Using the futures contracts at Palo Verde hub offered by NYMEX, for example, an independent power production (IPP) company in California could reduce the risks associated with reduction in its profit with respect to falling prices.

The futures contracts offered by the NYMEX works as follows:

Suppose on March 1, an IPP projects excess generation, finds attractive prices in the futures market for the April contracts and captures the market prices ahead of delivery time by selling 10 futures contracts for April at 23(\$/Mwh). Assuming perfect hedge, the arrangement yields \$169,280 for the April contracts (10 contracts \times 736 (Mwh/contract) \times 23 (\$/Mwh) = \$169,280).

Then, the IPP arranges to deliver 7,360Mwh of April power in the spot market according to the futures contract, but at the spot price which has fallen to 22 (\$/Mwh). As a result, the IPP receives \$161,920, which is \$7,360 less than the anticipated. Simultaneously, the IPP buys back the April futures contracts to offset the obligations at the NYMEX. The April contracts are now valued at \$22 (\$161,920), that were initially sold for \$23 (\$169,280). This difference yields the gain of \$7,360 at the futures market for the IPP. By combining the transactions at the spot market and the futures market, the net gain of the IPP is \$169,280 as anticipated.

In [5], [11] and [8] it is shown that when production is non-stochastic with only uncertainty in the spot price, the optimal production rule is to set marginal cost equal to the forward prices as given in Eq. (11). Since the optimal decision rule based on the given profit-maximization cost function results in a deterministic value for profit, the same decision rule is also optimal when the optimization problem is solved based on the mean-variance function. Indeed, the solution to

$$\max_{\theta, \psi} E\langle \pi_i \rangle - \lambda \text{var}(\pi_i) \quad (14)$$

matches the expressions in Eqs. (9) and (10), assuming the forward price is the expected value of the spot price. In Eq. (14), the supplier's preference in risk aversion reflected in λ .

However, suppliers in many industries are faced with production uncertainty along with price uncertainty. When the output is stochastic, the above generalization is, in general, not valid. In [2] the optimal decision rules different from Eqs. (9) and (10) are derived for the mean-variance cost function when there are uncertainties in production and price; it is shown that the optimal decision rule considers the supplier's preference in risk aversion and that the decoupling assumption between the production- and the marketing-decision cannot be made in general.

In electricity markets, there is a significant uncertainty in production. Many markets allow the production decisions to be made by the market makers called the system operators rather than by individual suppliers. For example, in the Pennsylvania-New Jersey-Maryland (PJM) market, suppliers initially bid supply curves to the system operator. The system operator subsequently determines the optimal generation output by individual suppliers using the optimal power flow (OPF) program.¹ Finally, the suppliers generate the amount of electricity determined by the system operators at the spot prices. The reason that the electricity industry operates this way is due to the strict requirement that the instantaneous supply of electricity has to continuously balance the instantaneous demand, as described earlier.

The coupling between production- and marketing-decisions becomes stronger if the assumption is relaxed for the forward price being the expected value of the spot price. The deregulation process of electricity industry is still at its infant stage. Plus, in many electricity markets being operated within the U.S., trades are conducted on the hourly basis in the spot markets as loads vary hour by hour, while futures markets allow trades only on the monthly basis. This results in considerable discrepancies between the spot prices and the forward prices. Thus, in formulating optimal decision rule for electricity supplier, it is preferable to use the mean-variance cost function formulation given in Eq. (14) than to use Eq. (8).

3. Supplier's Profits and Risks in Unit Commitment Problem

Determining unit commitment decisions is an essential problem to the suppliers in the electricity markets. The problem determines the optimal production level of each individual generator over a certain period of time, usually one week. The decisions are typically made at daily intervals for each of 24 hour decision horizon. An extensive study of this problem is performed in [1]. In the study, the

¹ The optimal power flow program determines the most economical mix of generation for given system load.

problem is posed as a stochastic optimization as described below:

Consider the case of a single generator. If the generator is turned on, a startup cost of S is incurred. Similarly, it requires a shutdown cost, T , when the generator is turned off. Each generator must also observe minimum up time and minimum down time constraints; a generator may not be on for fewer than t_{up} consecutive hours or off for less than t_{dn} consecutive hours.

Given these constraints, the profit of an electricity supplier at hour k , $\pi[k]$, is given by

$$\pi[k] = u[k](p_s[k]Q_G[k] - C_G(Q_G[k]) - I(x[k] < 0)S) - (1 - u[k])(c_f + I(x[k] > 0)T) \quad (15)$$

where

- u : Decision on production, 1 if the unit is on, 0 otherwise
- Q_G : Production output
- C_G : Cost of production
- I : Conditional statement, 1 if true, 0 otherwise
- x : Unit status, to turn on, $x[k] < t_{dn}$, and to turn off, $x[k] > t_{up}$
- c_f : Fixed costs incurred when the generator is off

Here it is assumed that the suppliers submit to the market maker/system operator supply bids at the beginning of each hour k . The supply bid describes how much the supplier is willing to produce at various spot prices. The spot price, $p_s[k]$, is determined exogenously, and the system operator decides on the output by individual suppliers based on respective supply bids.

From an individual supplier perspective the optimal output is then computed by solving

$$\min_{u[k], Q_G[k], p_s[k]} \sum_{k=0}^{23} -\pi[k] = \min_{u[k], Q_G[k], p_s[k]} \sum_{k=0}^{23} (1 - u[k]) \times (c_f + I(x[k] > 0)T) - u[k](p_s[k]Q_G[k] - C_G(Q_G[k]) - I(x[k] < 0)S) \quad (16)$$

for the profit-maximization cost function.

The DP technique is well suited for solving problems of the form in Eq. (16) in which each stage of the problem is a one hour time interval. The unit status, $x[k]$, and the spot price, $p_s[k]$, are treated as the evolving states of this system in applying the DP technique. The state transition equation of x_k is given by [15]

$$x[k+1] = \begin{cases} \max(1, x[k]+1) & : u_k = 1 \\ \min(-1, x[k]-1) & : u_k = 0 \end{cases} \quad (17)$$

The state transition equation of $p_s[k]$ is formulated as an appropriate stochastic process. For example,

$$p_s[k+1] = p_s[k] + \alpha \ln \left(\frac{\bar{p}_s}{p_s[k]} \right) + w[k] \quad (18)$$

where \bar{p}_s and $w[k]$ are the perceived mean of spot prices and random white noise process respectively. Clearly Eq. (16) is a stochastic optimization problem with the stochastic state transition equation such as Eq. (18). Due to the nonlinear constraints such as minimum up time and minimum down time, no general closed form solution is derived. The details of numerical solution to Eq. (16) is presented in [1].

Suppose the result is extended for solving the unit commitment problem to include the presence of the futures market where electricity suppliers can sell any amount of their outputs through forward contracts. Then, the profit of a electricity supplier at hour k , $\pi[k]$, given in Eq. (15) becomes

$$\pi[k] = \sum_{i=0}^{k-1} p_{f,i}[k]Q_{f,i}[k] + u[k](p_s[k](Q_G[k] - \sum_{i=0}^{k-1} Q_{f,i}[k]) - C_G(Q_G[k]) - I(x[k] < 0)S) - (1 - u[k]) \times (c_f + p_s[k] \sum_{i=0}^{k-1} Q_{f,i}[k] + I(x[k] > 0)T) \quad (19)$$

where

- $p_{f,i}[k]$: Forward prices at stage i for delivery at stage k
- $Q_{f,i}[k]$: Amount of electricity to be delivered at stage k at forward price, $p_{f,i}[k]$

In [1], the solution to Eq. (19) is derived as

$$Q_G[k] = \frac{E\langle p_s[k] \rangle - b}{2a} \quad (20)$$

$$Q_{f,k-1}[k] = \frac{\text{cov}\langle p_s^2[k], p_s[k] \rangle - 2b}{4a \text{var}\langle p_s[k] \rangle} \quad (21)$$

using the one-stage model for the quadratic generation cost function, i.e.,

$$C_G(Q_G[k]) = aQ_G^2[k] + bQ_G[k] + c \quad (22)$$

For the profit-maximization cost function, the solution in Eqs. (20) and (21) indicates the decoupling between the production- and the marketing-decisions, and the forward price is implicitly and *necessarily* assumed to be the expected value of spot prices. This suggests that in order to capture the inter-temporal effect of forward contracts, the problem needs to be formulated using the mean-variance cost function on at least the two-stage model.

4. Mean-variance Hedging Strategy

This section, the two-stage model is presented for unit commitment problem using the mean-variance cost function.

Assuming the generator is on, we can simplify Eq. (19) of the supplier's profit at the stages k and $k+1$, as

$$\pi[k] = p_s[k]Q_G[k] + p_{f,k+1}Q_{f,k+1}[k] - C_G(Q_G[k]) \quad (23)$$

$$\pi[k+1] = p_s[k+1](Q_G[k+1] - Q_{f,k+1}[k]) - C_G(Q_G[k+1]) \quad (24)$$

At the stage k , the supplier makes the marketing decision to sell the amount, $Q_{f,k+1}[k]$, of electricity for the delivery at the stage $k+1$ through the forward contract and the production decisions for the stages k and $k+1$, by solving a stochastic optimization problem given the mean-variance cost function:

$$\min_{\substack{Q_G[k] \\ Q_G[k+1] \\ Q_{f,k+1}[k]}} \lambda \text{var}(\pi[k] + \pi[k+1]) - E\langle \pi[k] + \pi[k+1] \rangle \quad (25)$$

Combining Eqs. (25), (23) and (24) the two-stage forward contract problem then may be solved by using the DP technique:

$$J_{k+1}(p_s[k+1]) = \lambda \text{var}(\pi[k+1]) - \pi[k+1] \quad (26)$$

$$J_k = \min_{Q_G[k], Q_G[k+1], Q_{f,k+1}[k]} E\langle \lambda \text{var}(\pi[k]) - \pi[k] + J_{k+1} \rangle \quad (27)$$

The solution to Eqs. (26) and (27) is given by

$$Q_G[k] = \frac{E\langle p_s[k] \rangle - b}{2a + 2\lambda \text{var}(p_s[k])} \quad (28)$$

$$Q_G[k+1] = \frac{E\langle p_s[k+1] \rangle - b + 2\lambda \text{var}(p_s[k+1])Q_{f,k+1}[k]}{2a + 2\lambda \text{var}(p_s[k+1])} \quad (29)$$

$$Q_{f,k+1}[k] = \frac{p_{f,k+1}[k] - E\langle p_s[k+1] \rangle}{2\lambda \text{var}(p_s[k+1])} + \frac{\text{cov}(p_s^2[k+1], p_s[k+1]) - 2b}{4a \text{var}(p_s[k+1])} \quad (30)$$

It is interesting to analyze the solution at the limiting cases. If $\lambda = 0$, then Eqs. (28), (29) and (30) are reduced to Eqs. (20) and (21). This is due to supplier's indifference towards risk, thus solving the optimization problem solely based on the expected profit as in Eq. (30). If $\lambda = \infty$, then Eq. (28) reduces to zero, and Eq. (29) yields $Q_{f,k+1}[k]$. Without prior commitment through forward contracts in the stage k , the supplier opt for no generation in order to minimize the variance of his profit. In the stage $k+1$ the supplier produces just enough to fulfill the maturing forward contracts without regarding the spot prices. This allows the supplier to eliminate any variance in his profit.

The approach in Eqs. (26) and (27) can be generalized to the optimization problem over several stages without assuming generator status:

$$J_N(x_N) = g_N(x_N) \quad (31)$$

$$J_k(x_k) = \min_{u_k \in U_k(x_k)} E_{w_k} \langle g_k(x_k, u_k, w_k) + J_{k+1}(u_k) \rangle \quad (32)$$

where the cost functions, g_k , are

$$g_N(x_N) = E\langle p_s[N](x_N - Q_G[N]) + C_G(Q_G[N]) \rangle \quad (33)$$

$$g_k(x_k) = p_{f,N}[k](x_k - u_k) + \lambda \text{var} \left(\sum_{i=k}^N \pi[i] \right) - \lambda \text{var} \left(\sum_{i=k+1}^N \pi[i] \right) \quad (34)$$

This problem is theoretically solvable; however, it requires a large amount of price information, including the mean and variance of all future forward prices up to the delivery date and the expected variance of the spot price at future times, which means along with the state transition equation defined for the spot prices as given in the Eq. (18), the state transition equation for forward prices has to be determined as well. A simple example will be defining the spot and the forward prices as correlated mean-reverting stochastic processed of the form

$$p_s[k+1] = p_s[k] + \alpha \ln \left(\frac{p_{f,k}[\bar{k}-1]}{p_s[k]} \right) + w[k] \quad (35)$$

$$p_{f,i-1}[k] = p_{f,i}[k] + \beta \ln \left(\frac{p_f}{p_{f,i}[k]} \right) + w[k] \quad (36)$$

where \bar{p}_f is the perceived mean of forward price as a stochastic process and $w[k]$ is a random white noise process uncorrelated with $w[k]$. The cost function can also be amended to include both fixed and variable transaction costs. This is computationally very complex. A complete study of this problem is left for future research.

5. Conclusion

In addition to providing the financial products for risk hedging by suppliers and consumers for electricity, the Power Exchange plays another very important role of financial safeguard system. Because of its unique characteristics, the Power Exchange is well suited for financial surveillance where it performs the early detection of unsound financial (and to a large extent operational) practices on the part of any system users and protect the system integrity and the market participants from the consequences of a default in the clearing structure.

This paper describes the opportunities for risk hedging available to competitive electric power suppliers through the use of forward contracts. The forward contracts have a payoff which increase as the spot prices drop and decrease as the spot prices rise. By understanding these opportunities the Power Exchange can anticipate any possible insolvency of market participants by simulating the effects of change market conditions and determining the overall risks. This function by the Power Exchange is particularly important in Korea where the electric power industry restructuring process is at its infancy.

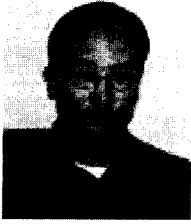
A complete solution is derived for the two-stage model. A more general optimization problem involving spot markets and futures markets can be defined, which calculates the optimal forward contract position over time as spot and forward prices for electricity evolve; however, this problem is very complicated to solve.

Acknowledgments

The author greatly appreciates the financial support provided by Korea Electric Power Corporation.

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